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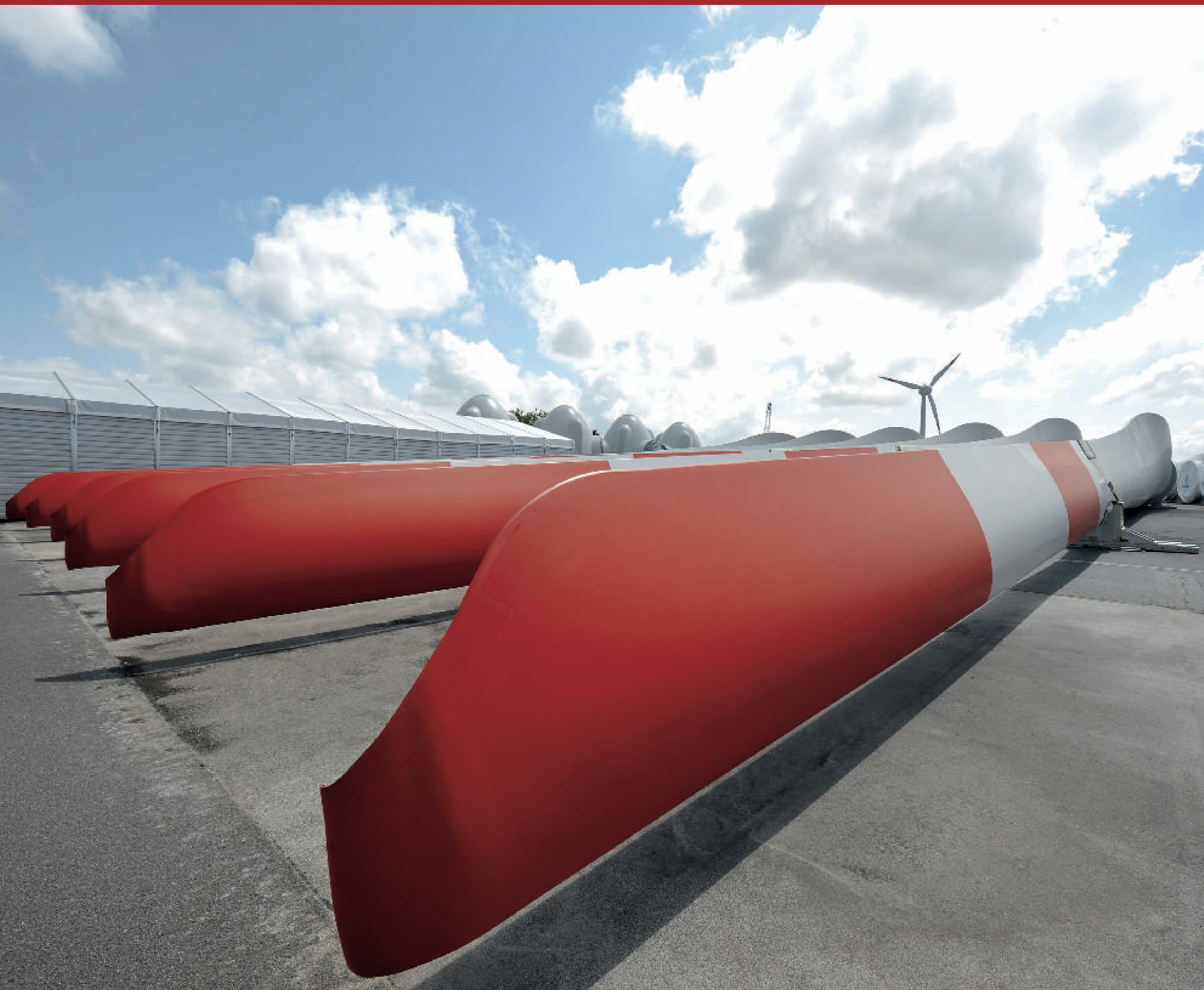
WIND ENERGY REPORT GERMANY 2013



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FOREWORD

CONTINUING INVESTMENT IN SUSTAINABLE ENERGY PROVISION

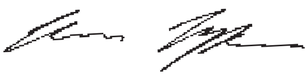
The expansion of electricity generation from renewable energy sources in Germany is continuing apace. Wind, solar, and bio-based energy now account for close to a quarter of Germany's electricity requirement. Public acceptance of the switchover to renewable energy is high because most people realize that this is an investment in sustainable and efficient energy provision for the future. Indeed, the phrase "Energiewende" is even now used by the international press to describe the global move away from fossil fuel usage and the transformation of energy systems. The whole electricity generating industry is involved in a pioneering and immense project.

Renewable energy utilization is now entering a new phase. Numerous offshore wind farms are under construction and will soon be connected to the grid. New generations of wind turbines mean that the expansion of wind energy onshore is being accompanied by ever better adaptation to location conditions. A typical onshore wind turbine now has a nominal power of 3 megawatts (MW). Without developing more wind farm locations than in previous years, this meant that the new wind turbine generating capacity in 2013 was a record high. The urgently needed grid expansion is proceeding at speed with the planning processes for so-called electricity highways from north to south. Increasing attention is being put on energy system technology for integrating the various renewable energies.

The stable political boundary conditions and the commitment for more than twenty years to withdraw from nuclear energy and fossil fuel energy has allowed a specialized industry to develop that has the know-how to be able to offer solutions for utilizing renewable energies not only in Germany but also throughout Europe and in other key foreign export markets. However, reform of renewable energy policy is in the offing. The new German government aims to modernize the Renewable Energy Act (REA). The worlds of politics, business, and science do though have a huge responsibility here to effectively and successfully continue with the switchover to renewable energy without endangering public trust. This is particularly so for the further development of wind energy in the southern states of Germany, some of which have set themselves ambitious targets for renewable energies. Rheinland-Palatinate has shown, for example, that it is possible to successfully utilize wind energy in heavily forested areas.

Fraunhofer IWES has published annual reports on the development of wind energy in Germany since 1991. This was initially the Annual Report of the Scientific Measurement and Evaluation Program (WMEP) and since 2008 the Wind Energy Report Germany. In addition, information about the ongoing expansion of wind energy and technical developments can be found at www.windmonitor.de.

The Wind Energy Report Germany is published as part of the Offshore~WMEP project funded by the Federal Ministry for Economic Affairs and Energy (BMWi).



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EXECUTIVE SUMMARY

Expansion of wind energy. The new wind power generating capacity installed in Germany in 2013 was at a level not seen for 10 years. The nominal power of more and more of these new wind turbines (WTs) was 3 MW. The 1093 new onshore wind turbines in 2013 equate to an additional generating capacity of 2851 MW. The new offshore generating capacity in 2013 was 240 MW from 48 wind turbines. Germany now has a total wind power generating capacity of 34,179 MW.

Energy mix. The renewable energies in 2013 accounted for 24.7% (147 TWh) of total electricity consumption. Wind energy amounted to 8% of total electricity generation in Germany. Despite the additional wind power generating capacity, the electricity generated from wind was less in 2013 than in the previous year due to the poorer wind conditions. Electricity generation from biogas and photovoltaic installations increased by 2.5 TWh and 1.9 TWh respectively.

Grid integration. In July the German Parliament (Bundestag) passed the Federal Requirements Plan Act (BBPlG) and thus laid the basis for the start of the technical planning for up to 36 expansion projects. This also includes the extra-high voltage direct current transmission lines which will transport the wind energy from the coast to the southern German states. The expansion of further lines is behind schedule. An offshore grid development plan was prepared by the transmission system operators for the first time and has been approved by the Federal Network Agency.

The utilization of feed-in management was slightly less in 2012 compared to 2011. Power output loss fell compared to 2011 by 8.5% to 385 GWh, because there was no extreme and simultaneous feed-in of wind energy and photovoltaic energy.

Onshore. Wind turbines of 3-5 MW size are starting to become established in the onshore market in Germany. The wind turbine manufacturers have brought out various new models of differing design. The average wind turbine diameter has now increased to 95.4 m and the average nominal power to 2.6 MW. Besides expansion in the states on the northern German coast, Rheinland-Palatinate is pioneering the way for wind energy at inland locations.

Offshore. As in 2012, the new offshore wind power generating capacity worldwide was about 1.6 GW. Large wind farms were connected to the grid in the UK and Denmark. In total, 2245 wind turbines having a total nominal power of 6890 MW are in use in 90 offshore wind farms.

In Germany, the farshore wind farm BARD Offshore 1 was completed. Also completed was the Riffgat wind farm (108 MW nominal power). There has been a delay with connecting this wind farm to the grid because of the need to clear old munitions from the seabed. Seven other wind farms are under construction.

		Onshore		Offshore		Total	
		2012	2013	2012	2013	2012	2013
Installed capacity (cumul.)	MW	30,863	33,658	280	521	31,144	34,179
Newly installed capacity	MW	2,253	2,851	80	240	2,410	3,091
Growth rate (gross)	%	7.9	9	40	86	8.1	9.7
Number of WTs		23,073	24,008	68	116	23,141	24,124
Newly installed WTs (gross)		943	1,093	16	48	959	1,141
Electricity feed-in	TWh	49.95	46.5	0.722	0.906	50.7	47.4
Percentage of total electricity demand	%	8.2	7.8	< 1	< 1	8.4	8

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WIND IN THE RENEWABLE ENERGY MIX

Situation in Germany

Renewable energies in Germany. The contribution of electricity generation from renewable sources to the total electricity consumption grew by 1.2% in 2013. The feed-in of 147,240 GWh of electricity generated from renewables corresponds to 24.7% of the total electricity consumption (see Figure 1). As such, renewables provided more electricity to the grid than all nuclear power stations together. Brown coal (lignite), which is currently the most important energy source in the German energy mix, made only a slightly higher contribution with 162,000 GWh. If the contribution of renewables to total power generation continues to grow at a similar rate, the target in the energy concept of the German government to increase the renewable energies in the energy mix to 35% by 2020 will be reached. Wind energy was, as in previous years, the largest contributor in 2013 (34%) to the renewable energy mix (see Figure 2). Over the year some 49,800 GWh of energy was supplied by German wind turbines to the electricity grid. Energy from biomass showed the largest growth. The electricity generated from biomass installations increased by 4050 GWh to 42,700 GWh [1, 2].

Renewable energy sources. Figure 2 shows the total electricity production from renewable energies and the installed nominal power of renewable energies in 1990 and 2013. Wind energy and PV today represent 83% of the installed nominal power of renewable energies. Whilst the largest percentage of the generated electricity can also be attributed to wind energy (34%), the second largest contributor is biomass (29%), and in third spot PV (19%). The hydroelectric power that is generated has remained almost constant since 1990 (on average 19,700 GWh), but only represents 14% of the current renewable energy mix.

The quantity of energy that is produced highlights the characteristic features of the different renewable energy sources. PV installations are highly dependent on incident sunlight. They account for 43% of the installed generating capacity. However, they contribute only about a fifth of the electricity that is produced. In 2013, PV installations supplied electricity for the

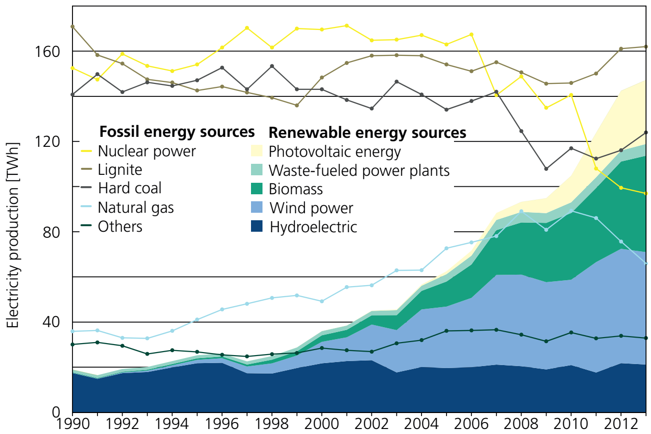


Figure 1: Electricity generation from renewables since 1990. Data sources: AGEE [1, 2] and AGEB [3]

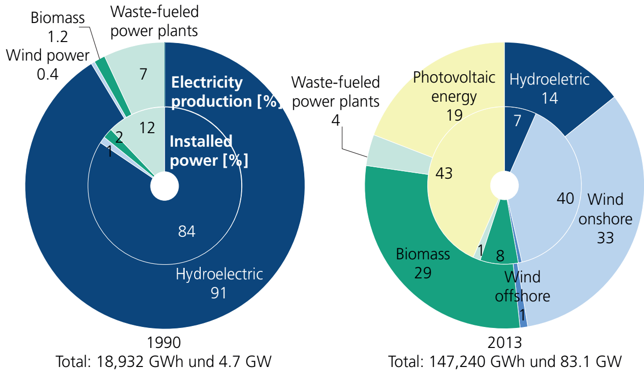


Figure 2: Gross electricity production and installed nominal power of renewable energies in 1990 and 2013. Data sources: AGEE [1, 2]

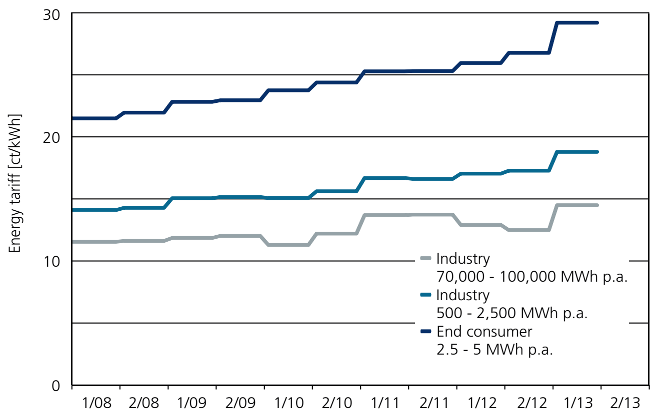


Figure 3: Increase in the electricity price for industrial and domestic customers. Data source: Eurostat [4, 5]

BUSINESS MODEL FOR RENEWABLE ENERGY

The debate about renewable energy is currently dominated by the costs. Dr. Carsten Pape, Fabian Sandaua, and Norman Gerhardt of Fraunhofer IWES are of the belief, however, that the debate here is focusing on too short a timescale. In their Special Report entitled "Business model for the switchover to electricity generation from renewable energies" on Page 66, they show that that the required investment can be turned into profit.

They compare the costs of fossil fuels for conventional power stations to the investment costs for renewable energies. They show that after about 20 years the switchover to renewables saves one money.

From an economic point of view, it is important that transport and heating also switchover at an early stage from being powered by fossil fuels to being powered by electricity. This is because although the amount of primary energy required for power generation is a similar order of magnitude to the amounts of primary energy required for heating and transport, the purchase costs are relatively low. In contrast, oil and gas are expensive and are difficult to substitute. Energy efficiency measures are also vital.

The report makes it clear that the investment opportunities and business models for renewable energies are more salient topics than the costs.

equivalent of 825 hours at full load. Biomass plants, which do not depend on the weather, achieved much higher utilization rates (6666 hours at full load). Hydroelectric plants achieved on average 3790 hours at full load in 2013.

Electricity price. The average price that a household with a annual consumption of 2500 – 5000 kWh paid in 2013 was ca. 29 ct/kWh (see Figure 3). The price for end-consumers has hence increased by 44% in 5 years [4], whilst the price for medium-sized industrial customers increased by 35% and for large industrial customers by 25% [5].

The electricity price paid by industrial and domestic customers is made up of the cost of generating and distributing the electricity and also various levies. The costs for generation, transmission, and distribution make up just under half of the electricity price and have increased by 10% over the last 5 years (see Figure 4). The remaining 34% of the price increase is due to seven statutory charges and levies [6]:

- Generation, transmission, and distribution (14.32 ct/kWh).
- Concession fee as payment for the granting of rights of way in the communities (§ 48 Energy Industry Act (EnWG)) varying from 1.32 ct/kWh to 2.39 ct/kWh depending on the size of the municipality. The average value was ca. 1.79 ct/kWh [6].
- The REA surcharge, namely the difference between the statutory guaranteed feed-in remuneration and the actual sales proceeds (§ 37 REA), is recalculated every October by the TSOs for the following year (5.277 ct/kWh) [7].
- The CHP surcharge for promoting electricity generation from CHP plants (0.126 ct/kWh) (§ 7 Combined Heat and Power Generation Act) [8].
- The § 19-surcharge (§ 19 StromNEV) provides exemption from grid charges for companies that use a lot of electricity (0.329 ct/kWh) [9].
- The offshore liability charge (§ 17f EnWG) to cover the cost of compensation for late connection of offshore wind farms was at the statutory maximum of 0.25 ct/kWh [10].
- Electricity tax has been 2.05 ct/kWh (§ 3 StromStG) [11] since 2003.
- There is also 19% VAT to pay on the sum of all these items (4.597 ct/kWh).

The REA surcharge increased from 3.592 ct/kWh to 5.277 ct/kWh in 2013 [12]. The pure funding costs for the expansion of renewable energies only increased, however, from 2.11 ct/kWh to 2.29 ct/kWh. Two main contributors to the increase in the REA surcharge are the extension of the so-called industry privilege and the fall in the spot electricity price (see Figure 5).

The compensation scheme for companies that use a lot of electricity (§§ 40 ff. REA) helps reduce their energy costs. Depending on their electricity consumption and electricity need, a lower REA surcharge is paid and in some cases none at all. The compensation scheme was extended in the REA amendment of 2012, resulting in an increase in the number of companies paying the lower surcharge in 2013 from 979 to 2276 [14]. The so-called industry privilege increased from 0.96 ct/kWh to 1.22 ct/kWh.

In October of each year the TSOs calculate the REA surcharge for the following year. The account balance in September is used for calculating the REA surcharge. Due to the difference between the forecasted and actual situation, the account balance in September 2012 (used for calculating the surcharge for the following year) was -2588 million euros [15]. This is reflected in the same REA surcharge as the previous year of 0.67 ct/kWh (see Figure 5). To take account of uncertainty in the calculations of the TSOs, 0.12 ct/kWh was taken as a liquidity reserve. The market premium introduced in 2012 is intended to promote the integration of renewables into the energy market and remunerate operators for additional expenditure for direct marketing. As of October 2013, 85.4% of wind energy, 44.1% of hydroelectric power, 48.3% of energy from biomass, and 12.3% of PV energy was directly marketed [16, 17].

The spot trading volume for Germany and Austria (Phelix) in the EPEX spot market has increased from 118 TWh in 2008 to more than 245 TWh in 2013. A contributory factor here has been the obligation since 2010 to market electricity from renewables via the spot market [18].

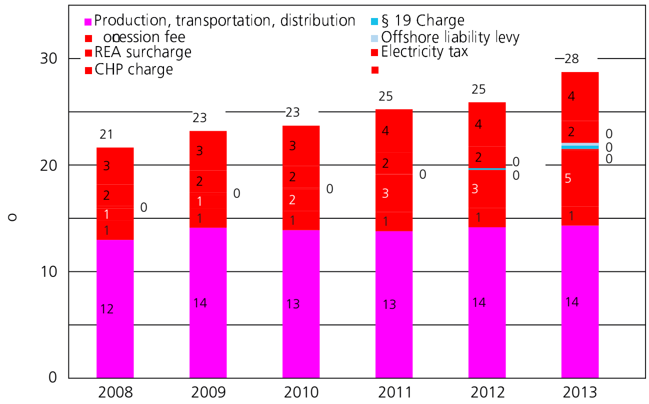


Figure 4: Make-up of the electricity price for households consuming 3500 kWh annually. Data source: BDEW [6]

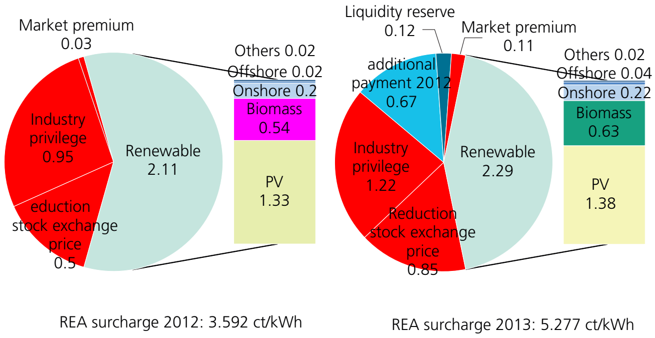


Figure 5 Make-up of the REA surcharge. Data source: BEE [13]. Due to the different data sources, there are differences to other figures cited in this report.

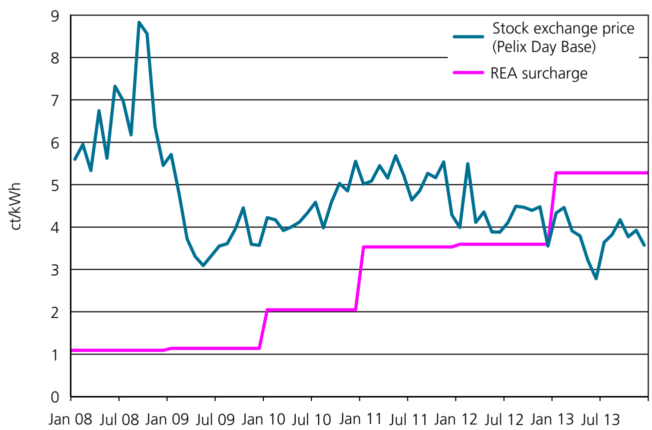


Figure 6: Changes in the monthly spot electricity price (based on the Phelix Day Base) and the annual REA surcharge. Data sources: EEX [18], REA surcharge [19]

MODELS FOR FUNDING RENEWABLE ENERGY GENERATION

The expansion of renewable energies cannot be funded in its entirety via the existing wholesale markets. The current and expected prices in these markets are too low for this, and indeed are not even sufficient to fund conventional power stations. The control energy markets are also not the answer, as the market volume is almost negligible compared to the required level of funding. As such, this therefore concerns not a "subsidization" or "sponsoring" of renewable energies, but rather their funding.

Prof. Dr. Uwe Leprich and Dr. Uwe Klann of the Institut für ZukunftsEnergieSysteme (Institute for Future Energy Systems) discuss this issue further in their Special Report entitled "Models for funding renewable energy generation" on Page 72.

The difference between the funding models is whether they take into account differences between the individual technologies, whether they are technology-neutral or not, and whether they bring electricity into the system via a physical transfer or marketing approach. A distinction is made between marketing models with a market premium and a capacity premium, with the former being a variable or (ex-ante) fixed premium.

Leprich and Klann recommend using different funding models depending on the renewable technology. For offshore wind energy they recommend an auction procedure with compulsory direct marketing. For onshore wind energy, PV, and hydroelectric energy, an options model with feed-in remuneration for small, risk-averse investors and a capacity premium with direct marketing for professional investors will entice a wide range of different investors.

The consumers must pay the difference between the remuneration payments to renewable energy producers and the ever falling spot electricity price. The average spot electricity price was 4.27 ct/kWh in 2012 and 3.78 ct/kWh in 2013. In order to close this gap, 0.85 ct/kWh was paid in 2013 [20]. In June 2013 the spot electricity price was at a more than six year low of 2.78 ct/kWh. Since 2008 the spot electricity price has fallen 38%.

Electricity generation from wind in Germany. Electricity generation from wind in Germany amounted to 47,400 GWh according to projections from the TSO in 2013. The contribution of offshore wind energy to the total electricity production was 906 GWh or 1.9% (see Figure 7). As in the previous year, wind energy accounted for about 8% of total electricity consumption in 2013.

Compared to 2012 when 50,670 GWh of electricity were generated by wind energy according to the annual statements of the TSOs pursuant to the REA, there was no large increase in the electricity generated from wind in 2013 despite the growth in the number of WTs. After a rather poor January for wind with 5018 GWh of electricity generated, the electricity generated in the summer of 2013 was also lower. In contrast, October in 2013 was very windy, including two major storms ("Burkhard" and "Christian"), and the wind-generated electricity output was 5492 GWh. Two storms in December ("Xaver" and "Dirk") ensured that WT operators had the second highest monthly electricity output ever. This meant overall that the output in 2012 was almost reached again in 2013, based on the extrapolations of the TSOs.

Expansion and wind energy utilization in Germany. The Electricity Feed-In From Renewables Act of 7. 12. 1990, the forerunner of the Renewable Energy Act (REA), obliged electricity supply companies (ESCs) to purchase electricity generated from renewables and guaranteed electricity producers minimum tariffs. Figure 8 shows the nominal power of the WTs installed in Germany year-by-year since 1990: After initial rapid growth, the growth rate has stabilized in recent years at about 2000 MW per year. In 2013 a total of 3035 MW of nominal wind power was newly installed. This level was last reached back in 2002. The total wind power generating capacity thus increased by 9.7% from 31,144 MW to 34,179 MW (see Figure 8).

Offshore wind farms in the North Sea and Baltic Sea with a total nominal power of 521 MW are now connected to the grid. Offshore WTs account for 1.9% of the total electricity generation from wind. This represents a small share but one which has grown since 2004. The year 2013 saw the last WTs in the BARD Offshore 1 wind farm being connected to the grid. Since August 2013 all the construction work in the Riffgat offshore wind farm has been complete. The connection of these WTs to the grid was put back to February 2014 due to the need to remove old munitions from the seabed [26].

The newly installed onshore capacity in 2013 was 2851 MW, and the last time it was this high was back in 2003. Figure 9 shows the rapid growth that took place after the Electricity Feed-In From Renewables Act came into force in 1991. Whilst the growth in new onshore wind power up to 1998 was in the hundreds of MW range, the maximum was achieved in 2002 when more than 3100 MW was installed onshore. The high growth rates in 2002 can be interpreted as a positive, time-delayed response to the Renewable Energy Act which came into effect in April 2000.

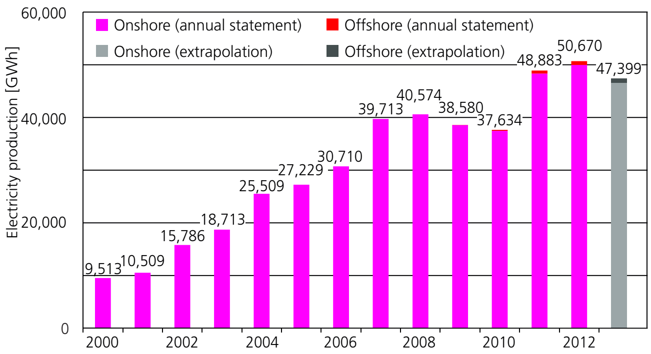


Figure 7: Electricity generation from wind in Germany. Data sources: Annual statements of the TSOs pursuant to the REA [21], AGEE [1, 2], Extrapolated data of the TSOs [22–25]. Due to the different data sources, there are differences to other figures cited in this report.

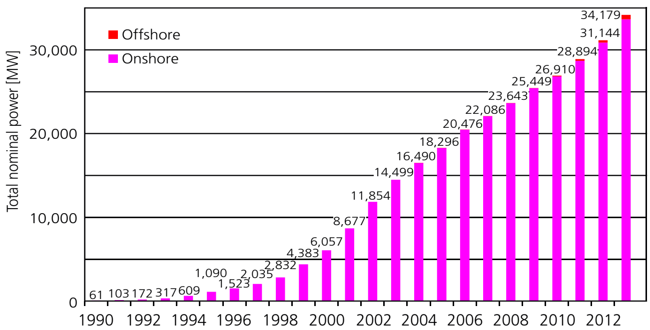


Figure 8: Growth in onshore and offshore wind power generation in Germany from 1990 to 2013. Data sources: IWET [27], Fraunhofer IWES

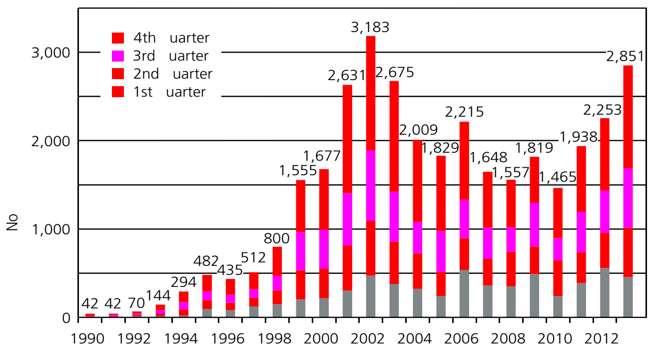


Figure 9: Annual installation of onshore wind power in Germany. Data source: IWET [27]

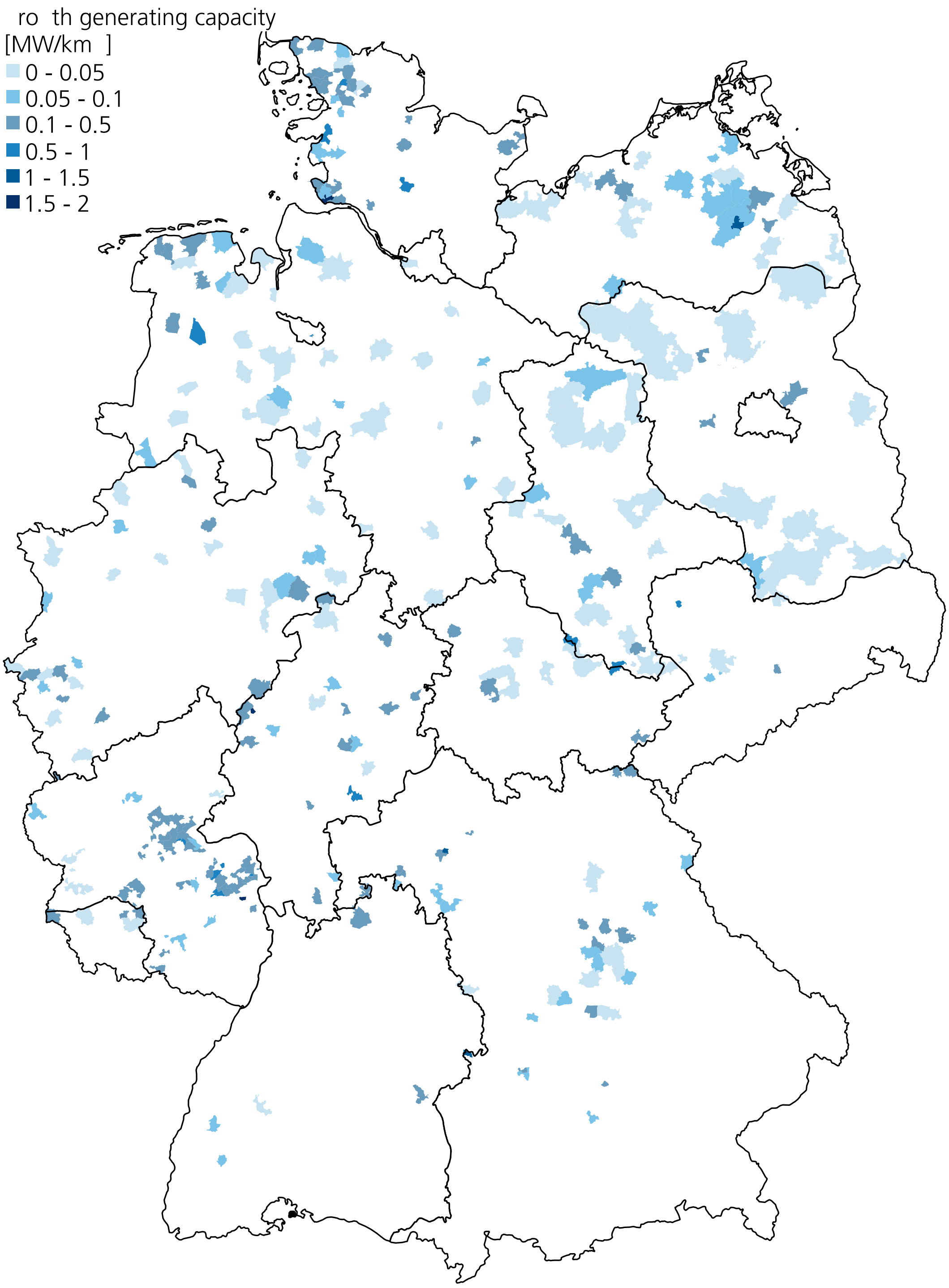


Figure 10a: New installed onshore wind power generating capacity in Germany in 2013 in different postcode regions. Data source: IWET [27]

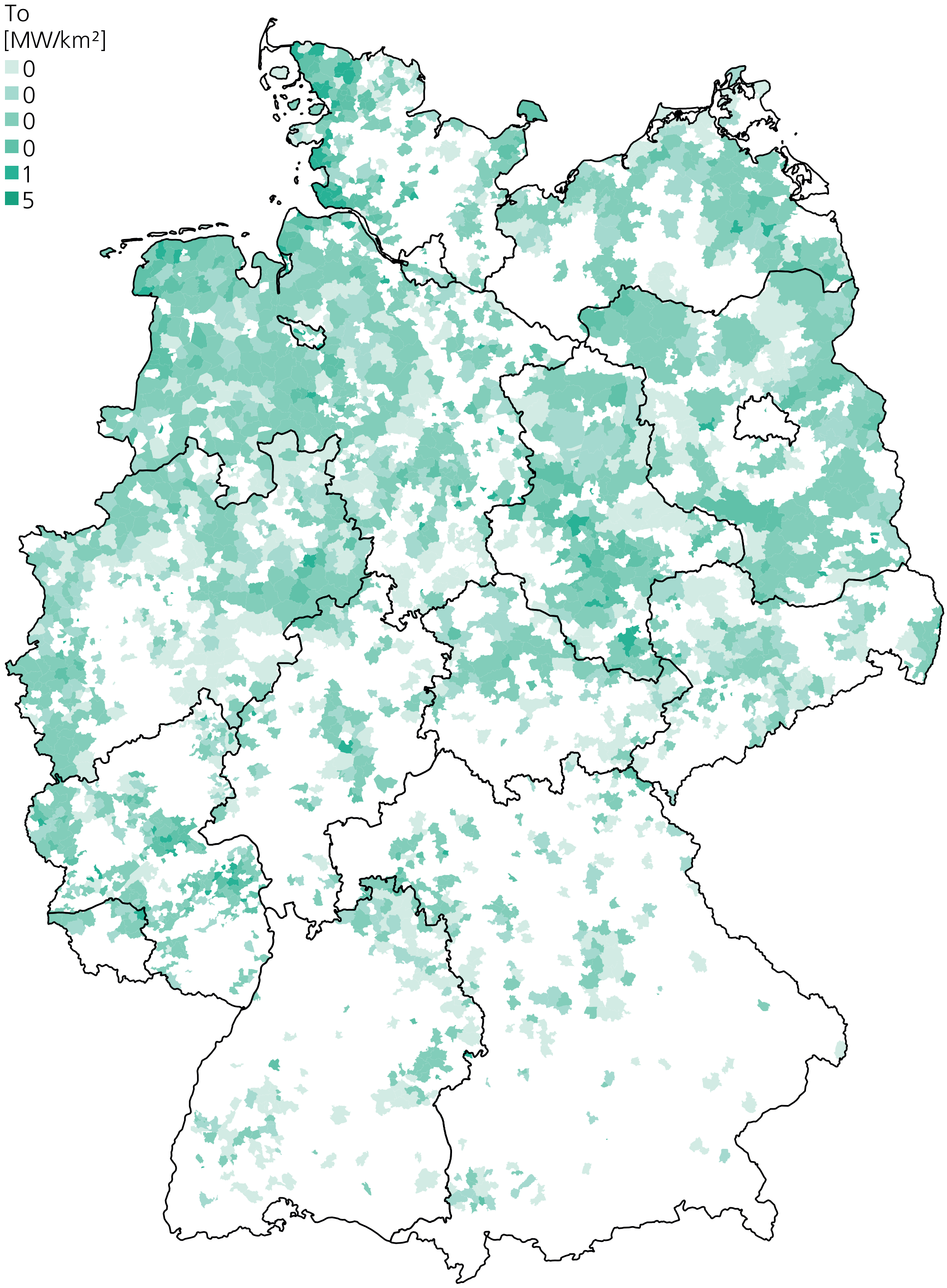


Figure 10b: Total onshore wind power generating capacity in Germany in 2013 in different postcode regions. Data source: IWET [27]

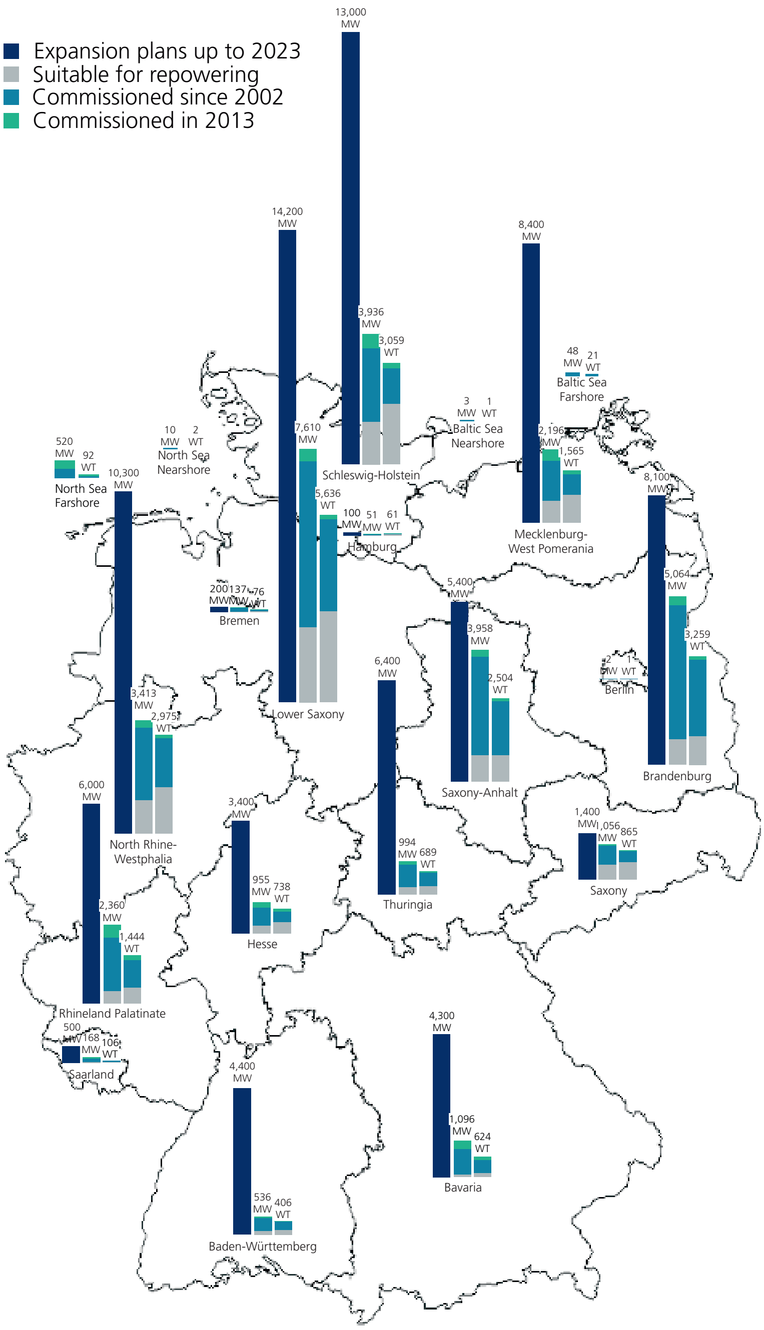


Figure 11: Total nominal power and number of wind turbines in each of the German states and in the North Sea and Baltic Sea (farshore and nearshore) for different times of installation and for expansion plans up to 2023 in Scenario C of the grid development plan (expansion targets of the German states). Data sources: IWET [27], Fraunhofer IWES, grid development plan 2013 of the TSOs [32]

State-by-state comparison. The Electricity Feed-In From Renewables Act set the remuneration for electricity generated from wind at 8 to 9 ct/kWh from 1991 to 2002 and this allowed profitable operation of WTs at locations having good wind conditions. Consequently in the mid 1990s there was a "WT boom" in Germany in the coastal regions. Technical improvements also resulted in ever more WTs being built far inland and in the low mountain regions of Germany. The start up of the alpha ventus wind farm in the North Sea in 2010 marked the beginning of commercial offshore wind power generation in Germany.

There are political endeavors in most states of Germany to utilize wind energy. Lower Saxony has a target of 14,000 MW onshore and 8000 MW offshore by 2020 [28]. The grid expansion initiative in Schleswig-Holstein is aiming for close to 8500 MW onshore [29] and Hesse wants to allocate 2% of its area as priority area for wind energy utilization in order to reach the target of having all its electricity generated from renewable sources by 2050 [30]. The plans and targets of the German states are outlined in Scenario C 2023 of the grid development plan and are depicted in Figure 11.

Despite its target of constructing 1000-1500 WTs in the future, the state government of Bavaria has enacted new regulations for the distance of WTs from settlements. According to the 10H regulations, the distance of a WT from a settlement must be at least ten times the height of the WT [31]. This limits the potential areas for new WTs.

The largest absolute capacity increase in 2013 was in Schleswig-Holstein with 436 MW. Rheinland-Palatinate constructed an additional 385 MW and Lower Saxony an extra 358 MW. Figure 11 shows that, as previously, Lower Saxony, Brandenburg, and Saxony-Anhalt have the largest nominal wind power generating capacity. Half of the total nominal onshore wind power generating capacity of Germany can be found in these three states. However, whilst Saxony-Anhalt is the state with the third highest installed nominal power, Schleswig-Holstein has the third highest number of WTs. Around the end of millennium, many WTs of low nominal power, and now considered to be small, were built there. In Schleswig-Holstein, Mecklenburg-Vorpommern, and Saxony every other WT is suitable for repowering.

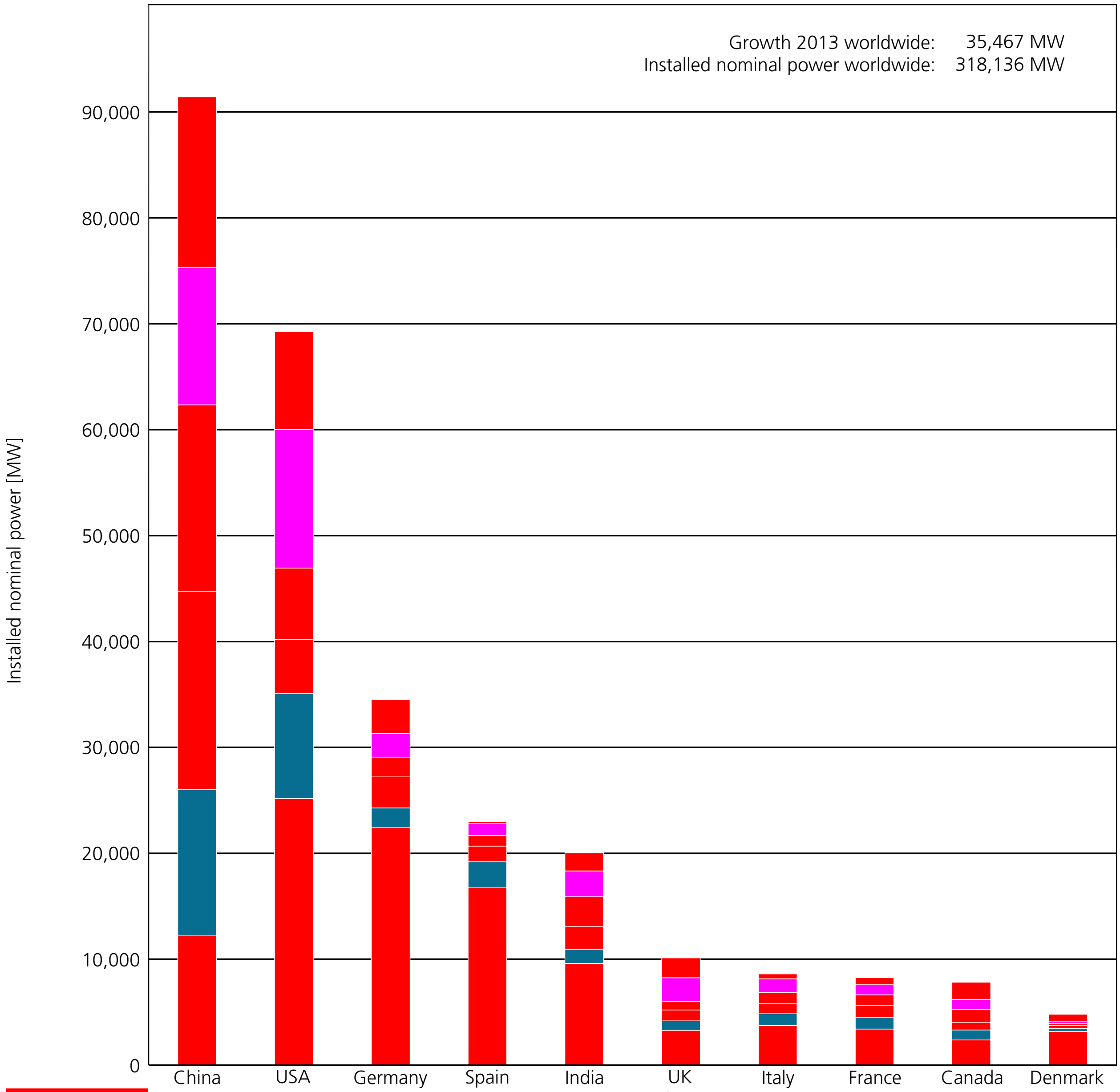
Schleswig-Holstein has the highest wind power generating capacity per unit area (on average 249 kW/km²), followed by Saxony-Anhalt (194 kW/km²). In the northern states the average is 160 kW/km² to 249 kW//km², whilst the southern states, and in particular Baden-Württemberg and Bavaria with 15 kW/km² and 16 kW/km² respectively, have much lower values. This north-south disparity and the differences between the various states are shown in Figure 10. The highest wind power generating capacity (about 401 MW) is in 14913 Jüterborg.

The different localities of newly installed WTs was reported in a study by Stiftung Agora Energiewende. The conclusion of the study was that the costs of switching over to renewable energy are virtually independent of the regional distribution of the WT expansion [33].

Growth of wind energy worldwide

The total onshore and offshore wind power generating capacity worldwide increased from 283,048 MW in 2012 to more than 318,137 MW in 2013. This corresponds to an increase of ca. 12.4%. Whilst the highest country growth in 2012 took place in the USA, China clearly led the way in 2013 (see Figure 12). With growth of 16,100 MW, the 90 GW mark was exceeded in China. The largest growth in Europe was in Germany (more than 3 GW) followed by the United Kingdom (just under 2 GW), which now occupies position 6 in the world ranking. Meanwhile there was a record increase in Denmark (657 MW) which pushes Denmark once again into the world top 10 [34].

Notable is the low growth of only 1 GW in the USA. The reason for this development is the uncertainty regarding the continuation of the favorable tax situation for wind farm operators (Production Tax Credits). As many feared the end was nigh for this favorable tax measure, numerous projects were advanced



	China	USA	Germany	Spain	India	UK	Italy	France	Canada	Denmark
Total 2013	91,424	61,091	34,546	22,960	20,050	10,111	8,596	8,254	7,800	4,819
Growth 2013	16,100	1,084	3,238	175	1,729	1,883	444	631	1,599	657
Growth 2012	12,991	13,088	2,233	1,112	2,428	2,210	1,275	983	936	235
Growth 2011	17,600	6,739	1,860	997	2,827	815	1,080	980	1,257	193
Growth 2010	18,723	5,088	2,922	1,476	2,141	1,018	947	1,139	689	269
Growth 2009	13,800	9,922	1,880	2,460	1,338	897	1,114	1,117	950	302
Total 2008	12,210	25,170	22,413	16,740	9,587	3,288	3,736	3,404	2,369	3,163

Figure 12: Ranking of leading countries utilizing wind energy at the end of 2013. Data sources: WWEA [36–38], GWEC [34]. Due to the different data sources, there are differences to other figures cited in this report.

into 2012. Although, as it turned out, the tax incentive was retained, the project pipeline was empty at the start of 2013. Things only really got underway again in the US market in the third and fourth quarters of 2013. Overall there was a loss of 92% compared to the previous year [35].

The main markets, representing about 72% of the total, were, as in previous years, China, the USA, Germany, Spain, and India. The United Kingdom, Italy, France, and Denmark are other European countries in the top 10. Only 4 of the top 10 countries operate commercial offshore wind farms (China, Germany, UK, and Denmark). There was very high growth in Canada with 1600 MW of new generating capacity installed in 2013. Other important markets with capacity growth between 600 MW and 1000 MW and a growth rate of more than 25% were Brazil, Poland, Romania, Australia, Mexico, and Turkey.

A region by region comparison shows that almost 38% of wind power generation worldwide is in Europe and in European waters. Following the weak growth in the USA, Asia's share grew by 1.8% to 36.4% (see Table 1).

If the installed nominal power per square kilometer is considered for different countries having greater than 200 MW total generating capacity, then the top 10 places in the ranking are all European countries (see Figure 13). Germany with close to 99 kW/km² still occupies second place behind Denmark. In Denmark, the installed nominal power per square kilometer increased by 15 kW/km² from 97 kW/km² (2012) to 112 kW/km².

European countries, most of which are relatively small, appear top here in the statistics. 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. India appears for the first time in these statistics.

Europe	121,474 MW	38.2%
Asia	115,939 MW	36.4%
North America	70,885 MW	22.3%
Latin America	4,709 MW	1.5%
Australia & Oceania	3,874 MW	1.2%
Middle East & Africa	1,255 MW	0.4%
Sum:	**318,136 MW**	**100%**

Table 1: Installed nominal power at the end of 2013 in different regions of the world. Data source: GWEC [34]

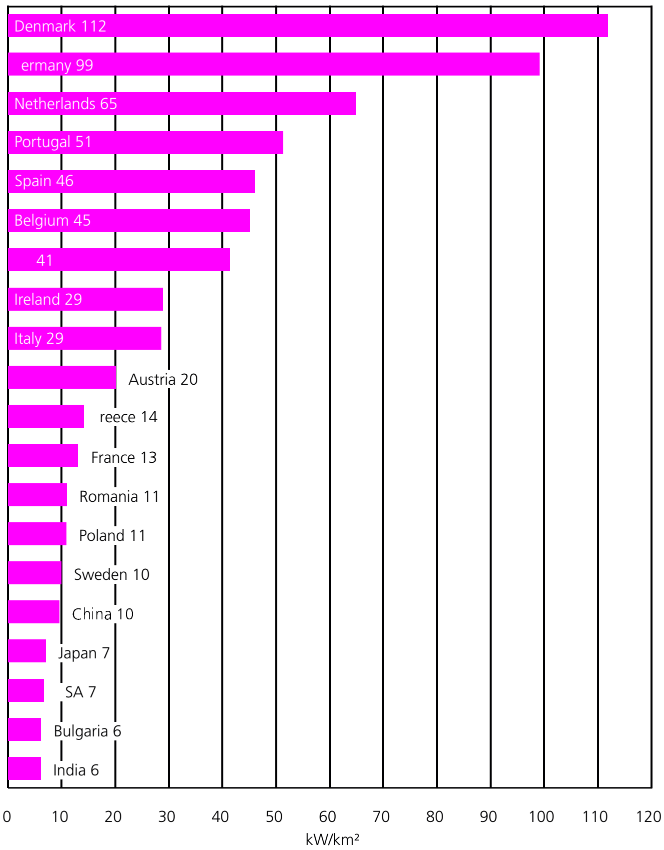


Figure 13: International comparison of installed wind power generating capacity per land area at the end of 2013 for countries with greater than 200 MW wind generating capacity. Data sources: WWEA and GWEC [34, 36–38] and CIA Factbook [39]

WIND ENERGY REPORT GERMANY 2013

GRID INTEGRATION AND GRID EXPANSION

Feed-in

Wind power feed-in 2013. The electricity generated by WTs fluctuates with the prevailing wind conditions and in contrast to conventional electricity generation cannot be adjusted to the demand. Due to the large number of decentralized WTs, full recording of the wind power feed-in is very complex. For this reason, the four German transmission grid operators (TSOs) use a special system to determine an actual value that calculates the actual wind power feed-in using a relatively small number of so-called reference measurement points. These measurement points are selected wind farms, or transformer stations with a high share of wind energy. Final figures for the electricity output only become available in the summer of the following year with the publishing of the "Annual statements of the TSOs pursuant to the REA".

Figure 14 shows the Germany-wide feed-in of wind power for the different calendar months. From January to December 2013 ca. 46.5 TWh of electricity generated by onshore WTs was fed into the German electricity grid. Compared to the previous year's extrapolations (just under 46 TWh), a slight output increase was achieved, although this was of the same order of magnitude. According to the annual statements of the TSOs for 2012, just under 50 TWh [16] of electricity generated from wind was fed into the grid. The extrapolated data tend to underestimate the actual feed-in. If one includes the considerable capacity growth in 2013 of 2850.76 MW (1,093 WTs), it is clear that 2013 was poorer from a wind energy feed-in standpoint than 2012. Although there was ca. 2.76 TWh less wind energy feed-in in the first half of 2013, the feed-in in the second half of the year was about 3.34 TWh higher than during the second half of 2012. The month of December had a major influence on the 2013 data with about 7.4 TWh of electricity feed-in, representing about 16% of the total annual feed-in. This also represented the second highest monthly wind energy feed-in ever, after December 2011. Figure 14 clearly shows the strong seasonal influence of the electricity generated from wind on a monthly basis.

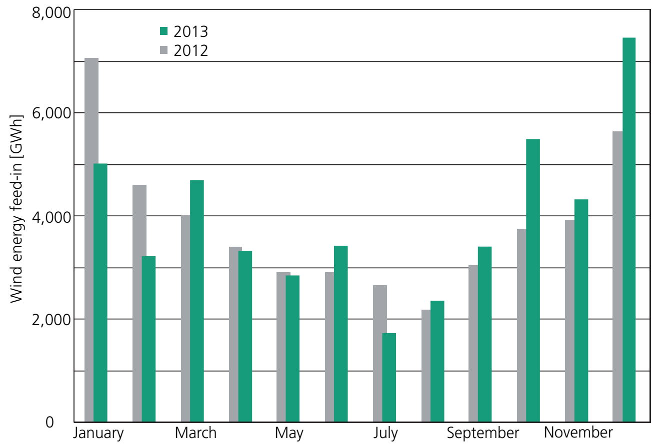


Figure 14: Extrapolation of the actual feed-in of onshore wind energy in 2013 month by month compared to the previous year. Data source: Extrapolated data of the TSOs [22–25]

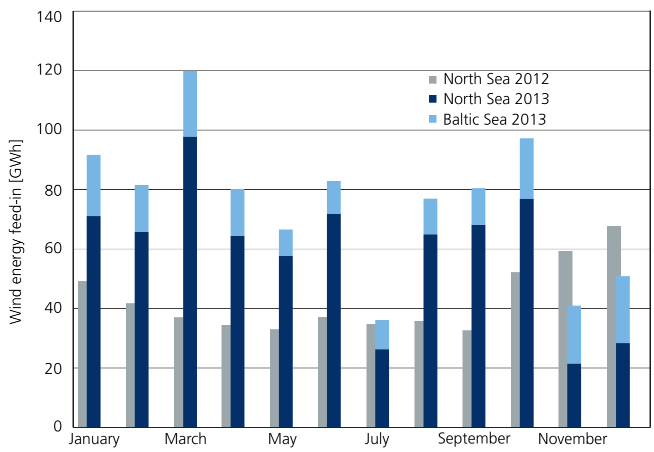


Figure 15: Extrapolation of the actual feed-in of offshore wind energy from the North Sea and Baltic Sea. Data source: Extrapolated data of the TSOs [22, 23]

Overhead line work

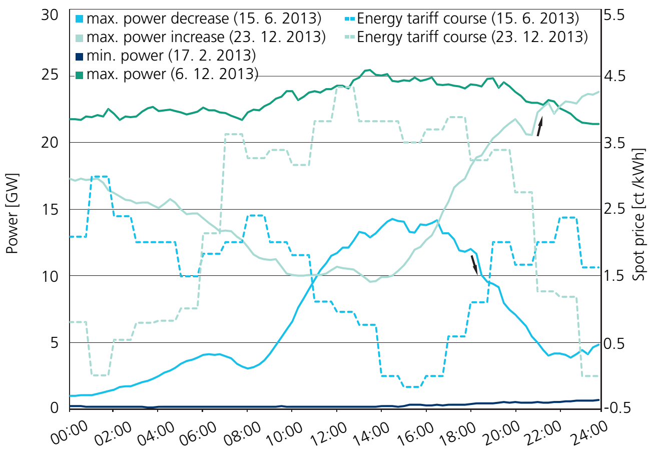


Figure 16: Extreme daily variations in the feed-in of wind energy to the German electricity grid in 2013, based on fifteen minute extrapolations of the wind power, and the electricity price movement on these extreme days in the EPEX spot auction market.
Data sources: Extrapolated data of the TSOs [22–25] and EPEX [40]

Figure 15 shows the electricity feed-in from offshore WTs in 2013. At 906 GWh (extrapolated data), 2013 was a new record for electricity feed-in from offshore WTs and the value exceeded the 2012 feed-in by 25%. This considerable increase was due to the 48 new WTs in the the BARD Offshore 1 wind farm. In March 2013 there was a very high feed-in of about 120 GWh, representing some 13% of the total annual feed-in. This contrasts with the less productive months of July, November, and December which gave a cumulative feed-in of only 128.03 GWh. The extrapolated data indicate there was technical disruption of the feed-in from the North Sea lasting several weeks.

Daily variations. Figure 16 shows the wind power feed-in on selected extreme days in 2013 as a function of time. The highest electricity production in one day was achieved on 6th December 2013 with an average of 23,219 MW, with 557 GWh being fed into the electricity grid. This day accounted for 7% of the December feed-in total. The highest power output on this day was 25,455 MW and this was generated between 13:30 and 13:45. At this time about 75% of the total nominal power of WTs in Germany was producing for the grid. The reason for this situation was the "Xaver" storm that passed over Germany on 5 and 6 December, causing winds of up to 44 m/s in northern Germany [41].

The day with the lowest wind power output in 2013 was 17 February. With average production of 277 MW, only 6.6 GWh was fed into the electricity grid. The biggest power increase over 15 minutes was on 23rd December 2013. From 20:45 to 21:45 the wind power output increased by 2444 MW to a level of about 23,000 MW, equating to an 11% increase over 60 minutes. Prior to this, the wind power output had more than doubled in 7 hours from less than 10,000 MW to just under 22,000 MW. The biggest power output decrease was observed on 15th June 2013. On this day the wind power output sank by 2070 MW between 18:15 and 18:45, representing an 18% fall within 30 minutes.

The magnitude of the wind power output is clearly reflected in the spot electricity market prices. The bell-shaped profile of the wind power output on 15 June 2013 between 08:00 and 21:00 is the inverse of the electricity price. The increase in the wind power output saw the electricity price fall to a minimum of -0.17 ct/kWh at 15:00. At this time the wind power output was at its maximum. The decrease in the wind power output from 15:00 to 20:00 saw the spot electricity price increase to a level of about 1.9 ct/kWh. The same situation was encountered on 23 December 2013. The wind power output on this day reached its minimum at 13:30 (just under 9.5 GW) and the electricity price at this time was 3.83 ct/kWh. A significant increase in the wind power output over 11 hours to close to 24 GW saw the spot market price fall by 3.83 ct/kWh to a value of -0.005 ct/kWh. The fall in the spot market price follows the wind power output with a certain delay. The reasons for this are the fall in the PV power output at this time of day and the increase in demand for electricity in the early evening, with consequently the spot market price being affected.

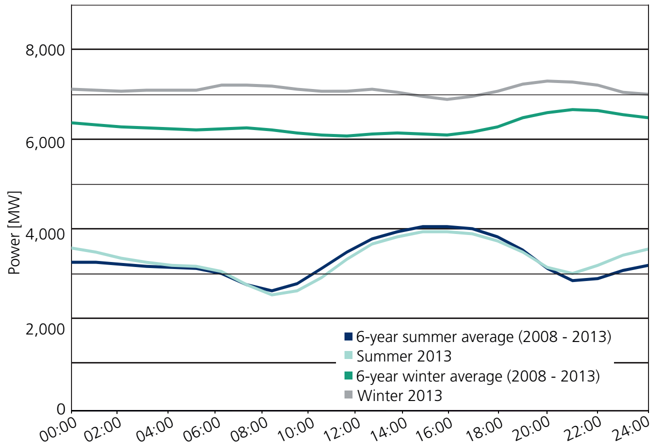


Figure 17: Average daily variation of the onshore wind power generated during the summer and winter months of 2013 compared to the 6-year average (2008-2013).
Data source: Extrapolated data of the TSOs [22–25]

Daily variations onshore. Figure 17 shows the average daily variation of the onshore wind power generated during the winter months (December, January, February) and summer months (June, July, August). The 2013 values are compared to the 6-year average (2008-2013). The power output in the summer months of 2013 was on average 47% less than in the winter months of 2013. The average power in the summer months of 2013 was 3329 MW. With average power generation of 7098 MW in the three winter months of 2013, about 15.5 TWh of electricity was fed into the German electricity grid during this period, corresponding to about 33% of the total wind power feed-in for the year.

The power generated during summer 2013 was thus slightly higher than the 6-year average. Onshore wind power generation in the winter months of 2013 was about 13% above the 6-year average (see also Figure 14).

In the summer months there is a clear relationship between the time of day and the wind power output. Between 00:00

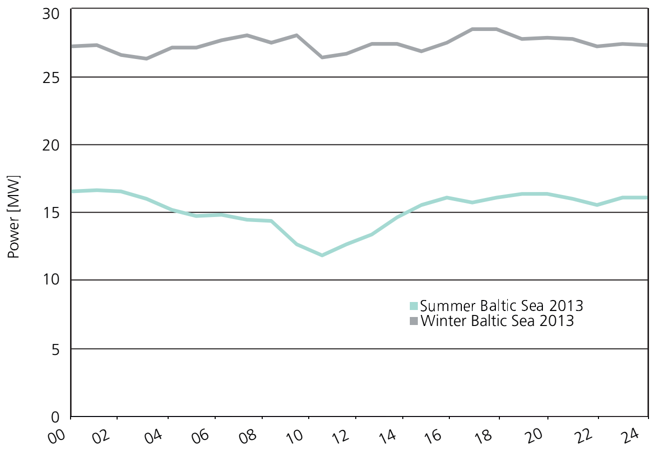


Figure 18: Average daily variation of the offshore wind power generated in the Baltic Sea during the summer and winter months of 2013. Data source: Extrapolated data of 50Hertz [22]

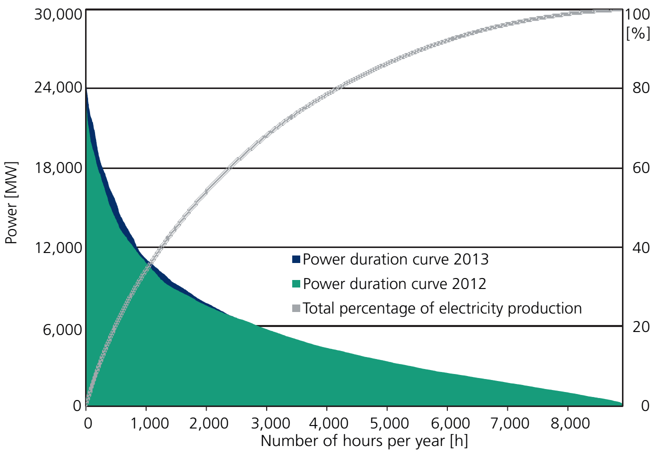


Figure 19: Power duration curve for onshore wind power in Germany in 2012 and 2013. Data source: Extrapolated data of the TSOs [22–25]

and 06:00 the wind power output is relatively constant. From 08:00 to 14:00 the wind power output increases on average by about 36% and reaches its maximum of about 4000 MW between 14:00 and 15:00. In the evening the wind power output is again at the level of the early morning hours. In the winter months, however, the time of day has only a minor influence on the wind power output. This effect arises due to the better integrity of the near-surface air layers during the summer months as a consequence of the higher incident sunlight and accompanying thermal effects. The greater thermal turbulence causes impulses from higher layers of the atmosphere to reach the near-surface layers and this maximizes the wind power density during the day.

Daily variations offshore. Figure 18 shows the daily variation of the offshore wind power generated during the summer and winter months of 2013 from the extrapolated data for the Baltic Sea (available for the first time). As only the power data from the Baltic Sea were used, there is no distortion from newly constructed WTs. Unlike in Figure 17, no clear dependence of the wind power output on the time of day can be seen.

The winter month average power output in 2013 of 27 MW is close to 12 MW (80%) greater than the summer month average. The reason for this is the much more favorable wind conditions in the winter months.

Power duration curve for onshore wind power. The power duration curve in Figure 19 shows the number of hours over the year when the feed-in from the WTs to the grid was above a certain power. The profile of the curve depends on the wind conditions and in particular the distribution of the latter across the area where the WTs are installed. The area under the curve represents the total annual electricity production from onshore wind. The large number of newly installed WTs in 2013 resulted in higher wind power generation for some of the time. This was so, however, for only 28% or about 2450 hours of the year. In the remaining period, namely ca. 6310 hours, the poor wind conditions meant that the wind power output was below that of the previous year. When viewing the power duration curve, it must be remembered that this represents all onshore wind power in Germany, meaning there are equalization effects and hence considerable differences to classical power duration curve for individual WTs or wind farms. It means that very high and very low power outputs are seldom seen.

Half of the 2013 wind power output occurred in the 1744 windiest hours of the year. In 2012 this value was 2270 hours. During half of 2013, wind power generation of at least 3728 MW was achieved. The highest value of 26,014.5 MW was achieved on 5 December 2013.

Power duration curve for offshore wind power. The power duration curve for offshore WTs in 2013 has a convex shape. The more uniform wind conditions offshore and the higher wind speeds there mean that higher powers were generated more often. As currently there is only the Baltic 1 wind farm offshore in the Baltic Sea, Figure 20 shows a genuine power duration curve for a single offshore wind farm. During close to 1000 hours the wind farm operated at full output. As there are no geographical equalization effects (see Figure 19), there are longer periods (ca. 900 hours) when the wind farm feeds in no electricity to the grid.

Overall, the offshore wind farms in the North Sea and Baltic Sea achieved higher power output and feed-in in 2013 than 2012 due to the further expansion. The maximum power output of offshore WTs was 299.5 MW on 2 September 2013. In 2013 there were 103 hours with no power output from offshore WTs and output was less than 10 MW for 7% of the time.

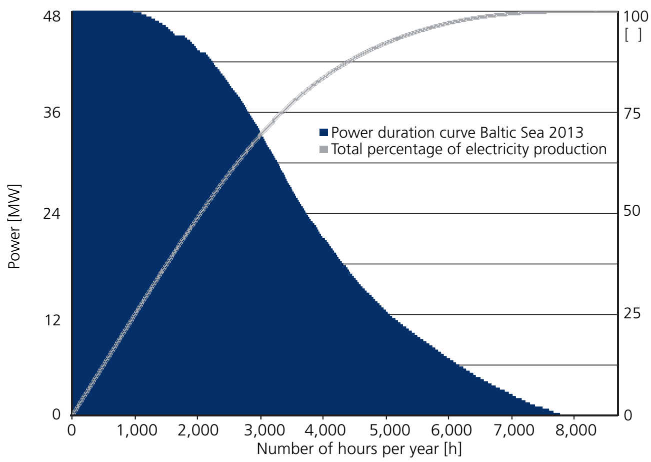


Figure 20: Power duration curve for offshore wind power in the Baltic Sea in 2013. Data source: Extrapolated data of 50Hertz [22]

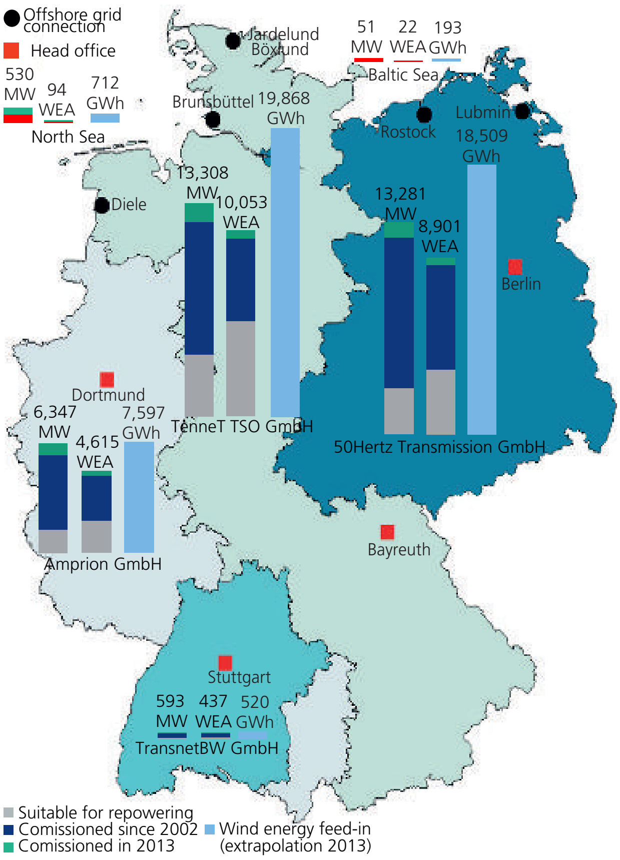


Figure 21: Control zones of the TSOs showing the installed wind power generating capacity, number of wind turbines, and wind energy feed-in in 2013. Data sources: IWET [27], Extrapolated data of the TSOs [22–25]

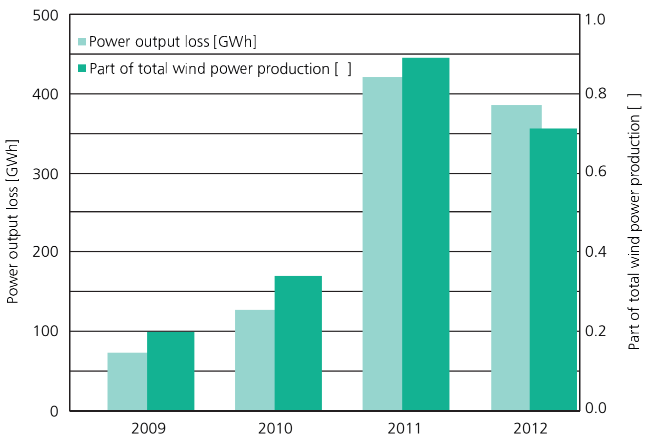


Figure 22: Effects of feed-in management. Data source: Federal Network Agency [42]

Grid operation and grid expansion

The four control zones. The electricity generated from wind in Germany is fed into the four control zones of TransnetBW GmbH, TenneT TSO GmbH, Amprion GmbH, and 50Hertz Transmission GmbH (see Figure 21). The figure also shows the total nominal power of all WTs in the control zones, the nominal power of newly installed WTs (onshore and offshore) in 2013, and the electricity feed-in to the grid. Just under 80% of the nominal wind power generating capacity is in the control zones of 50Hertz Transmission GmbH and TenneT TSO GmbH (13,281 MW and 13,308 MW respectively). Most of the newly installed wind power generating capacity in 2013 (representing almost 1.2 GW) was in the control zone of TenneT TSO GmbH. About 80% of the wind energy output was fed into the control zones of TenneT TSO and 50Hertz. About 20 TWh of electricity was fed into each of these zones in 2013.

Feed-in management. Under certain conditions, the TSOs can temporarily reduce the feed-in from WTs to prevent overloading of the electricity grid. Beforehand this is done, however, all measures against conventional power generators must be exhausted (§ 11 REA).

The downpowering of renewable power generators in 2012 mainly concerned wind power generation (93.2%). In 2012 a total of 19 feed-in management measures were reported. Northern Germany and, for the first time, Bavaria were affected by these measures.

Due to the weather conditions in 2012 there were no extreme simultaneous feed-in values from WTs and PV installations. The energy output loss thus fell compared to 2011 by 8.5% to 385 GWh (Figure 22). This corresponds to 0.71% of the total wind energy production. In accordance with § 12 REA, the TSOs must provide compensation for downpowering. Although there was less downpowering in 2012 than 2011, the compensation payments of 33.1 million euros were fairly similar in total to the previous year. The reason for this was the increased downpowering of PV installations. As PV installations receive higher feed-in remuneration than WTs, the compensation payments are also higher [42].

Grid expansion onshore. The increasing utilization of renewable energies, and in particular offshore wind energy, necessitates expansion of the transmission grids. According to the Energy Industry Act (EnWG), transmission system operators in Germany have since 2012 been obliged to present a joint grid development plan [43]. The plan must show what expansion is required for reliable and effective operation of the grid over the coming decade [32].

The Federal Requirements Plan Act (BBPlG) dated 23 July 2013 [44] for the first time lays down in law the grid expansion requirements. This outlines 36 projects, including 15 transmission lines between German states and one cross-border transmission line. Besides the construction of three new north-south electricity lines having a total length of 2800 km, taking wind-generated energy from the coast and offshore to the industrial regions of southern and western Germany, the Act also makes provisions for improvements to a further 2900 km of electricity lines. The new Act also limits the complaint procedure to one appeal before the Bundesverwaltungsgericht (Federal Administrative Court) in order to avoid protracted cases from opponents of the projects.

Five of the expansion projects onshore will for the first time involve extra-high voltage direct current transmission. The lines from Wilster near Itzehoe to Grafenrheinfeld in Bavaria and from Oberzier, near the power station in Weisweiler, to the Belgian border will have some trial sections of underground cabling in order to accelerate the construction in densely populated areas. The extra-high voltage alternating current line to improve the Rhine region in Baden will trial the use of high temperature conductors in a pilot project [44].

The cross-state and cross-border projects require approval by the Federal Network Agency. The TSOs can submit applications for federal planning of their projects to the Federal Network Agency. The federal planning includes the strategic environmental assessment, and 500 to 1000 m wide corridors are set for the power lines. According to the Federal Network Agency, the new lines should where possible be constructed alongside railway lines, highways, and existing electricity lines. With regards to the Wilster-Grafenrheinfeld line, TenneT has already proposed a route [46].

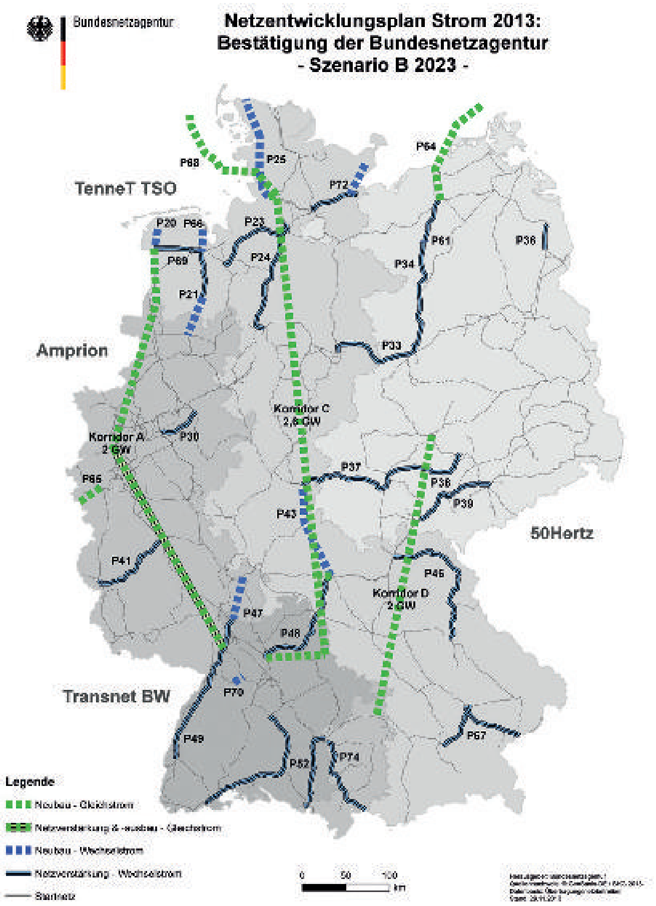


Figure 22b: Grid development plan confirmed by the Federal Network Agency (BNetzA) in 2013. Source: BNetzA [45]

TECHNICAL GRID ASSESSMENT

Grid expansion in Germany reached an important milestone in 2013. The grid development plan was assessed and approved by the Federal Network Agency. The German government passed the Federal Requirements Plan Act as the basis for specific planning procedures. What grid expansion measures are, however, necessary to keep pace with the expansion of renewable energy generation?

The Federal Network Agency carries out a technical grid assessment to determine whether the proposed measures are effective and necessary. Besides assuring electricity provision, it also ensures that the grid expansion measures are proportional, economically viable, and robust.

Based on the assumptions in the scenarios in the grid development plan, the assessment involves determining the hourly electricity inflow and outflow to the grid and performing load flow calculations. Based on these models, the effect of the grid expansion measure and potential utilization of the new line are determined.

How the Federal Network Agency actually undertakes the technical grid assessment and approaches for improving the assessment procedures are described by Dr. Swantje Heers, Thomas Dederichs, and Achim Zerres of the Federal Network Agency in the Special Report entitled "Technical grid assessment by the Federal Network Agency" on Page 80.

Grid expansion offshore. The connection of offshore wind farms to the grid remains a key challenge for expansion of offshore wind power. The electricity from offshore wind farms in the North Sea is fed into the transmission grid of TenneT; Wind power from the Baltic Sea is fed into the transmission grid of 50Hertz. Currently three offshore wind farms (alpha ventus, BARD Offshore 1, and Baltic 1) are connected to the grid. Munition finds on the seabed resulted in the Riffgat wind farm not becoming operational in 2013. It was finally connected to the grid on 12 February 2014 [26].

Due to the large number of planned and approved offshore WTs, there is a need for a grid development plan that takes account of environmental, economic, and geographical aspects. The offshore grid plan prepared by the Federal Maritime and Hydrographic Agency (Bundesamt für Schifffahrt und Hydrographie (BSH)) favored a connection concept in the form of so-called clusters. Wind farms with a close geographical and commercial relationship make up these clusters. In total, transmission systems for 21 GW of power were planned. Standard here are 900 MW direct current systems with a voltage of ±320 kV.

In total 13 different clusters were identified which meet the economic and environmental targets. Three clusters are ready. The alpha ventus and BARD Offshore 1 wind farms represent cluster 2 and cluster 7 in the North Sea and the Baltic 1 wind farm represents cluster 3 in the Baltic Sea (see Figure 23 and 24).

According to the plan, the clusters which contain WTs under construction or which are in priority wind energy regions should be further developed first. The resulting experience would be invaluable for the further planning of offshore grid connections.

In addition to the classic grid development plan, an offshore grid development plan was for the first time drawn up in 2013 and was largely approved by the Federal Network Agency on 8 January 2014 [47]. The plan gives a schedule for connection of the planned offshore wind farms to the grid and creates planning certainty for wind farm operators and the TSOs.

Under the plan, four direct current connections in the North Sea and one alternating current connection in the Baltic Sea are deemed necessary. The realization of the projects will be staggered. Each project will take 5 years and work will start in 2015 on the NOR-3-3 connection system for the Gode Wind, Innogy, and Delta Nordsee wind farms in cluster 3 [47]. The connection systems in the Baltic Sea must be complete by 2017 and the work will start in 2014.

The hitherto used Scenario B 2023 assumes 12.8 GW of offshore wind power in the North Sea and 1.3 GW of offshore wind power in the Baltic Sea by 2023. Following the German government's announcement to lower the targets for offshore wind power expansion by 2020 from 10,000 MW [48] to 6500 MW [49], there are new assumptions for preparing grid development plans from 2014 onwards. The Federal Network Agency expects there to be consequences for specific transmission line construction measures but no changes to the base planning concept [45].

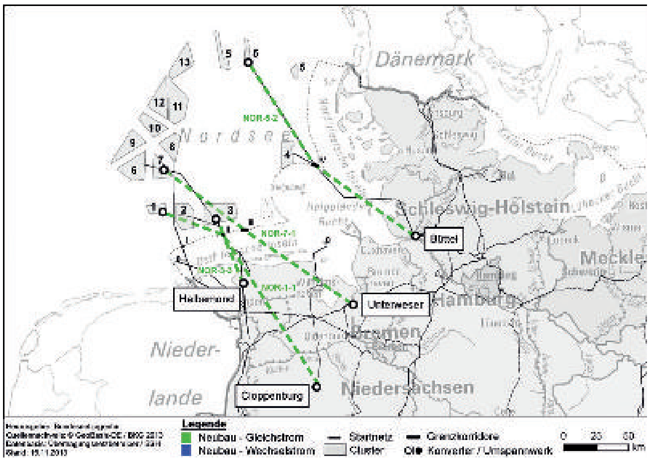


Figure 23: Confirmed North Sea measures in the offshore grid development plan 2013. Data source: Federal Network Agency [47]

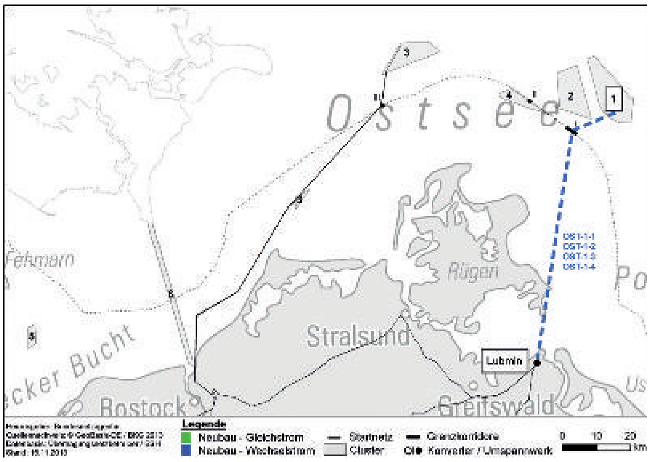


Figure 24: Confirmed Baltic Sea measures in the offshore grid development plan 2013. Data source: Federal Network Agency [47]

WIND ENERGY REPORT GERMANY 2013

ONSHORE

Technical developments

Newly installed wind turbines. During 2013 a total of 1093 new WTs were installed onshore in Germany having a nominal power of 2850 MW. This represented 26.5% more than in 2012, and was the second highest annual increase ever. The year 2002 with 3200 MW has the record, with some 2268 WTs having to be constructed in 2002 to generate this wind power. Figure 25a shows the newly installed WTs in Germany from 1990 to 2013 classified by location.

Locations of wind turbines. Unlike the previous year, most new WTs (496 WTs, 43%) were constructed in the low mountain regions. As such, wind energy expansion in central and southern Germany further accelerated. There was a 5% increase over 2012. The average power per new WT at this location was 2.58 MW, meaning a total power increase of 1212 MW in 2013. In contrast, the number of new WTs in the northern German lowlands has continuously decreased since 2008. In 2013 its share of 38% (411 WTs) was the lowest value for 16 years. The average power per new WT at this location was 2.55 MW, meaning a total power increase of 1051.5 MW in 2013. Some 19% (213 WTs) of all the new WTs in 2013 were constructed at coastal locations. The coastal region comprises a strip of land about 5 km in width along the north Germany coast. More powerful WTs are constructed here (2.75 MW per WT), giving a total power increase of 586 MW in 2013.

Wind turbine class size. As was already evident in 2012, a new class of WT is becoming a major market player (see Figure 25b). In 2012, 175 WTs (19%) of 3-5 MW size were constructed. This number rose to 440 in 2013 or 40% in percentage terms. The dominance of 2-3 MW WTs in past years has now been replaced by a larger class. It is expected that this trend will continue further over the coming years. The reason for this is also the additional WT designs in the 3-5 MW class that are now available in the marketplace. Although the majority of the new WTs, as in recent years, have once again been in the 2-3 MW class (608 WTs, 56%), this share fell by 20% in 2013 compared to 2012. The majority of the new WTs (96%) are in the 2-3 MW and 3-5 MW classes. The remainder are in the class

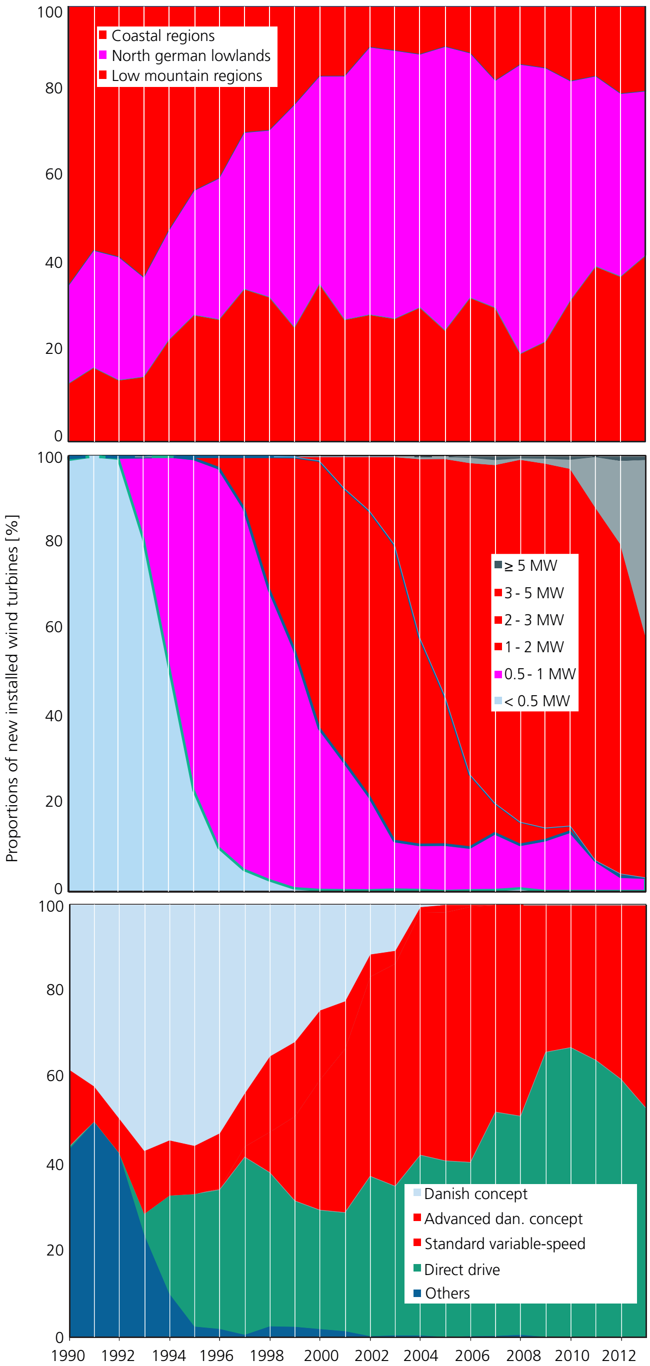


Figure 25: Year by year installation of WTs in Germany classified by location, class size and turbine design (1990-2013). Data source: IWET [27]

Zuidlob

Test-based development of wind turbine control systems

The development of control systems for WTs is increasingly being aided by automated test systems. Martin Shan and Dr. Boris Fischer of Fraunhofer IWES describe in the Special Report entitled "Test-based development of WT control systems" on Page 92 how automated testing of control systems can be used for developing WTs and the operation of wind farms.

The use of hardware-in-the-loop (HiL) systems allows simulation of the behavior of the total system when testing individual components. It enables development and commissioning times to be significantly shortened and the testing of extreme or abnormal situations without risks to safety. The tests may in the future play an important role for the certification of WT control systems.

The benefits of HiL systems also apply for the development of wind farm control systems. With in-line WTs, for example, more power can be generated overall if the power output of the first WT is reduced. The simulation of shadowing effects on the HiL test stand means that such optimization tasks, taking into account wind farm communication, can be undertaken in the laboratory in comfort.

above 5 MW (1%) and in the 0.5-1 MW class (3%). WT of over 5 MW have been constructed since 2004, but there has been no growth in this class in recent years. Besides the prototype of an AREVA offshore WT, only 10 other WTs in this class were constructed in 2013, and all of these were of the Enercon E-126 type.

The share of direct drive WTs has decreased for the third successive year (see Figure 25c). Its share had risen sharply since 1994, but fell by 7% in 2013 to 53% (566 WTs). The share of WTs with a conventional drive train (rotor, gears, generator) and variable speed accordingly increased. Since 2011 the share of newly constructed WTs having this drive design has markedly increased. All WTs constructed since 2009 have the two aforementioned drive designs.

Wind turbine dimensions. A total of 73 different designs of WT with differing rotor diameters and differing hub heights were constructed in 2013. Although most of these WTs – with just a few exceptions - had nominal powers of 2-4 MW, the WTs were increasingly adapted to the conditions at specific locations by prudent choice of the rotor diameter and hub height. Figure 26 shows that the rotor diameter of the newly constructed WTs in 2013 varied from 48 m to 126 m. The largest rotor diameter, designed for the onshore market, was the Enercon E-126 with 126 m.

The rotor diameter largely determines the power that can be generated by a WT. The area of the rotor determines how much wind energy can be collected and turned into electrical energy. The large variation in WT design becomes clear on considering the power range just over 2 MW. Various new WTs of differing design were constructed in 2013 having a nominal power of 2.3 MW. The rotor diameters ranged from 71 m (Enercon E-70) to 113 m (Siemens SWT-2.3-113). The swept area hence differs by a factor of 2.5.

The power that can be generated by a WT is also affected by the hub height. The wind speed increases with height. Given that the power generation is proportional to the third power of the wind speed, the hub height has a major effect on the power output of a WT. The hub height varies from 50 m to 149 m (see Figure 27), namely over a wider range than the rotor diameter. The highest hub constructed in 2013 was 149 m for an Enercon E-101. This hub height was about 27% above the average for newly installed WTs in 2013. The hub heights for WTs of 2.3 MW nominal power ranged from 64 m (Enercon E-70) to 138 m (Enercon E-92).

Figure 28 shows the hub height of newly constructed WTs in 2013 and also the hub height of all WTs. In 2013, 33% of new WTs had hub heights in the 120 m-140 m range. Whilst most WTs have hubs between 60 m and 80 m, only 10% of the WTs constructed in 2013 are in this category.

Most of the WTs constructed in coastal regions in 2013 had hub heights of between 60 m and 100 m, whilst just under 80% of WTs constructed in the low mountain regions had hub heights of more than 120 m. As there are strong winds at lower height in coastal regions, WTs there can generate high power with a lower hub height. Only 14% of the hubs there are over 120 m high. Due to the greater complexity of the topography in the low mountain regions, wind speeds similar to those in coastal regions are only found at greater height.

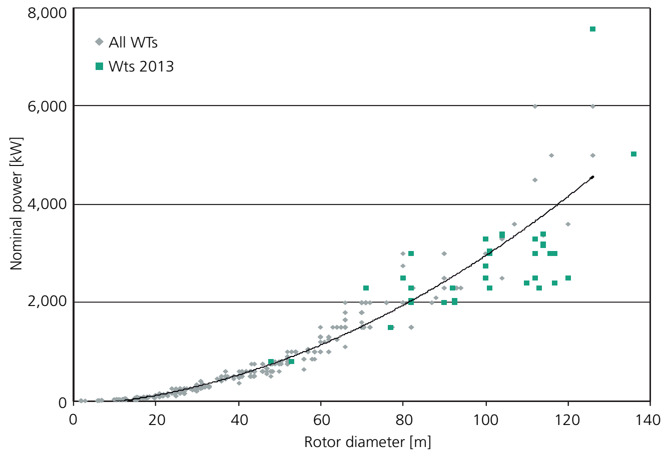


Figure 26: Nominal power as a function of rotor diameter for different wind turbine designs. Data source: IWET [27]

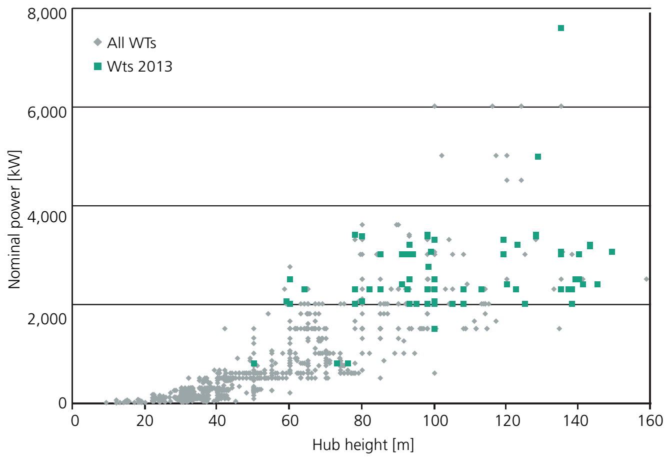


Figure 27: Nominal power as a function of hub height for different wind turbine designs and configurations. Data source: IWET [27]]

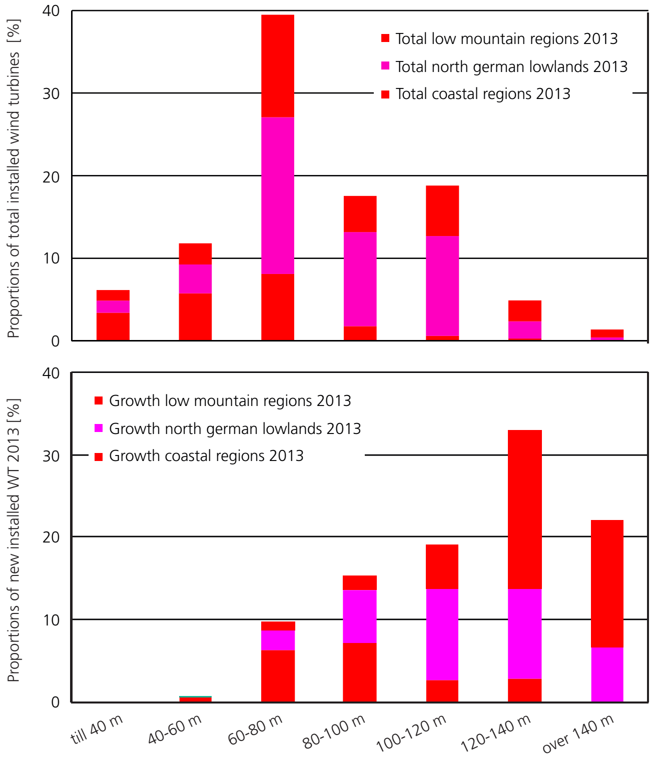


Figure 28: Hub height of all installed wind turbines in different locations; hub height of newly constructed wind turbines in 2013 in different locations. Data source: IWET [27]]

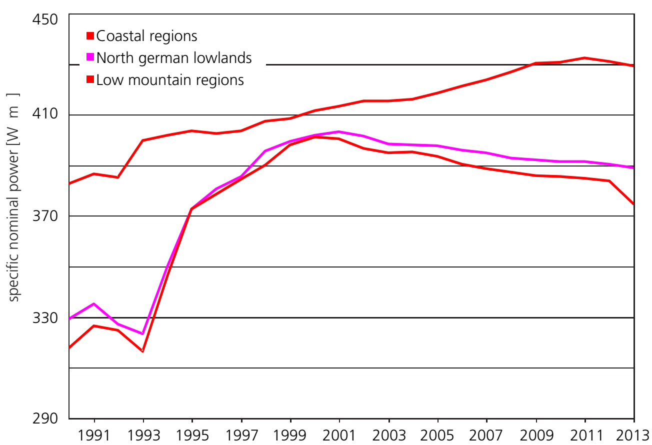


Figure 29: Growth in the specific nominal power as a function of the start-up year for different locations. Data source: IWET [27]

There is also a relationship between hub height and the nominal power. Whilst the WTs erected in coastal regions had an average nominal power per meter height ratio of 31.07 kW/m, the value for WTs inland was 20.94 kW/m.

The difference in the WTs constructed at windy locations and less windy locations is also seen in the average nominal power per square meter rotor area, namely the specific nominal power, in the different locations. Figure 29 shows the increase in this parameter over time in the three different locations. In coastal regions the specific nominal power of new WTs has grown continuously since 1990 by more than 12% to 429.56 W/m² in 2013. In the last three years the specific nominal power for WTs in coastal regions has, however, slightly fallen. Following a marked increase in the specific nominal power in the low mountain regions and northern German lowlands up to 2000, it has steadily fallen since then and in 2013 the values of 389.29 W/m² (the northern German lowlands) and 375.12 W/m² (the low mountain regions) were the lowest for 16 years. The reason for these trends is the very different wind conditions in these different locations. In coastal regions the norm is for larger WTs to be built with relatively small rotor blades. Here, the good wind conditions mean that high utilization rates can be achieved for the WTs. In contrast, WTs in the low mountain regions and northern German lowlands are often built where the wind conditions are adversely affected by obstacles such as forests. In order to be able to utilize the wind as effectively as possible, the WTs here generally have lower nominal powers but have larger dimensions. On average the specific nominal power of all new WTs built in 2013 was 391.06 W/m², a decrease of 1.3% compared to 2012.

The trend towards larger WT dimensions is also seen in the new WTs being developed by the major WT manufacturers. Examples here are the new Enercon E-115, Vestas V112-3.3 MW, and Nordex N131/3000 are in this specific power range. These WTs are being supplied with a wide spectrum of hub heights and, in some cases, different nominal powers in order to allow optimal adaptation to the conditions at specific locations [50, 51].

Onshore

Accompanying the trend to bigger WTs is a continuous increase in the average nominal power. At just over 2.6 MW, the average nominal power of new WTs constructed in 2013 was 8.7% greater than in 2012. The WTs constructed in 2013 had an average hub height of 117.5 m (a 5.4% increase over 2012) and an average rotor diameter of 95.44 m (an 8.2% increase over 2012). These values represent new record highs for the average hub height and average rotor diameter of newly constructed WTs. However, new absolute highs were not achieved for onshore WTs in 2013. Indeed, the record hub height of 160 m onshore was achieved back in 2006. The record rotor diameter increased to 135 m in 2013 with the installation of the AREVA M5000-135 offshore prototype. It is expected that 2014 will see further new records for the rotor diameter with the construction of other offshore prototypes (Senvion 6.2M152) [52].

The average nominal power of onshore WTs was 1.39 MW, an increase of 5% compared to 2012 (see Figure 31). Whilst the total nominal generating power of WTs with nominal powers below 2 MW has been fairly constant since 2004, there was a considerable increase in 2013 in the total nominal generating power of WTs in the 2-3 MW class and in particular in the 3-5 MW class. With a total nominal generating power of 2437.44 MW, the latter class grew by 127% in 2013. The class with the largest total nominal generating power remains the 2-3 MW class. This class now totals 15,651 MW and grew by 9.6% in 2013. The growth was, however, the lowest since this class entered the marketplace. The ≥ 5 MW class accounted for 10% of the new wind power generating capacity in 2013, namely 338.92 MW.

Age profile of wind turbines. At the end of 2013 some 1311 of the WTs installed in Germany had either reached or exceeded their assumed 20 year service life. As Figure 32 shows, this represents 5.5% of the total number of WTs but only 0.68% of the total nominal power (average 172 kW). The decommissioning of these WTs thus has very little influence on the total wind power generating capacity. Moreover, subject to current planning regulations at the relevant locations, these

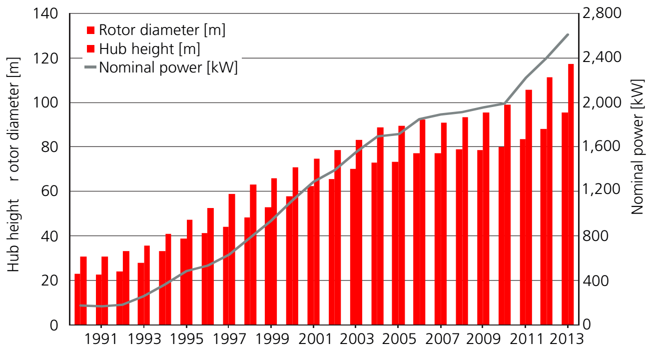


Figure 30: The changing size of wind turbines. Data source: IWET [27]

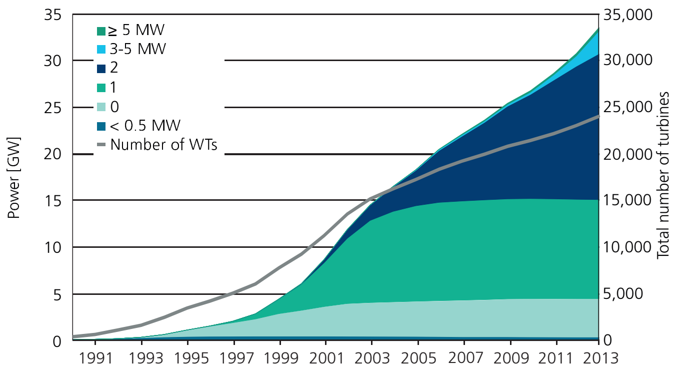


Figure 31: Cumulative onshore wind power generating capacity and number of onshore wind turbines. Data source: IWET [27]

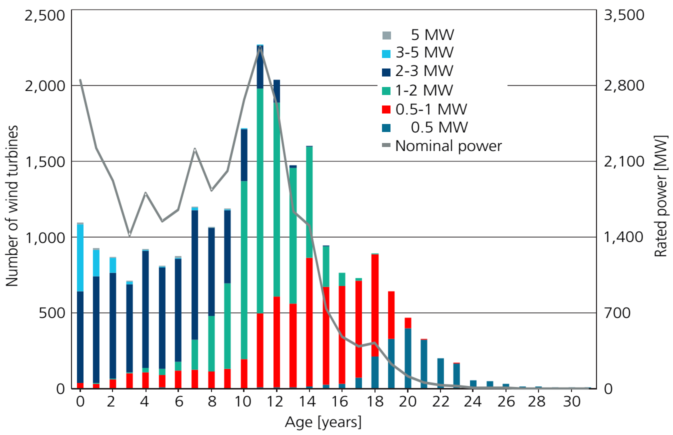


Figure 32: Age structure of wind turbines. Data source: IWET [27]

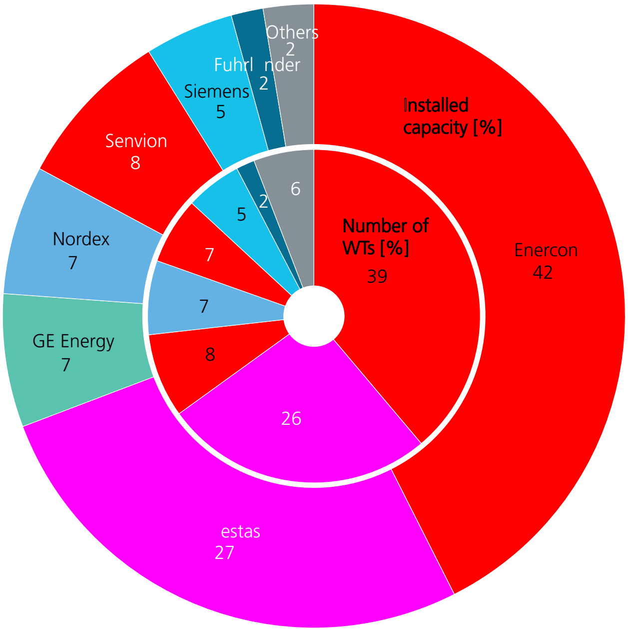


Figure 33: Market share of wind turbine manufacturers for wind turbines in operation in Germany up to 2013. Data sources: IWET [27], Fraunhofer IWES

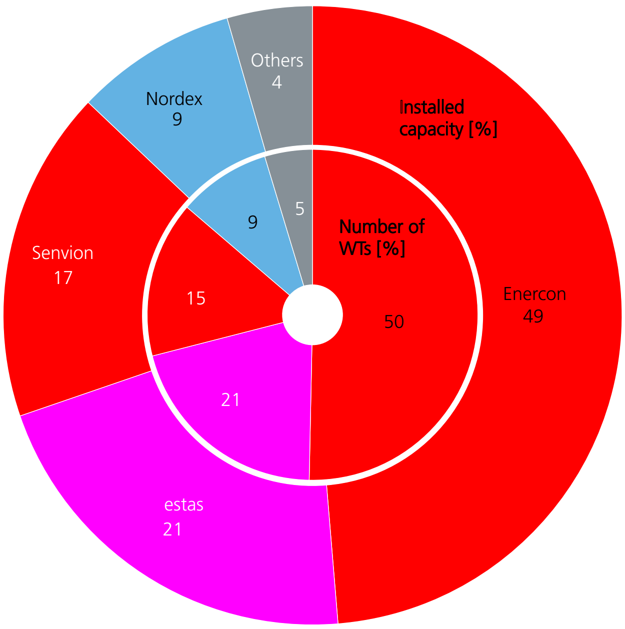


Figure 34: Market share of wind turbine manufacturers for new wind turbines brought into operation in Germany in 2013. Data sources: IWET [27], Fraunhofer IWES

WTs can be repowered, namely replaced by newer and more powerful WTs.

The REA of 1 April 2000 prescribes a bonus on the feed-in remuneration for all WTs installed before 1 January 2002 which are disassembled and replaced by new WTs [53]. At the end of 2013 this regulation applied to 10,386 WTs, namely 43% of all WTs. The WTs that are suitable for repowering have a total nominal power of about 8246 MW, corresponding to about a quarter of the total nominal power of WTs installed in Germany.

Schleswig-Holstein has the most WTs suitable for repowering. Some 59% (1817 WTs) of all the WTs in this state are suitable for repowering. Figure 10 in the first part of this report gives an overview of the repowering situation in the different German states.

Wind turbine manufacturers. WTs in Germany (Figure 33) come from more 40 different manufacturers. Some 94% of them, however, come from just seven manufacturers. Enercon and Vestas (15,702 WTs, 65% of the total) have a dominant position in the German marketplace. The Enercon share grew slightly in 2013, whilst a small fall was observed in the Vestas share.

Four manufacturers provided most of the new WTs that were constructed in 2013 (see Figure 34). Enercon supplied 550 of the new WTs in 2013 (a 50% share) and Vestas supplied 226 WTs (a 21% share). About 75% of the new WTs were supplied by German companies. Senvion (formerly REpower) and Nordex significantly increased their market shares in 2013. Indeed, Nordex doubled its market share compared to 2012. The market share of Enercon for new WTs fell by 8% in 2013, even though Enercon installed 100 MW more nominal generating capacity than in 2012. In 2013 GE Wind Energy and Siemens, unlike in recent years, once again installed a double-digit number of WTs in Germany.

Recycling of wind turbines

WTs are designed to generate clean electricity for a period of 20 years. Once this period lapses, WTs are either decommissioned or repowered (namely replaced by a new WT). In both situations, the end-of-life WT must be disassembled and, where possible, recycled.

Recycling is becoming an ever more important issue given that a growing number of WTs are approaching the end of their service lives. Prof. Dr. Henning Albers and Saskia Greiner, authors of the Special Report entitled "Recycling of wind turbines" on Page 86, explain that this does not solely concern bulk materials such as concrete and steel. For these materials there are already established return and recycling systems. Rather, WTs also contain large amounts of glass fiber reinforced plastics from the rotor blades and small but valuable amounts of heavy metals and rare earth metals.

Albers and Greiner outline the targets, tasks, and responsibilities in the process chain, quantify the mass flows, and summarize the available recycling technologies. They highlight that there are only a small number of options at present for recycling rotor blades and the recovery of heavy metals and rare earth metals is still unresolved. The wind energy industry must meet the challenge of developing material-efficient and environmentally-friendly recycling systems for end-of-life WTs.

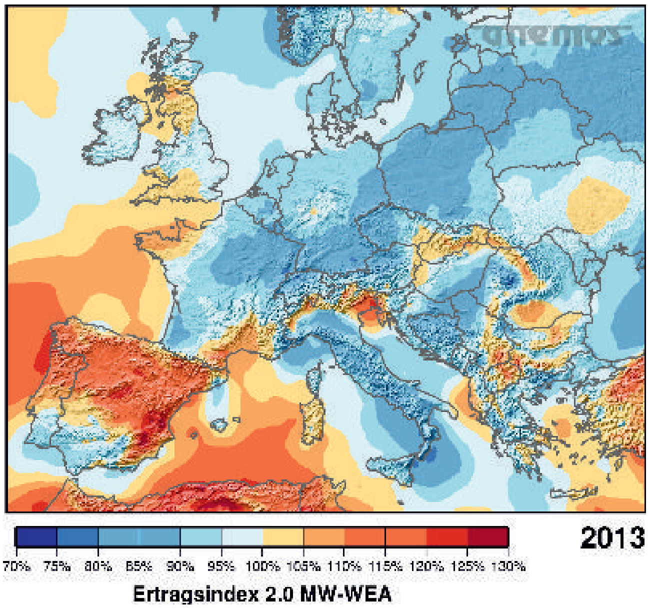


Figure 35: Wind conditions in 2013 compared to the 20 year average. Data source: anemos GmbH [61]

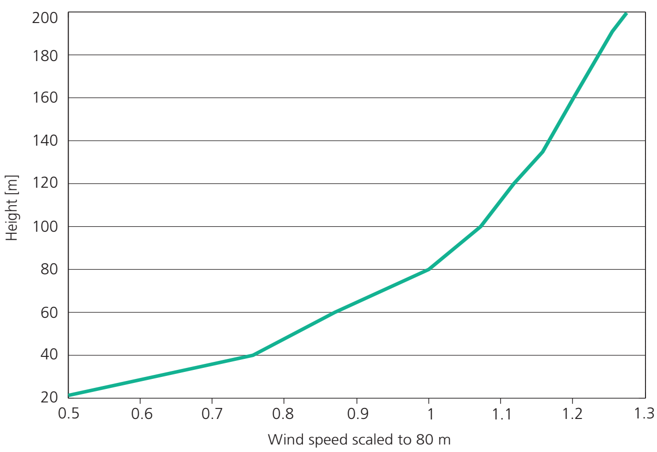


Figure 36: Wind profile at the 200 m measuring mast of Fraunhofer IWES, normalized to the wind speed at a height of 80 m. Data source: Fraunhofer IWES

Wind conditions

Energy yield index. The most important external factor for onshore WTs is the wind speed. The wind conditions are influenced by a number of complex climatic parameters. The wind speed varies constantly and is thus the major uncertainty, from both a technical and economic viewpoint, for wind energy utilization. Apart from the short-term fluctuations, there are considerable differences year by year from long-term average values. On top of this, there are regional differences caused by different geography and topography. When selecting locations for WTs, it is thus vital to evaluate the wind conditions over the long term. Figure 35 shows the wind conditions in 2013 compared to the 20 year average value. The energy yield index shows that the wind conditions in 2013 in Germany and in most of Europe were considerably below the long-term average. The energy yield index mirrors the evaluation of the hours at full load (see Figure 38). The energy yield index is calculated by refinement of so-called reanalysis data using a 3-dimensional atmospheric model and verification of the results using wind and energy yield data.

Conditions at different locations. Regardless of the regional wind conditions, the wind conditions prevailing at the specific locations of WTs are decisive for the wind farm design and subsequent energy output. A description of one example location will suffice to highlight this. Fraunhofer IWES operates a 200 m high wind measuring mast, which forms part of the "Wind Energy Inland 2" project being funded by the Federal Ministry for Economic Affairs and Energy (BMWi). The measuring mast is on a ridge of the Rödeser Berg about 20 km northwest of Kassel in North Hesse. This is a typical inland location with forested and complex topography. Figure 36 shows the wind profile measured for 2013. The profile is typical for locations with a large roughness length, with a large difference in wind speed between the lowest and highest measuring points, and a small gradient at low heights.

The large differences in the wind speed at different measuring heights are also evident in Figure 37 which shows the average daily variation of the wind speed at different heights. There is also an effect at lower heights. Whilst the maximum at low height is during the afternoon, the highest average wind speed at high hub height occurs at night. The reason for this phenomenon is the incident sunlight. At night the different layers of air move largely independently of each other at different speeds, but incident sunlight during the day leads to heating of the near-ground air. The resulting uplift means there is mixing of the air layers and greater interaction. The lower layers of air move at greater speed and the speed of the higher air layers is reduced [62].

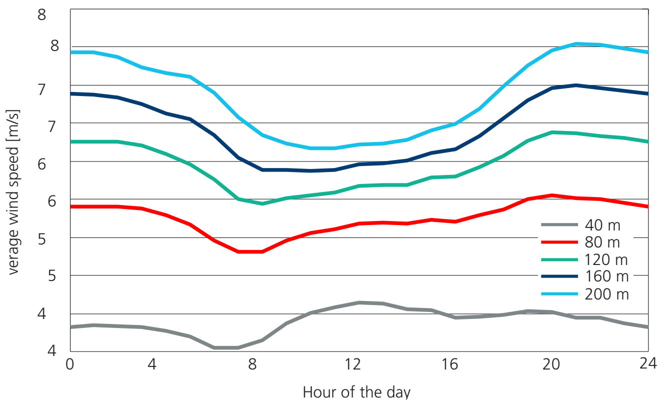


Figure 37: Average daily variation of the wind speed in 2013 at different heights at the site of the 200 m measuring mast of Fraunhofer IWES.

Data source: Fraunhofer IWES

Operating results

In 2013 onshore WTs in Germany achieved just under 1440 hours operating at full load, some 13.6% fewer than in 2012 (see Figure 38). This value is thus also considerably below the 5-year average (1619 hours at full load) and the 10-year average (1641 hours at full load). The effect of the new WTs installed means that there is an uncertainty in the 2013 value of about 9%.

The evaluation of the hours operating at full load serves primarily to compare different WTs and the conditions at different locations. The calculation of the hours operating at full load in 2013 is based on the extrapolations of the four TSOs. We therefore have to use provisional values until publication of the actual feed-in values. The hours operating at full load are calculated based on the total nominal power at both the start and end of a year and are hence represented in the graph as a range.

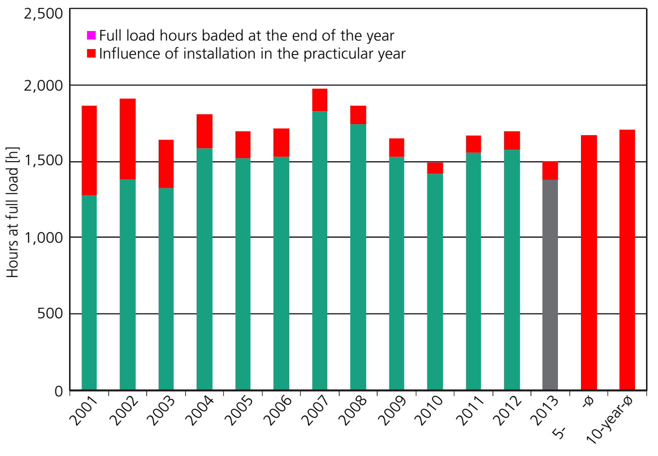


Figure 38: Hours operating at full load for onshore wind turbines in all of Germany on a year-by-year basis.

Data sources: TSOs [16, 22–25], IWET [27]

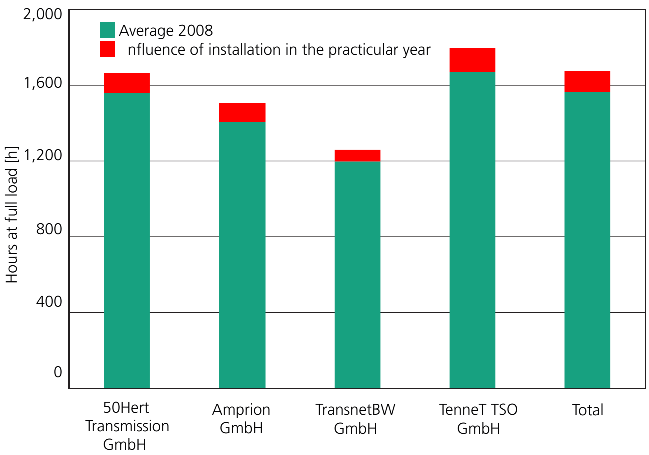


Figure 39: Hours operating at full load in the four control zones of the TSOs (2008-2012).

Data sources: TSOs [16], IWET [27]

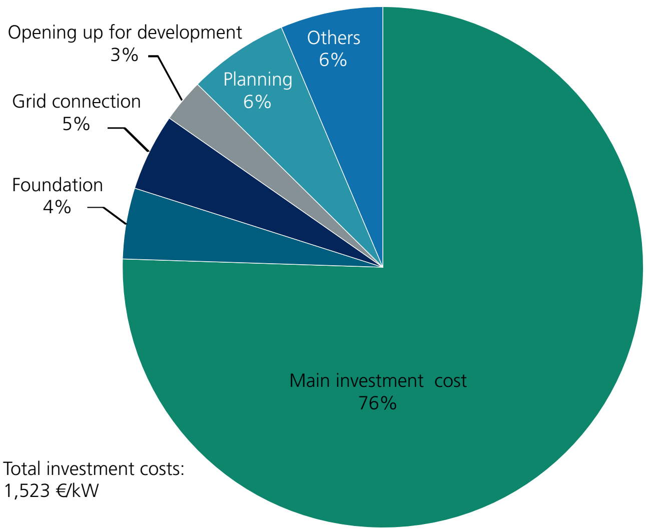


Figure 40: Distribution of the total average investment cost into main and secondary costs (WTs: 2 MW – 3.5 MW, hub height 100 m to 120 m). Data source: Deutsche WindGuard [63]

Figure 39 shows the hours operating at full load in the four control zones of the German transmission grid. WTs installed in the control zone of TenneT achieved an average of 1734 hours operating at full load in the period from 2008-2012, which was about 7% above the 5-year average for all Germany. The WTs in the control zone of 50Hertz averaged 1610 hours at full load, the second highest in that time period. The large difference of on average 507 hours operating at full load between the WTs in the control zones of TenneT and Transnet is due to the WTs at coastal locations, where there are generally better wind conditions and so more hours operating at full load.

Investment and operating costs

Investment costs. The cost of constructing WTs can be split into main investment costs and secondary investment costs. The main investment costs cover the nacelle, tower, rotor blades, transport, and installation of the WT. A study published in 2013 by Deutsche WindGuard looked at both the investment costs and operating costs for WTs. The results are shown in Figure 40 for the most commonly employed WTs in Germany (2 MW to 3.5 MW, hub height between 100 m and 120 m). The average main investment costs are about 1150 €/kW, and make up more than 75% of the total investment costs. The secondary investment costs were found to be 373 €/kW, so giving total investment costs of about 1523 €/kW. There are differences depending on the specific project and location [63]. Fraunhofer ISE, in its study on electricity generation costs, estimated the total investment costs in 2013 to be about 1400 €/kW [64].

Operating costs. Operating costs mainly comprise maintenance and repair costs, operational management costs, lease payments, and insurance premiums. Provisions for decommissioning the WT and other incidental costs are also considered to be operating costs. Figure 41 shows the operating costs over two different decades. The second decade shows an increase of about 11% in the operating costs. This is due to the higher maintenance and repair costs. Also to be taken into account here is that different WTs were considered for comparing the two decades [63].

Electricity generation costs. The specific electricity generation costs (in ct/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. Indirectly, the electricity generating costs therefore also depend on the attractiveness of wind energy projects for investors, the increases in the market price of raw materials, and the fluctuations in the rate of interest on borrowed capital [63].

The study of Deutsche WindGuard determined the electricity generating costs for different qualities of location using sensitivity analysis based on the "reference output". The range starts at a 60% quality for a location with poor wind conditions and ends at 150% quality for a very windy location. This resulted in electricity generation costs ranging from 6.25 ct/kWh to 11 ct/kWh [63].

In its study, Fraunhofer ISE made assumptions about WTs in coastal regions and inland. The study considered WTs having a hub height from 80 m to 130 m and having between 1300 h and 2000 h operating hours at full load. This gives electricity generating costs of about 8.5 ct/kWh to 10.7 ct/kWh for locations with poorer wind conditions and costs of 6.1 ct/kWh to 7.6 ct/kWh at locations with good wind conditions [64].

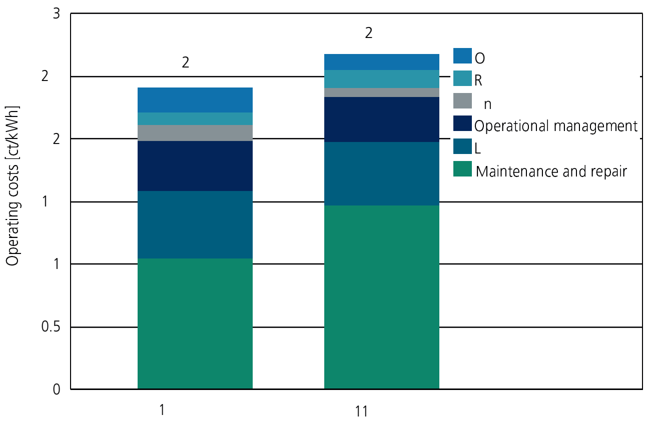


Figure 41: Wind turbine operating costs over time.
Data source: Deutsche WindGuard [63]

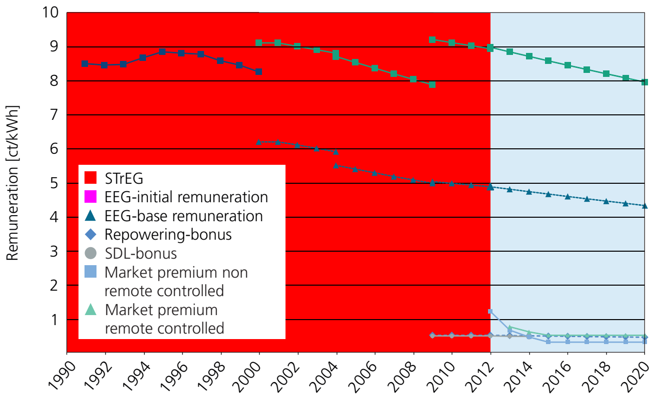


Figure 42: REA funding in accordance with amendment of 1 January 2012.

Data source: EEG [53]

Legal and financial boundary conditions

Remuneration for electricity feed-in. In Germany the remuneration for electricity feed-in was initially regulated by the Electricity Feed-In From Renewables Act (StrEG) which came into force at the start of 1991. The level of remuneration at that time was at least 90% of the average revenue per kilowatt hour (kWh) from electricity 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 relevant amendment was approved in June 2011 and came into force in January 2012. This concerns the remuneration rates for onshore wind energy. Although there were no amendments to the REA in 2013, the current coalition government plans far-reaching changes during 2014. Figure 42 shows the current and planned future remuneration rates under the REA as it presently stands.

Base remuneration and initial remuneration. The Renewable Energy Act lays down a minimum remuneration based on electricity output. In addition, a so-called "reference output" is defined. The reference output is the amount of electricity which the relevant type of WT would generate at a fictitious reference location under set conditions over five operating years.

For WTs it prescribes an initial remuneration for a period of at least 5 years. Depending on the quality of the location, the feed-in remuneration may subsequently be reduced to a base remuneration. For WTs at very windy locations the reduction takes place immediately at the end of the fifth year. For WTs at locations with poorer wind conditions, the payment at the higher rate is prolonged for two months for each 0.75% less output than 150% of the reference output. The remuneration rate for new WTs also depends on the year of installation. WTs installed in 2014 get an initial remuneration of 8.7 ct/kWh and a base remuneration of 4.7 ct/kWh. The annual lowering of the remuneration is 1.5%. Small WTs up to a nominal power of 50 kW always receive the initial remuneration for 20 years.

The initial and base remuneration can be supplemented by additional bonus payments. The initial remuneration increases by a system service bonus of 0.47 ct/kWh for WTs that are installed before 1 January 2015 and which at all times meet the requirements of the System Service Regulation. In situations where WTs are installed as part of repowering, a repowering bonus of 0.49 ct/kWh is awarded on top of the initial remuneration in 2014.

Direct marketing. Besides making provision for fixed remuneration for wind energy feed-in, the REA also allows direct marketing. The sale of electricity directly to third parties in this way can be undertaken to claim the market premium, to reduce the REA surcharge of the energy provider or as other direct marketing. At the end of 2013 over 85% of the installed WT generating capacity was utilizing direct marketing. Virtually 100% of direct marketing WTs claim the market premium. Direct marketing is rewarded by a management premium which was reduced to 0.45 ct/kWh (not remote-controllable WTs) or 0.60 ct/kWh (remote-controllable WTs) on 1 January 2014.

Developments in the wind turbine market

The year 2013 had both good news and bad for WT manufacturers. The change in name of REpower to Senvion in October 2013, due to expiry of the license to use that name, was one of the biggest changes in 2013 [54].

Following the start of insolvency proceedings in 2012 [55], Fuhrländer AG was liquidated in August 2013 [56]. FWT Trade GmbH, which was founded in 2013 on the former Fuhrländer site, became the indirect successor and now offers maintenance and also new WTs [57].

In September 2013 Vestas and Mitsubishi Heavy Industries (MHI) announced a joint venture (JV) to serve the offshore market in the future. The JV will start by March 2014 and will first of all offer the Vestas 3 MW (V112) and 8 MW (V-164) offshore WTs. The hydraulic drive train developed by MHI will also be offered and a WT for this based on the V164 will be developed [58].

AREVA and GAMESA also announced a JV in mid January 2014. In the future they will jointly develop, produce, and sell offshore WTs. AREVA brings with it its German sites and its existing WT technology (AREVA M5000). GAMESA has its own 5 MW offshore prototypes. The immediate goal of the JV is to develop an 8 MW WT [59].

The wind energy sector received bad news in November 2013. The BARD Group announced that it would be closing all BARD companies by mid 2014 due to a lack of follow-up orders. The operation and maintenance of the BARD Offshore 1 wind farm will be taken over by Offshore Wind Solutions GmbH [60].

WIND ENERGY REPORT GERMANY 2013

OFFSHORE

Expansion of offshore wind energy

Worldwide utilization of offshore wind energy. At the end of 2013 the number of offshore WTs worldwide was 2245, having a nominal generating capacity of 6890 MW (see Figure 43). In 2013 some 66 WTs were newly installed in nearshore locations and 368 WTs in farshore locations, having a total generating power of more than 1607 MW (see Figure 44). Wind farms are counted as newly installed generating capacity once they have been connected to the grid and can feed-in electricity. This now covers 90 wind farms: 41 farshore and 49 nearshore. Farshore is defined as offshore locations at least 3 nautical miles or 5.5 km from the shore (see § 3 REA). A nearshore location is accordingly less than 3 nautical miles (5.5 km) from the shore.

Europe currently leads the way in offshore wind energy utilization, followed by Asia. When countries are compared, the United Kingdom is the forerunner in offshore wind energy utilization, followed by Denmark and Germany. Most of the 66 European wind farms are in the North Sea (32), followed by the Kattegat, Irish Sea, and Baltic Sea each with 9 wind farms. Of the 23 Asian wind farms, 10 are in the East China Sea, 6 in the Sea of Japan, and 3 in the Yellow Sea.

In 2012, new WTs having a total nominal power of 1620 MW were installed. The new installations in 2013 totaled 1607 MW (see Figure 44). There are plans to further increase the number of WTs in European waters. The action plans of EU countries on renewable energy generation target 15 GW power generation from renewables by 2015 and 44 GW by 2020. With the actual 2013 figure being 6463 MW this means that just 15% of the target level for 2020 has so far been realized [66]. In order to achieve the 15 GW target by 2015, there must be 8700 MW of new generating capacity installed in the next two years. Even if the growth of 1600 MW would increase in the further years, it is clear that offshore generating capacity would expand more slowly than planned. According to the coalition agreement, the targets for Germany should be changed to 6.5 GW by 2020 and 15 GW by 2030 [49].

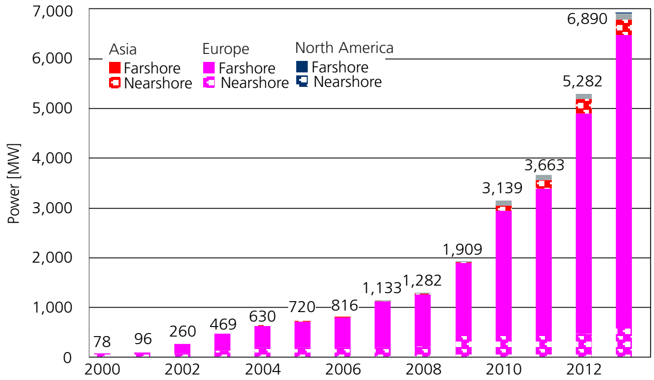


Figure 43: Growth of nearshore and farshore wind power generating capacity. Data source: Fraunhofer IWES

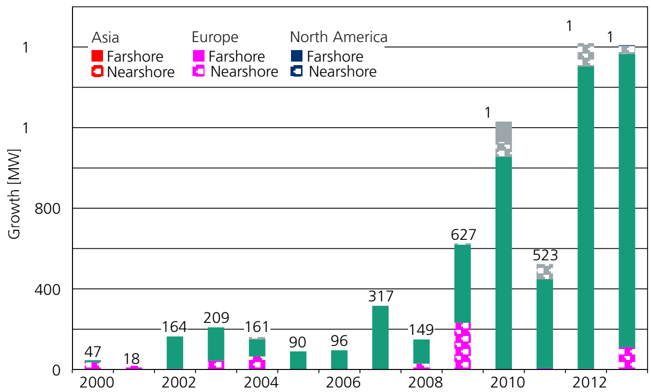


Figure 44: Annual newly installed offshore wind power generating capacity. Data source: Fraunhofer IWES

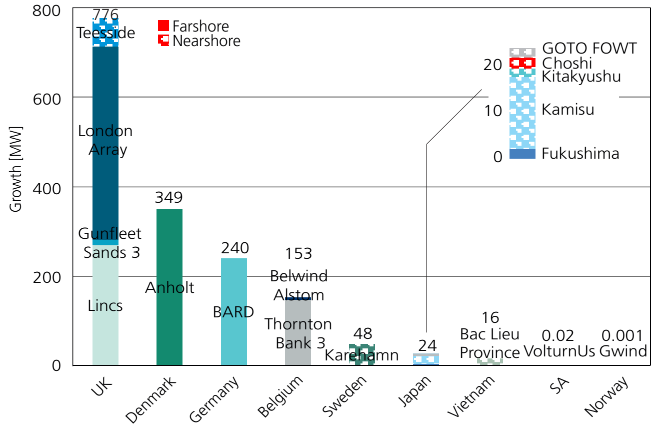


Figure 45: New offshore wind power generating capacity installed in 2013. Data source: Fraunhofer IWES

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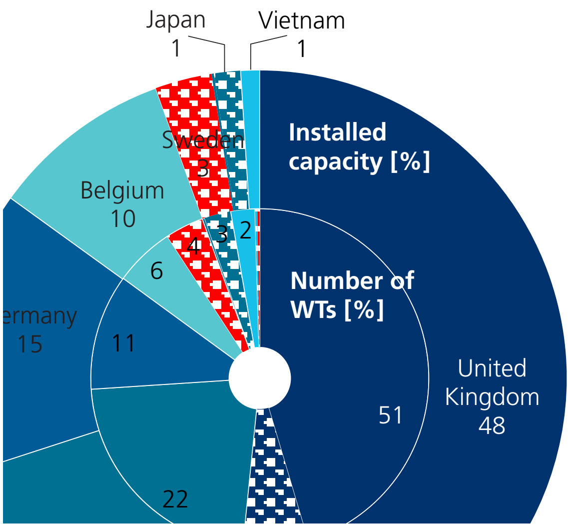


Figure 46: New offshore wind power generating capacity installed worldwide in 2013.

Data source: Fraunhofer IWES

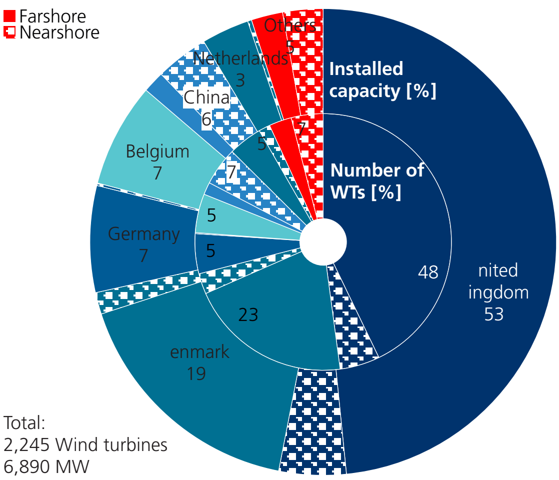


Figure 47: Installed wind power and number of wind turbines worldwide offshore in 2013.

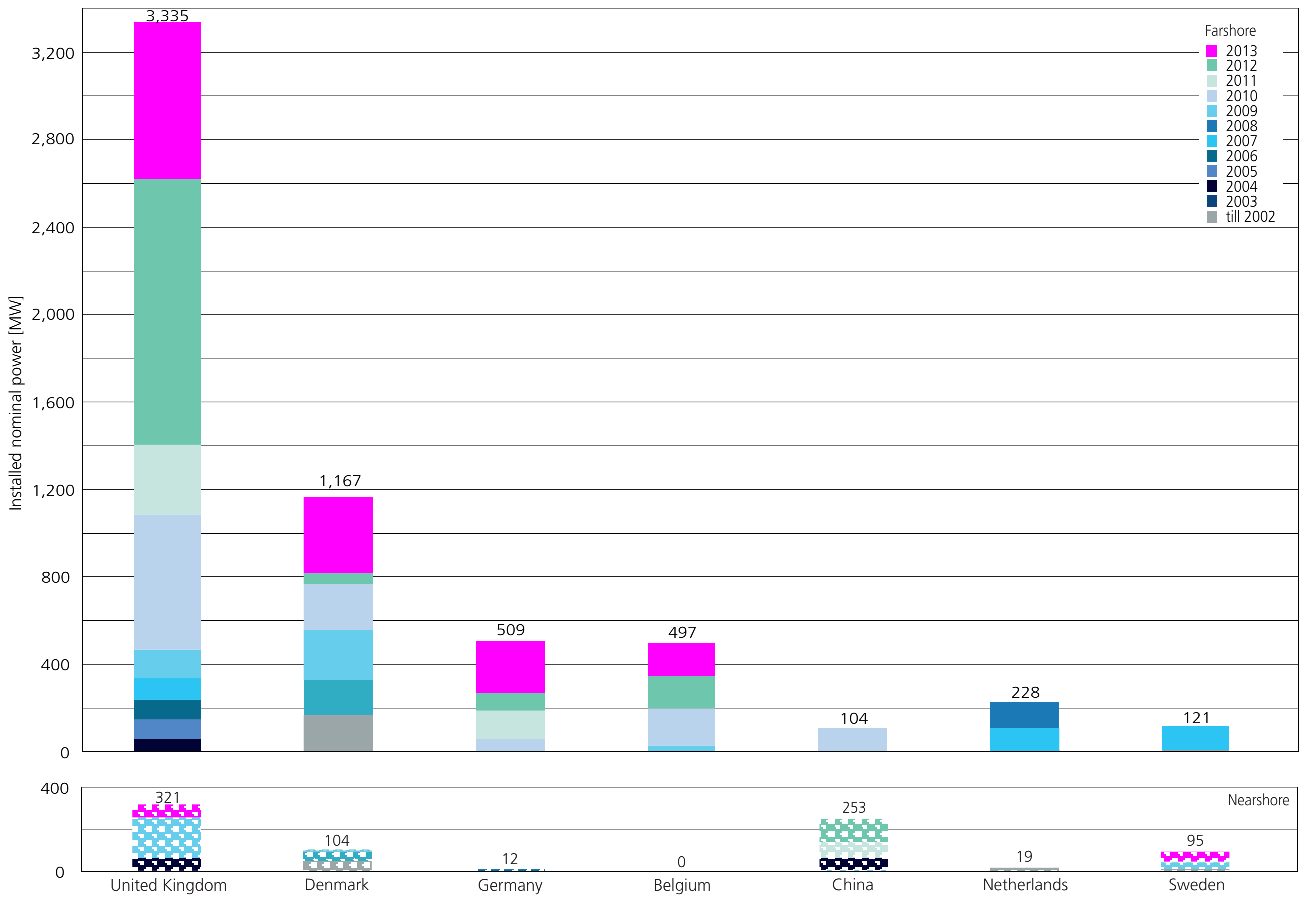
Data source: Fraunhofer IWES

The UK clearly led the offshore expansion in 2013. When countries are compared, the UK has led the way since 2009 and at the end of 2013 (3335 MW) accounted for just under half of the offshore wind power generating capacity installed worldwide (see Figure 47). The UK accounted for 44% (776 MW, 224 WTs) of the newly installed generating capacity offshore in 2013 (see Figure 45 and 46). By 2020 the UK plans to have 10 GW of offshore generating capacity [67]. The granting of the leasing rights for the realization of offshore projects in the UK is carried out by an auction procedure. The third round of bidding concerned 9 development zones and a generating capacity of 31 GW.

In 2013 Denmark finished construction of the Anholt wind farm, installing a further 97 WTs (349 MW). Construction start was in 2012. Germany completed the BARD Offshore 1 wind farm, installing a further 48 WTs (240 MW) and connecting these to the grid. Belgium and Sweden were other European countries to construct WTs. Following its intense installation of WTs in 2012, China constructed no further offshore WTs in 2013. China now has 143 WTs (356 MW) offshore, and from a generating capacity standpoint is behind Germany with 116 WTs (521 MW) and Belgium with 110 WTs (497 MW) (see Figure 48).

Japan started its offshore wind energy program with various experimental WTs having a total power of 24.4 MW. Vietnam installed its first offshore wind farm, Bac Lieu Province Wind Power Plant, in a nearshore location. This wind farm has 10 WTs (16 MW). The USA built its first offshore experimental farm, Dyces Head, having a single WT (0.02 MW). The Norwegian 1 KW experimental WT Gwind was constructed in the middle of the year and after trial operation for several months was disconnected from the grid (as planned).

The world's two largest offshore wind farms are now in UK waters, namely Greater Gabbard (504 MW) and the recently completed London Array (630 MW). These are followed by BARD Offshore 1 (400 MW) in Germany and Anholt (399 MW) in Denmark.



far- / nearshore	United Kingdom	Denmark	Germany	Belgium	China	Netherlands	Sweden
Total 2013	3,656	1,271	521	497	357	247	216
Growth 2013	714 / 62	349 / -	240 / -	154 / -	- / -	- / -	- / 48
Growth 2012	1,221 / -	50 / -	80 / -	148 / -	- / 113	- / -	- / 4
Growth 2011	313 / -	- / 4	128 / -	- / -	- / 74	- / -	- / -
Growth 2010	621 / -	207 / -	60 / -	165 / -	102 / 59	- / -	- / -
Growth 2009	126 / 195	230 / 7	- / -	30 / -	- / 7	- / -	- / 30
Growth 2008	- / -	- / -	- / 5	- / -	- / -	120 / -	- / -
Growth 2007	100 / -	- / -	- / -	- / -	2 / -	105 / -	110 / -
Growth 2006	90 / -	- / -	- / 3	- / -	- / -	3 / -	- / -
Growth 2005	90 / -	- / -	- / -	- / -	- / -	- / -	- / -
Growth 2004	60 / 60	- / -	- / 5	- / -	- / -	- / -	- / -
Growth 2003	- / -	166 / 44	- / -	- / -	- / -	- / -	- / -
Till 2002	- / 4	165 / 49	- / -	- / -	- / -	- / 19	11 / 13

Figure 48: Country ranking and year-by-year annual increase in new farshore and nearshore generating capacity.

Data source: Fraunhofer IWES

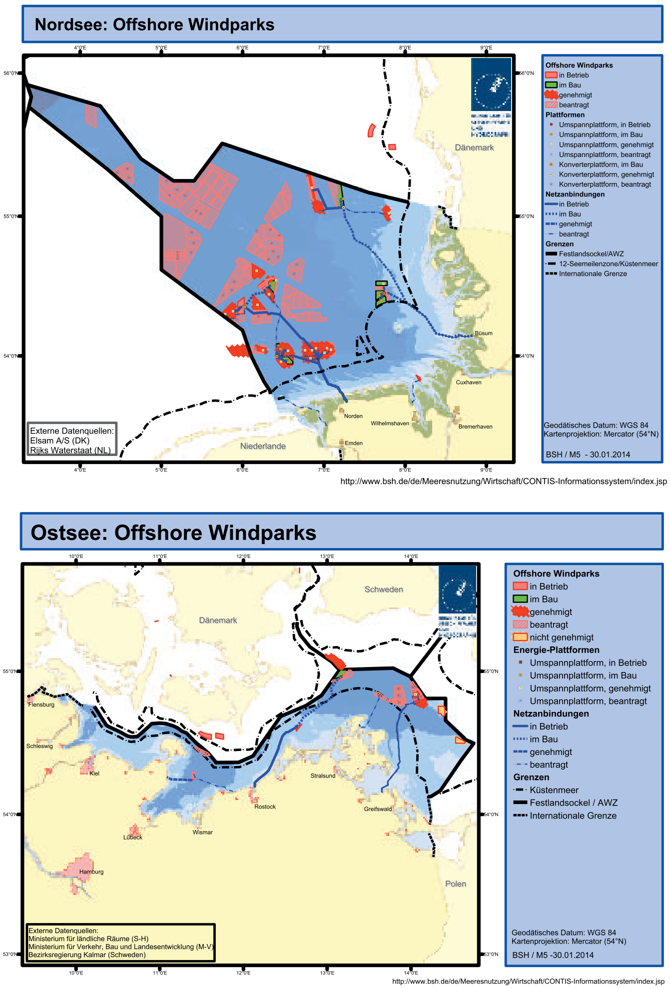


Figure 49: Overview of operational, constructed, approved, and planned wind farms in the German North Sea and Baltic Sea
© Federal Maritime and Hydrographic Agency (BSH) 2013 [71, 72]

Fourteen countries, namely nine EU member states, China, Japan, South Korea, the USA, and Vietnam produced electricity using offshore WTs in 2013. Denmark was the forerunner for a long time. The first large commercial offshore wind farm was built there. Today there are 519 offshore WTs in Denmark having a total nominal power of 1271 MW. The seven leading countries in offshore wind power generation are now increasingly focusing on expanding their farshore wind power generation. In recent years more than 2956 MW of new generating capacity was installed in farshore locations (see Figure 48).

Many countries are preparing to start commercial utilization of offshore wind energy. Japan, South Korea, and the USA are gaining their first experience with smaller WTs. Norway, the USA, Canada, Brazil, and India have offshore projects planned for the years ahead. In the USA the first approved offshore wind farm Cape Wind (468 MW, 130 WTs) will be connected to the electricity grid in 2015. Other wind farms are planned [68]. The Indian government also wants to trial offshore wind energy generation and is establishing a National Offshore Agency [69].

Situation in Germany. In German waters there are currently 116 WTs having a total nominal power of 521 MW. Germany is focusing its offshore wind projects in deep waters and in farshore locations so as not to adversely affect the marine environment in the Wadden Sea (Wattenmeer) National Park. The planned locations for offshore wind farms in German waters hence differ considerably from the locations of international offshore projects that have already been realized (see Figure 56).

In total 39 offshore wind farms have been approved in Germany up to December 2013, 34 of which are in the North Sea and 5 in the Baltic Sea. The Nordergründe and Riffgat (North Sea) wind farms and the Baltic I and GEOFReE (Baltic Sea) wind farms lie within the 12 mile zone. The relevant German states are responsible for giving approval for wind farms in this zone. The Bundesamt für Seeschifffahrt und Hydrographie BSH (Federal Maritime and Hydrographic Agency) is responsible for approval procedures outside the 12 mile zone, in the Exclusive Economic Zone. Further offshore wind farms are in the approval process.

Up until now offshore wind farms have been approved for an area covering almost 1235 km² and having a nominal power of 10,862 MW. The wind farms in the North Sea are planned at an average water depth of 29.3 m and at an average of 60.8 km from the shore. In the Baltic Sea the average planned water depth is 22.8 m and the average distance from the shore is 24.5 km (see Table 2 and 3).

An ecological research study was undertaken over a period of 5 years at the alpha ventus experimental wind farm. The results were published in 2013 and show that life on the seabed near the wind farm benefits from there being no fishing with bottom trawls there, and the number of fish species also increased [70].

The first test experimental WTs were installed nearshore in 2004 - 2008 by Enercon [74], Nordex [75], and BARD [76] (Figure 50).

In 2009 the installation of the **alpha ventus** wind farm marked the start of farshore wind energy utilization in Germany. The official opening of this experimental wind farm took place in April 2010. This North Sea wind farm consists of 12 WTs, each having a nominal power of 5 MW. It is ca. 45 km north of the island of Borkum at a water depth of 30 m [77].

In April 2011 the **Baltic 1** wind farm was the first commercial wind farm to start operating in the Baltic Sea. Baltic 1 is off the Mecklenburg-Vorpommern coast, ca. 16 km north of the Darß-Zingst peninsula, at a water depth of ca. 19 m. The 21 WTs made by Siemens have a total nominal power of 48.3 MW [78].

The **BARD Offshore 1** wind farm first supplied electricity to the grid in 2011 [79]. Since the end of August 2013 all 80 BARD 5.0 WTs having a total nominal power of 400 MW have been connected to the grid [80]. BARD Offshore 1 covers about 60 km² and lies about 90 km northwest of Borkum at a water depth of ca. 40 m [81]. It is thus at present the largest offshore wind farm in German waters.

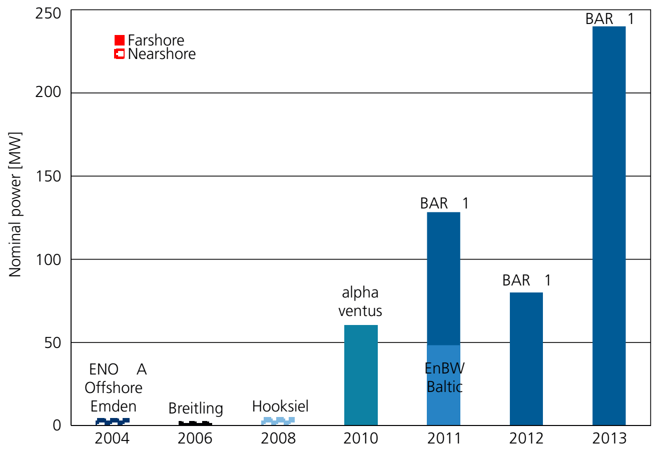


Figure 50: Start-up of new German offshore wind farms.
Data source: Fraunhofer IWESS

Wind farm name	Nominal power [MW]	Water depth [m]	Distance from shore [km]	Area [km²]	Status	Latest start of construction
alpha ventus	60	30	43	8	In operation	
BARD Offshore 1	400	39 - 41	89 - 111	58.9	In operation	
ENOVA Offshore Ems-Emden	4,5	0 - 2	0 - 0,6		In operation	
Hooksiel	5	2 - 8	0,4	0.16	In operation	
Riffgat	108	18 - 23	30 - 42	13.2	Completely installed	
Borkum West II (Trianel Windpark Borkum)	200	28 - 33	65.6 - 66.3	56	Under construction	
Global Tech I	400	38 - 41	109.4 - 115	41	Under construction	
Innogy Nordsee Ost	295,2	22 - 25	51.4 - 57	24	Under construction	
Dan Tysk	288	21 - 32	70 - 74	70	Under construction	
Amrumbank West	288	19.5 - 24	36 - 55	32	Under construction	
Borkum Riffgrund I	277.2	23 - 29	54	35.7	Under construction	
Meerwind Süd / Ost	288	23 - 26	52.4 - 53	40	Under construction	
MEG Offshore I	400	27 - 33	60	40	Approved	31. 10. 2013
Veja Mate	400	39 - 41	114	50	Approved	30. 6. 2014
Innogy Nordsee 1	332.1	26 - 35	44 - 47.3	34	Approved	1. 7. 2014
Butendiek	288	17 - 22	32	34	Approved	31. 12. 2014
Delta Nordsee 2	160	29 - 33			Approved	31. 12. 2014
Deutsche Bucht	210	39 - 41	98 - 117	22.6	Approved	31. 12. 2014
Albatros	474	39 - 41	75 - 113	39	Approved	1. 6. 2015
Gode Wind 01	330	26 - 35	40 - 42.1	37	Approved	30. 6. 2015
Gode Wind 02	252	26 - 35	33 - 34	29	Approved	30. 6. 2015
Borkum Riffgrund 2	349	25 - 30	40	43	Approved	31. 12. 2015
Gode Wind 04	252	30 - 34	33	29	Approved	31. 12. 2015
EnBW Hohe See	500	39 - 40	90 - 104		Approved	30. 6. 2016
Borkum Riffgrund West I	400	29 - 33	67 - 76	30	Approved	31. 7. 2016
Nördlicher Grund	384	25 - 38	84 - 88	55	Approved	31. 12. 2016
Sandbank 24	288	25 - 37	83 - 96	59	Approved	31. 12. 2016
EnBW HeDreiht (1)	400	39	97 - 104	62.49	Approved	30. 6. 2017
EnBW HeDreiht (2)	195	39	97 - 104	19	Approved	30. 6. 2017
Delta Nordsee 1 (Enova Northsea)	235	29 - 35	50 - 51.4	28	Approved	31. 12. 2017
Innogy Nordsee 2	295.2	26 - 34	47.3 - 48	36.45	Approved	1. 7. 2018
Innogy Nordsee 3	360	26 - 34	47.3 - 49	29	Approved	1. 7. 2019
Kaikas	415	39 - 41	110 -125	65	Approved	
Nordergründe	110.7	4 - 14	16 - 17.6	6	Approved	
Sum	**10,043.9**			**1,247.8**		
Average		**29.3**	**60.8**			

Table 2: Approved wind farms in the German region of the North Sea (status as of Dec 2013). Data sources: BSH [73], Fraunhofer IWES

Wind farm name	Nominal power [MW]	Water depth [m]	Distance from shore [km]	Area [km²]	Status	Latest start of construction
Breitling	2.5	2	0 - 0.3	0	in Betrieb	
EnBW Baltic 1	48.3	16 - 19	16 - 17.1	7	in Betrieb	
EnBW Baltic 2 (Kriegers Flak)	288	23 - 44	32 - 35.4	27	in Bau	31. 10. 2013
Wikinger	400	36 - 40	35 - 39	35	genehmigt	31. 12. 2015
Arkona-Becken Südost	480	21 - 27	35 - 37	40	genehmigt	1. 10. 2016
Sum	**1,218.8**			**109**		
Average		**22.8**	**24.5**			

Table 3: Approved wind farms in the German region of the Baltic Sea (status as of Dec 2013). Data sources: BSH [73], Fraunhofer IWES

Further expansion in German waters. In August 2013 the last of 30 Siemens WTs was installed in the **Riffgat** wind farm in the North Sea. The Riffgat wind farm lies about 14 km northwest of the German island of Borkum in the German-Dutch border zone. Due to old munition finds on the seabed, the connection of this wind farm to the grid was delayed until 11 February 2014 [26].

In September 2011 the first construction phase of the **Borkum West II** wind farm started. This wind farm is at a water depth of about 30 m and is 45 km offshore in the North Sea. Repeated shifting of the connection date resulted in the construction work being suspended in the autumn of 2012 and moved to the start of 2013. By April 2013 all 20 foundations (tripods) had been constructed. The first complete WT in this wind farm was finished on 27 July 2013 [82]. The repeated putting back of the connection date meant that the construction schedule for the wind farm was shifted [83]. The second construction phase for a further 40 WTs is planned to start in 2014. The total of 80 WTs will supply a power of 400 MW [84].

The **Global Tech I** wind farm in the North Sea some 96 km off Borkum is planned to have 80 WTs (total nominal capacity 400 MW). By September 2013 the first three WTs had been constructed. The construction of all the WTs is planned to be complete in early 2014, with full operation scheduled for the summer of 2014 [85]. Until the grid connection is finalized, the connection will temporarily be via the BorWin alpha converter platform.

The construction of the **Meerwind Süd | Ost** wind farm in the North Sea, the first to be financed by the KfW development bank, started in September 2012. The 80 Siemens WTs (each 3.6 MW) will be on monopiles at a water depth of 22 m - 26 m some 23 km north of the island of Helgoland [86]. By April 2013 all the monopiles were in place. The construction work on the first WT was however delayed and only started in July 2013 [87].

Construction work for the **DanTysk** wind farm, 70 km west of Sylt, started in February 2013. By 13 December 2013 all the 80 monopiles were ready. This wind farm borders Danish territorial waters and will comprise 80 Siemens WTs with a total nominal power of 288 MW. Operational start-up is planned for autumn 2014 [88].

The first seven jacket foundations are now in place in the **Nordsee Ost** wind farm, 30 km north of Helgoland. This wind farm will comprise 48 Senvion 6M WTs, each with a nominal generating capacity of 6.15 MW [89]. Start-up is scheduled for 2014 [90].

The **Borkum Riffgrund 1** wind farm is planned to be operational in 2014 with 77 Siemens-3.6-120 WTs on monopiles having a total nominal generating capacity of 277 MW. The Borkum Riffgrund 1 wind farm is situated 37 km north of the island of

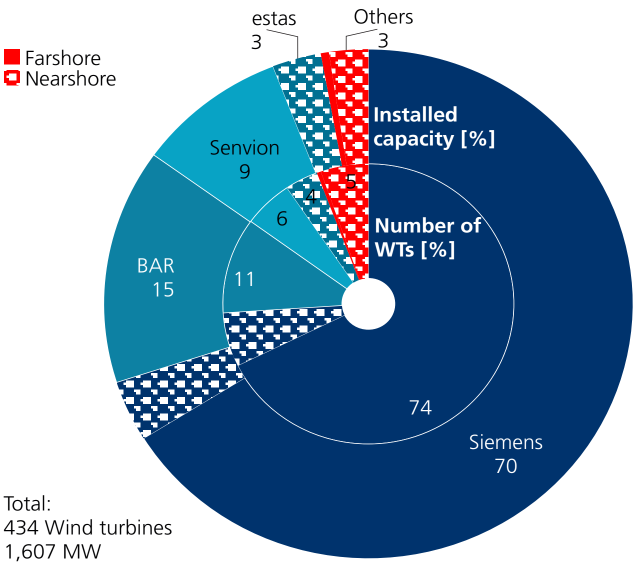


Figure 51: Manufacturer market share of the new offshore wind turbines installed worldwide in 2013. Data source: Fraunhofer IWES

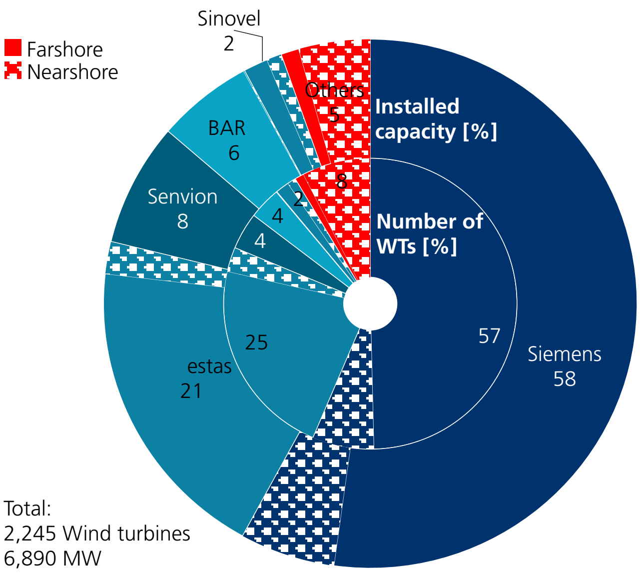


Figure 52: Manufacturer market share of offshore wind turbines worldwide (status as of 2013). Data source: Fraunhofer IWES

Borkum. The water depth there is 25 m – 35 m. The transformer platform was taken out to sea in August 2013 and connected to the DolWin Alpha converter platform. The first electricity is planned to be produced in 2014 and the wind farm will become fully operational in 2015 [91].

Preparatory work started in April 2013 for the **Amrumbank West** wind farm. This will consist of 80 WTs, each with a nominal power of 3.6 MW. This wind farm represents an investment of more than one billion euros and the start-up of operations is planned for the summer of 2015. E.ON is constructing so-called scour protection. This involves dumping two layers of special sand bags on the seabed to prevent the current washing away the sand from around the foundations. This is new technology and it will reduce the costs because the scour protection can be installed separately from the installation of the foundations [92].

Work has been ongoing on the **Baltic 2** wind farm since August 2013 with the construction of foundations for 80 WTs. Depending on the water depth, either monopiles or three-legged jackets are being used. The wind farm will on completion have 80 Siemens SWT-3,6-120 WTs with a total nominal generating capacity of 288 MW [93]. The interconnection of offshore wind farms in the Baltic Sea will in the future allow electricity to flow between Scandinavia and Central Europe. The power line will connect the Kriegers Flak wind farm (Denmark, 600 MW) with the Baltic 2 wind farm (Germany). Completion of this is planned for 2018 and will involve a converter platform and two parallel submarine cables 15 km long [94].

Technical developments

Wind turbine manufacturers worldwide. Siemens dominates the global market for offshore WTs. Of the current 6890 MW of offshore generating capacity provided by 2245 WTs, Siemens WTs represent over 3992 MW of this with 1266 WTs. This represents a market share of 58% of the offshore generating capacity (see Figure 52). This dominance is also evident in the newly installed WTs in 2013, with Siemens manufacturing 74% of the new WTs (see Figure 51).

The Danish WT manufacturer Vestas Wind Systems has the second largest share of the global market. It now has 559 Vestas WTs installed offshore, having a total nominal generating capacity of 1435 MW. This corresponds to 21% of the total nominal offshore wind power (see Figure 52). Besides Siemens, another key player in 2013 was Senvion. The completion of the Thornton Bank 3 wind farm in Belgium meant that in 2013 this manufacturer installed 24 WTs having a total nominal power of more than 147 MW. BARD Engineering ceased operations in 2013. Its successor, OWS, is focusing on operating the BARD Offshore 1 wind farm [60]. The remaining WTs accounting for a nominal power of 291 MW (10%) come from 34 further WT manufacturers.

Wind turbine manufacturers in Germany. In 2013 much construction work took place in a number of offshore wind farms, although only in the BARD Offshore 1 wind farm were WTs connected to the grid. BARD Engineering's share of the total nominal power increased to 78% (see Figure 53). This situation will change on connection of the wind farms that are currently under construction.

Wind turbine class size. The average nominal power of all installed offshore WTs at the end of 2013 was 3.1 MW (see Figure 54). Currently there are 183 offshore WTs installed with a nominal power of 5 MW and above, all in European waters.

In the Thornton Bank wind farm (Belgium) there are 48 Senvion 6M WTs each having a nominal power of 6.15 MW and rotor diameters of 126 m [95]. The Gunfleet Sands 3 experimental wind farm in the UK has had two Siemens SWT-6.0-120 WTs since September 2013. In November 2013, Alstom completed the installation of the Haliade150-6 MW experimental WT in the Belwind offshore wind farm in Belgium [96]. This WT had with 150 m the largest rotor diameter up to end of 2013 In December 2013 Vestas manufactured the prototype nacelle for what would become the world's most powerful offshore WT. The V164-8.0 MW, with a rotor diameter of 164 m, has been operational in the Lindø Industriepark (Denmark) since 28 January 2014 as the largest rotor in the world [97, 98].

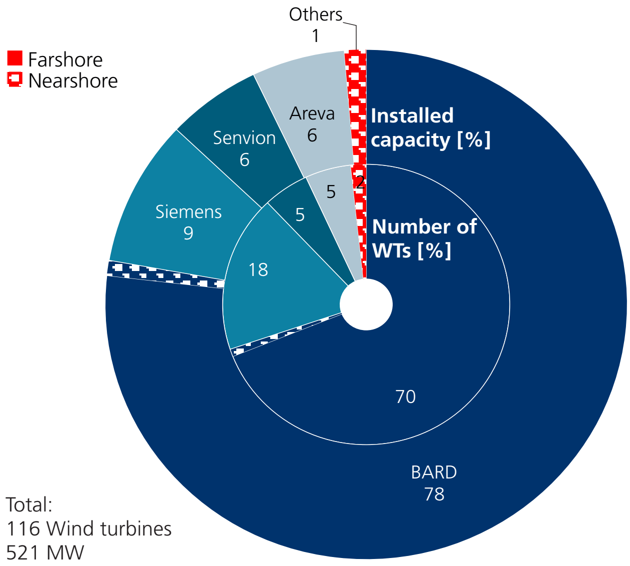


Figure 53: Manufacturer market share of offshore wind turbines in Germany (status as of 2013). Data source: Fraunhofer IWES

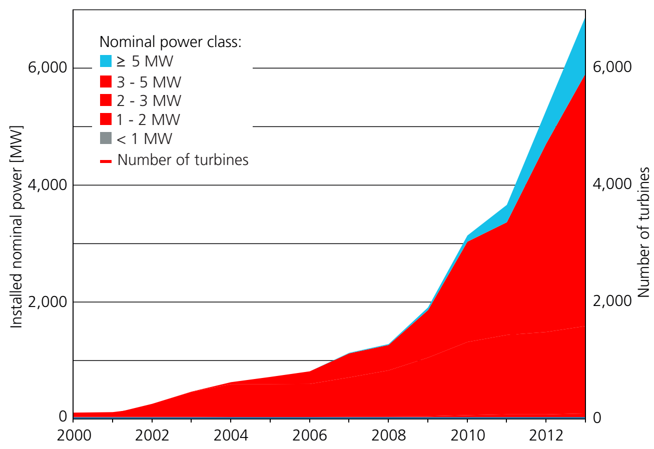


Figure 54: Cumulative offshore wind power generating capacity worldwide as a function of the nominal power and number of offshore wind turbines. Data source: Fraunhofer IWES

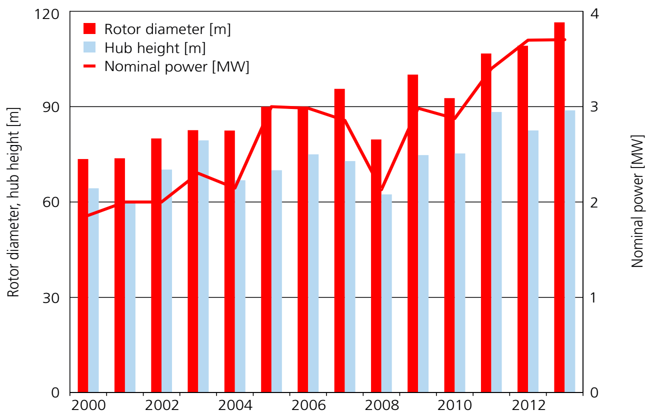


Figure 55: The changing physical size of newly installed offshore wind turbines. Data source: Fraunhofer IWES

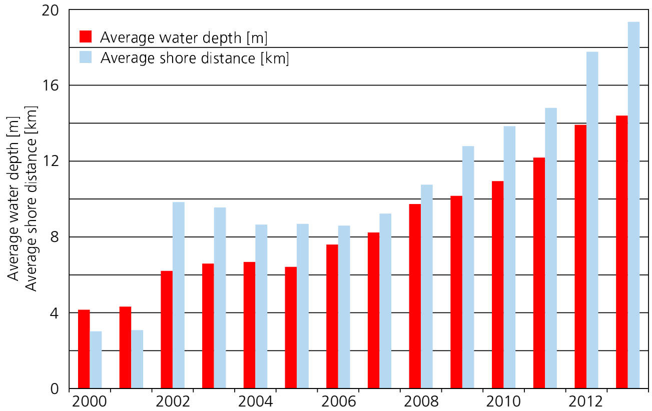


Figure 56: Change in the average distance of offshore wind turbines from the shore and change in installation depths over time for all offshore wind turbines. Data source: Fraunhofer IWES

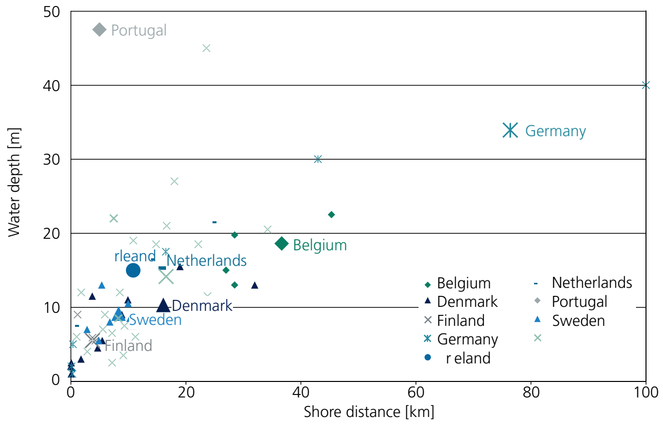


Figure 57: Water depth and distance from the shore of offshore wind farms in different European countries.

The average nominal power of newly installed offshore WTs has risen from 1.9 MW in 2000 to almost 3.7 MW in 2013. The average power of new WTs fell slightly from 2005 to 2010, but has increased again since 2010 (see Figure 55). Unlike in Europe, China's nearshore wind farms mostly consist of WTs having a lower nominal power in the 1.5 MW to 2.3 MW range. The high number of newly installed WTs in this class size is the reason for the slight decrease in the average nominal WT power from 2005 to 2010. Offshore wind energy utilization gained momentum once again in the UK. The UK not only led the way with new WTs but also influenced the average nominal power. Two of the four new offshore wind farms constructed in the UK in 2013 have WTs of 3.6 MW nominal power. Another has WTs of 6 MW and the other new wind farm utilized WTs of 2.3 MW.

Offshore locations allow the installation of WT having a high nominal power and relatively low hub height. The average hub height offshore of just under 89 m is considerably lower than onshore due to the smoothness of the sea surface. Rotor blade diameters have markedly increased. The average rotor diameter in 2013 was 117 m. The new 6 MW WTs have rotor diameters of 150 m and above.

Distance from the shore and water depth. The move away from the shore to far offshore is continuing. Compared to today, where offshore WTs are on average 19.3 km from the shore and at water depths of 14.4 m, the first experimental off-shore wind farms were constructed relatively close to the shore in rather calm waters. With increasing experience, however, ever more projects have been realized further from the shore at greater water depth. Back in 2002 the average offshore WT was 9.8 km from the shore in 6.2 m of water (see Figure 56).

German offshore WTs are on average 76 km from the shore at a water depth of ca. 34 m (see Figure 57). As such, they are furthest from the shore on a worldwide country by country ranking. In greater water depths, floating WTs are being tested in a variety of projects. In Norway in 2009 the first prototype of a floating WT (Hywind, 2.3 MW) was installed at a water depth of over 200 m. Other experimental projects underway in Norway are Gwind [99] and Sway [100]. R&D projects underway at present include the Windfloat project in Portugal, Poseidon 37 in Denmark [101], VolturnUS in the USA [102], and also projects in Japan (see information box).

Figure 57 shows the average distance from the shore and water depth of offshore wind farms in Europe. The Norwegian floating WTs that are being tested are not included in this data. Following Norway the greatest average water depths are for wind farms in Portugal (48 m), Germany (34 m), and Belgium (19 m). The WTs in the shallowest waters are found in Finland (5.9 m) and Sweden (9 m). Wind farms in Germany (76 km) and Belgium (37 km) have the largest average distances from the shore. The offshore wind farm furthest from the shore is BARD Offshore 1, more than 100 km out to sea. The WTs in Finland have the smallest average distance from the shore (3.8 km).

Foundation structures. Offshore WTs are being increasingly installed in deep waters and one of the special challenges here concerns the foundation structures. A variety of foundation designs are being developed, tested, and installed. Whereas in the early stages only gravity and monopile foundations were used, nowadays seven different types of foundation structures are in use. In addition to the high-rise-pile cap used in Asia, jacket, three-legged (tripile, tripod), and floating foundations are being used. Other foundations in use include suction buckets and artificial islands (see Figure 58).

The different structures are suited to different location conditions. Gravity foundations, monopile foundations, and high-rise-pile caps are mostly used nearshore and in calm waters. Of the most commonly used foundation structures, the high-rise-pile caps, which are solely used in Asia, are found on average at a water depth of 3.7 m and 2.5 km out to sea. These foundations are used in the calmest waters and closest to the shore. Tripod and tripile foundations are used furthest from the shore, on average 94.9 km out to sea. Floating structures are currently still being trialed. Figure 59 shows how far out to sea and in what water depths the various foundation structures are used.

Japan considering offshore wind energy

The Japanese government wants to pull out of nuclear energy by 2030. The required investment in renewable energies will be close to 500 billion dollars over the next 20 years [103]. The plan is to have offshore generating capacity of 8030 MW by 2030 [104]. In order to promote wind energy, the electricity feed-in remuneration rate has been considerably improved. In July 2012, the feed-in remuneration for WTs have a nominal generating capacity of 20 kW was set at 23.10 Yen/kWh (16.19 ct/kWh) for 20 years [105].

The Japanese Ministry of the Environment estimates that offshore generating capacity of 1600 GW can be realized [106]. There are promising expansion opportunities on the continental shelf around the Japanese Archipelago in water depths up to 200 m [107].

The "Kyushu University Wind Lens Project" has since the end of 2011 been testing a floating platform with two 3 kW WTs and one 2 kW solar installation [108, 109]. There have been other floating WTs in Japan since 2013: the "GOTO Floating Offshore Wind Turbine" and the pilot WT in the "Fukushima Floating Offshore Wind Farm", each with a nominal generating capacity of 2 MW. Some 20 km off the shore of Fukushima a floating 2 MW WT is being trialed in a joint project involving the University of Tokyo, Mitsubishi, and nine other companies. In 2014 the installation of two further WTs, each of 7 MW, is planned and by 2020 the floating wind farm is planned to have a total nominal generating capacity of 1 GW [110, 111].

A consortium of six companies including Toshiba and Hitachi want to construct offshore wind farms in Japan along the lines of the UK model. Total investment of 1.2 billion euros is planned over the next 10 years. The plans are for offshore wind farms with a total nominal generating capacity of 300 MW in the Kyushu coastal region of southern Japan [112].

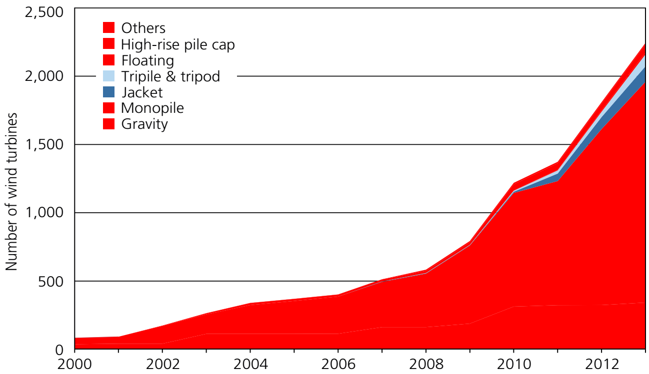


Figure 58: Use of different foundation structures for offshore wind turbines over time. Data source: Fraunhofer IWES

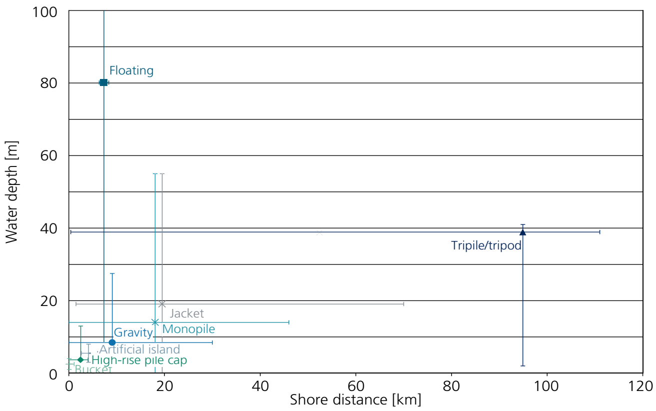


Figure 59: Water depth and distance from the shore of different foundation designs. Data source: Fraunhofer IWES

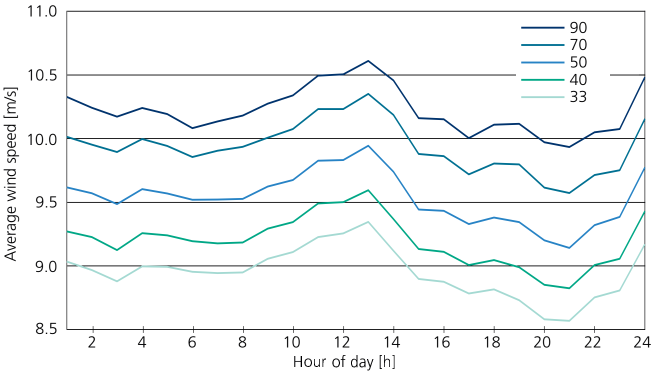


Figure 60: Average daily variation of the wind speed in 2013 at different heights measured at the location of the FINO1 platform. Data source: FINO1 measuring mast [114]

Wind and wave conditions

External conditions. The external conditions offshore are very important. High wind speeds have a positive effect on the amount of electricity that can be generated. However, offshore WTs are not only subjected to the wind but also to waves and marine currents.

Offshore WTs are therefore subjected to greater forces than onshore WTs and must be more robustly designed. Besides strengthening the mechanical components, better protection against corrosion is also necessary. Corrosion is exacerbated by the high air humidity and salty conditions. Corrosion is a particular risk to the outer walls of the tower, nacelle, and rotor blades, as well as to electrical contacts.

Wind conditions. The data from the FINO measuring masts, which are funded by the German government, show that considerably better wind conditions exist offshore than even at the best onshore locations [113]. The FINO1 research platform is north of Borkum in the North Sea and provided the data for the analyses described hereafter. In the following graphs, the wind speeds affected by shadowing effects from the FINO measuring masts and WTs were excluded.

Figure 60 shows the average daily variation of the wind speed in 2013 at different heights. As the wind offshore is little influenced by the relatively smooth water surface, at a height of just 33 m the average wind speed was just below 9 m/s. At 90 m, namely the typical height of a hub, the average wind speed was between 10 m/s and 10.5 m/s.

Figure 61 compares the annual frequency profiles for the wind speed at a height of 90 m. The little Weibull distributions also indicate that the wind conditions offshore in 2013 were also poor. Wind speeds in the range of the nominal wind speed, typically above 12 m/s, and high wind speeds of greater than 15 m/s occurred less frequently than in previous years. The average wind power density at a height of 90 m was 860 W/m². This value was low and confirms that 2013 had poor wind conditions.

The prevailing directions of the wind at FINO1 at a height of 90 m in 2013 were southwest and northeast (see Figure 62).

Wave height and accessibility. The accessibility of offshore WTs by ship is largely determined by the height of the waves. In general, weather situations with a significant wave height (H_s) of more than 1.5 m are termed "weather days". Above that wave height, WTs can no longer be safely accessed by service ship. In order to compare the wave heights in the North Sea and Baltic Sea, the data from the FINO1 and FINO2 measuring masts collected from 2009 to 2013 were analyzed. Figure 63 shows the distribution of the average significant wave height at both measuring masts in 2013 and in the 2009 to 2012 period. It is clear to see that wave heights are higher in the North Sea (FINO1) than in the Baltic Sea (FINO2), leading to poorer accessibility in the North Sea (see Table 4).

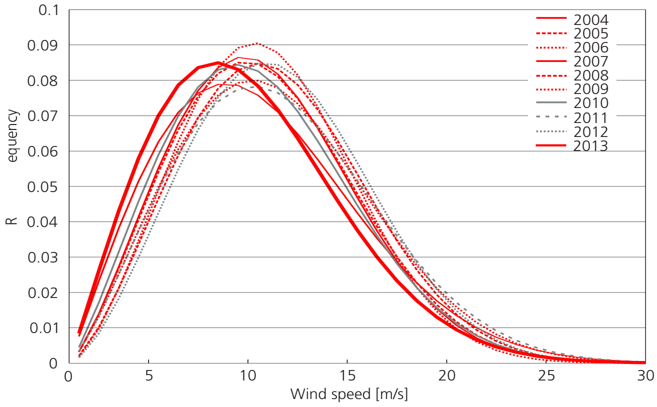


Figure 61: Frequency of wind speeds (2004-2013) at a height of 90 m measured at the location of the FINO1 measuring mast. Data source: FINO1 measuring mast [114]

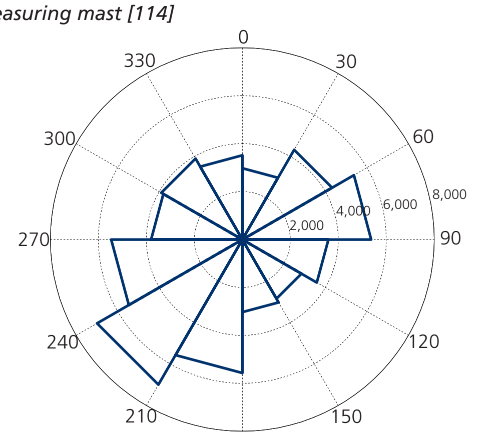


Figure 62: Wind measurements in 2013 at a height of 90 m at the location of the FINO1 measuring mast. Data source: FINO1 measuring mast [114]

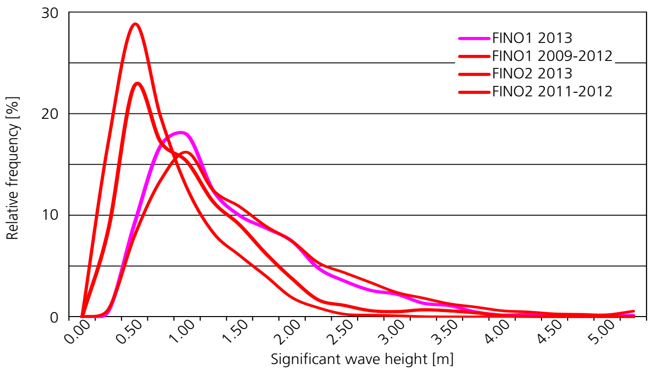


Figure 63: Average significant wave height at the FINO1 and FINO2 measuring masts in 2013 compared to the average for 2009-2012. Data sources: Measuring masts FINO1 [114] and FINO2 [134]

Floating LIDAR systems

The recording of wind measurements for evaluating potential locations for offshore wind farms provides a challenge for wind project development. Floating LIDAR systems are a useful alternative to installing wind masts at high sea and they considerably reduce the cost of the development and planning phase for an offshore wind farm. As part of IEA Wind Task 32, recommendations were made for using this technology in the wind industry.

Within the framework of the "Offshore measuring buoy" project funded by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), Fraunhofer IWES developed a floating LIDAR system based on an adapted light buoy. An island system comprising three small WTs, PV modules, and three battery banks provides the power. An offshore test from August to October 2013 in the direct vicinity of the FINO1 measuring mast allowed considerable operational experience to be gained and allowed the measurements to be compared with the FINO1 data. In addition, correction algorithms were developed and verified. These algorithms allow errors in the wind speed and turbulence measurements due to buoy movements to be compensated.

The tests showed that the LIDAR buoy meets the key requirements of high data accuracy and good system reliability. A detailed account of the technical properties of the system, the correlation of the measured wind speeds with reference measurements, and the effect of buoy movements on the measurements is given by Julia Gottschall in the Special Report entitled "Floating LIDAR systems" on Page 98.

Figure 64 shows the average monthly significant wave height at the FINO1 measuring mast. Very evident is the lower wave height in the summer months. As there are also lower wind speeds in the summer, most wind farm operators plan their maintenance work at this time of year (see also Figure 15).

Due to the problem of limited accessibility, the existing access systems must be optimized to allow efficient use of offshore WTs. This area is being actively researched. The aim is 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.

Table 4 shows the weather threshold values (wind speed and significant wave height) in the Baltic Sea (2013, FINO2) and in the North Sea (2009 to 2013, FINO1) and how these affect four different ship types accessing WTs. The different ships are used for different maintenance work. As little equipment is required for standard inspections, relatively small service ships suffice for this task. The replacement of large components requires larger crane ships. In general, the Baltic Sea has better accessibility for the various ships. The overall accessibility in 2013 in both the North Sea and Baltic Sea was above average.

Weather threshold for ships		Accessibility		
Wind speed | wave height		FINO1 (North Sea)		FINO2 (Baltic Sea)
		2009-2012	2013 (up to Oct.)	2013
Service ship	12 m/s | 1.5 m	60.53 %	65.88 %	79.15 %
Crane ship	10 m/s | 2.0 m	62.86 %	68.58 %	67.86 %
Jack-up barge	10 m/s | 2.0 m	62.86 %	68.58 %	67.86 %
Crane ship / jack-up	15 m/s | 2.0 m	77.88 %	82.96 %	93.31 %
Mother ship	15 m/s | 4.0 m	92.80 %	94.42 %	94.54 %

Table 4: Weather-dependent accessibility for various types of ships in the North Sea and Baltic Sea. Data source: Fraunhofer IWES [115]

Mother ships and offshore accommodation for offshore wind farms

Extreme weather conditions can drastically limit the accessibility of offshore WTs. The consequence can be major delays to maintenance and repair work and thus turnover loss. Standard ships for technical personnel and equipment used at present are generally only suitable for small components and up to 12 persons. These ships can operate at significant wave heights up to 1.5 m and can travel at up to 20 knots. The price for chartering such a ship is about 1500 euros per day and outright purchase would be about 1.5 million euros.

Due to these limitations, offshore service companies are trying to increase the accessibility in new ways and now propose that mother ships be used at all times. These mother ships will be up to 80 m long and can continue operating at significant wave heights up to 4 m due to the use of gangway systems with movement compensation. They can accommodate up to 60 persons, have medical facilities, have space for a spare parts storeroom, and can be reached by the crew in different ways. They have a helipad and smaller auxiliary boats.

The Horns Rev-2 wind farm in Denmark was the first to commission the construction of a platform for offshore accommodation. The platform can accommodate up to 24 persons and also has space for storing small spare parts [116]. The Global Tech 1 wind farm in Germany is pursuing a similar concept with a manned transformer platform (for up to 38 people) [117].

The use of either mother ships or accommodation platforms drastically shortens the travel time to WTs. The work time of the service personnel is more efficiently used and the accessibility is increased. The interest in mother ships and accommodation platforms is likely to further increase with the growing number and size of offshore wind farms and with the increasing number of farshore locations.

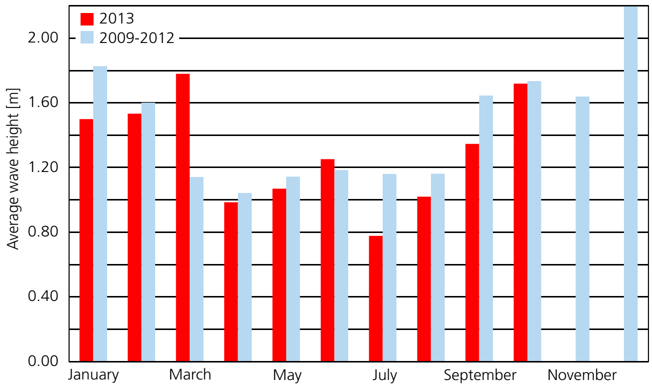


Figure 64: Average monthly significant wave height at the FINO1 measuring mast in 2013 compared to the average for 2009-2012. Data source: Measuring mast FINO1 [114]

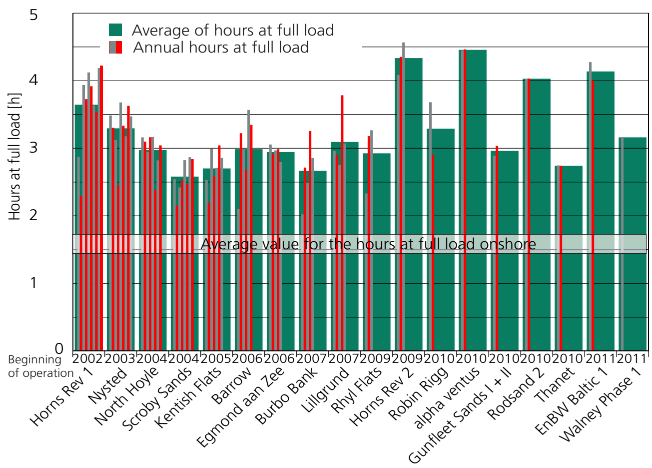


Figure 65: Comparison of the hours operating at full load for different offshore wind farms having a nominal generating capacity above 45 MW. Data source: Wind park operators [118–123]

Operating results

Hours operating at full load. Different locations and the performance of the WTs there can be compared by normalizing the energy generated per year to the nominal power of the WTs. The resulting so-called equivalent number of hours at full load depends on the performance of the WT and also on the conditions at the location of the WT.

Figure 65 compares the hours operating at full load of different European offshore wind farms to the hours operating at full load of onshore WTs in Germany over the last 10 years. Clear is that the number of hours operating at full load is considerably higher offshore than onshore. In its first year of operation, the WTs in the alpha ventus wind farm, Germany's first commercial offshore farm, reached three times as many hours operating at full load than the average for onshore WTs.

There are, however, clear differences between the individual wind farms and between different years. In general, the older nearshore wind farms attain fewer hours operating at full load than newer farshore wind farms. Comparison of the operating years also shows that the differences, some of which are marked and occur in the first few years of operation, can be explained by the technical availability (see Figure 67).

Offshore electricity generation from wind in Germany. The extrapolation of the TSOs for the electricity generated by offshore wind in Germany in 2013 showed a moderate increase over the previous year (see Figure 66). This was due to the completion of the BARD Offshore 1 wind farm.

Availability. The objective of all maintenance is to achieve high WT availability at as low as possible cost. Modern WTs onshore generally have an availability of 95% to 99% [128]. The availability is usually considerably less offshore due to the special location and related challenges such as high stresses and poorer accessibility. Figure 67 shows the technical availability of various offshore wind farms. They are ordered chronologically by date of start-up. Whilst the older wind farms, consisting of WTs with relatively low nominal power and relatively close to the shore, have availabilities in the region of the average availability of onshore WTs, the availability of the more recently commissioned wind farms further from the shore is much lower. As alpha ventus and Egmond aan Zee show, high availability is also possible far from shore, but such wind farms usually require greater maintenance effort.

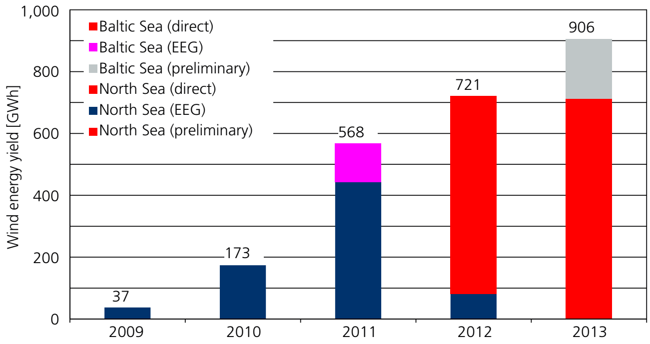


Figure 66: Offshore wind power generation in Germany.

Data source: Annual statements pursuant to the REA [16, 21, 124, 125], Directly marketed offshore wind energy from TSO extrapolations [126]

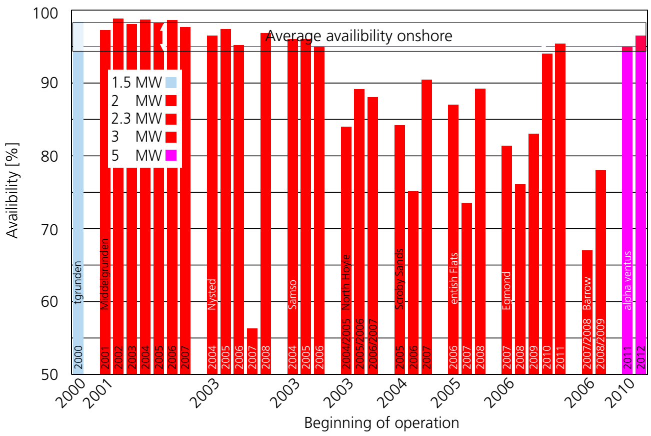


Figure 67: Availability of offshore wind farms.

Data source: Wind farm operators [119–121, 129, 130]

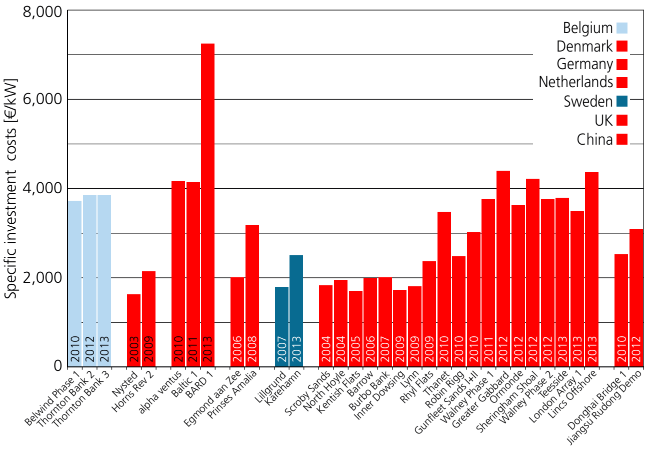


Figure 68: Specific investment costs for selected wind farms in different countries having a nominal power of 45 MW and above. Data source: Fraunhofer IWES

The cost of offshore wind energy. In general, the technical challenges involved in generating power offshore are considerably greater than onshore. The foundations, cabling, installation, and operation are all more challenging when WTs are out to sea. The stresses on the WTs are also greater and servicing and maintenance work are more complex. On the plus side, the amount of wind power that can be generated offshore is greater.

Figure 68 gives an overview of the specific investment costs of selected offshore wind farms in Europe. 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, for example in Germany the grid operators bear the costs for grid connection. On the other hand, wind farms have different location-dependent features such as different distances to the shore, water depths, foundation structures, and wind farm sizes.

Figure 69 shows the investment costs for five fictitious wind farms having 4 MW WTs. The numbers come from a 2013 study of costs by the German Offshore Foundation [131] and a 2012 study in the UK for The Crown Estate [132]. The German study calculated the costs for three fictitious wind farms having a total nominal power of 320 MW which started operating in 2012. The three locations are 40, 80, and 120 km from the shore (DS) and at water depths of 30, 40, and 50 m (WD). The UK study calculated the costs for two fictitious wind farms, with the investment decision being made in 2011 and the wind farm becoming operational two to four years later. The two locations are 40 km from the shore in water depths of 25 m and 35 m respectively.

In order to be able to compare the studies, the costs calculated in the UK study were multiplied by a factor of 1.23 to recognize the British pound / euro exchange rate. The specific investment costs for the German wind farm 40 km from the shore and at a 30 m water depth were very similar to those for the UK wind farm 40 km from the shore and at a 35 m water depth (3540 €/kW and 3504 €/kW respectively). In order to allow comparison, the costs for grid connection were not considered in Figure 69. In the UK these costs are borne by the investors whilst in Germany they are borne by the TSOs.

The annual specific operating costs were calculated to be 122 €/kW (DS 40 km, WD 30 m), 134 €/kW (DS 80 km, WD 40 m), and 138 €/kW (DS 120 km, WD 50 m). The operating costs for the British wind farms included the costs for power transmission of 84.5 €/kW and were higher: 202.4 €/kW (DS 40 km, WD 25 m) and 205.3 €/kW (DS 40 km, WD 35 m).

For decommissioning, the following provisions were assumed in Germany: 135 €/kW (DS 40 km, WD 30 m), 153 €/kW (DS 80 km, WD 40 m), and 172 €/kW (DS 120 km, WD 50 m). The provisions assumed in the UK were three times as high: 378.7 €/kW (DS 40 km, WD 25 m) and 489.7 €/kW (DS 40 km, WD 35 m). In addition, the UK study assumed lower electricity outputs for its calculations: 3,482 MWh/MW (DS 40 km, WD 25 m) and 3691 MWh/MW (DS 40 km, WD 35 m), whereas 3888 MWh/MW (DS 40 km, WD 30 m) was used in the German study.

These assumptions ultimately result in very different offshore electricity generating costs, as shown in Figure 70. The electricity generating costs calculated in the UK study are greater than those calculated in the German study due to the grid connection costs, higher provisions, higher operating costs, and the lower expected electricity output.

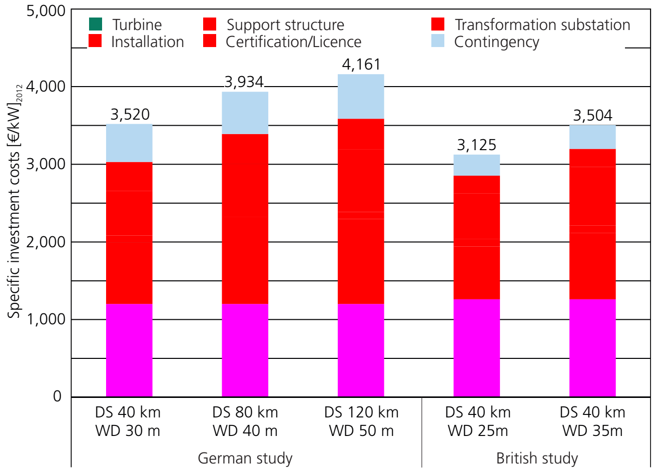


Figure 69: Comparison of investment costs for offshore wind farms in Germany and the United Kingdom with 4 MW wind turbines located at different distances from the shore and in different water depths. Data sources: PwC [132], Prognos/Fichtner [131]

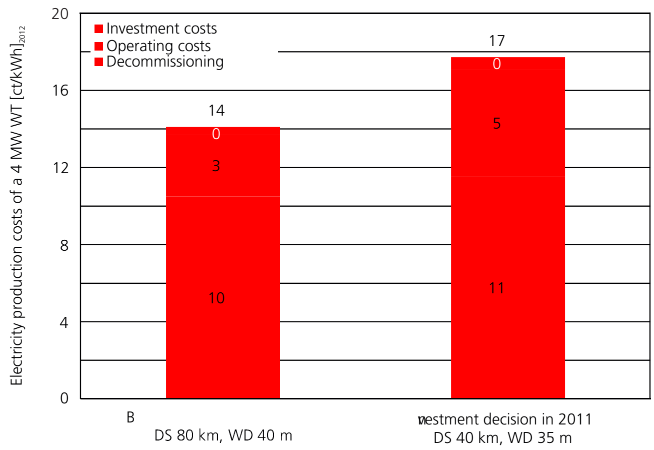


Figure 70: Comparison of electricity generation costs for offshore wind farms in Germany and the United Kingdom with 4 MW wind turbines located at different distances from the shore and in different water depths. Data sources: PwC [132], Prognos/Fichtner [131]

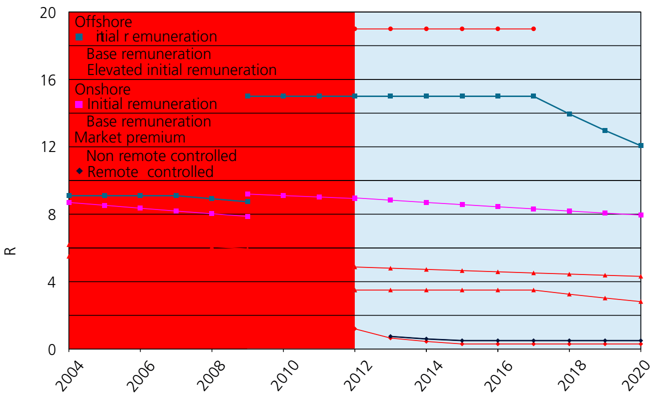


Figure 71: Remuneration for offshore wind power feed-in to the electricity grid. Data source: REA [53]

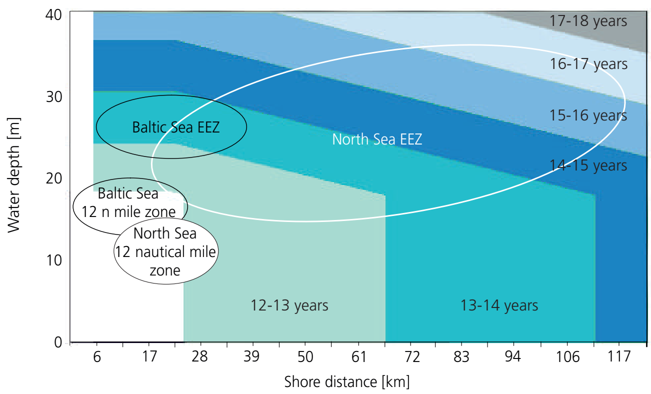


Figure 72: Duration of the initial remuneration for offshore wind turbines in Germany. Data source: REA [53]

Legal and financial boundary conditions

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 WTs, the Renewable Energy Act has since 2004 laid down special regulations for WTs at sea. Offshore WTs are defined here as WTs at least 3 nautical miles (ca. 5.5 km) from the coast. The current REA remuneration rates and the annual lowering are shown in Figure 71.

As an accompanying measure, the Kreditanstalt für Wiederaufbau (KfW development bank) initiated a special program in 2011 entitled "Offshore Wind Energy" with credit amounting to a total of 5 billion euros at market rates. This funding program can be availed by up to ten offshore wind farms [133].

Base remuneration and initial remuneration. The initial remuneration for offshore WTs is 15 ct/kWh and the base remuneration thereafter is 3.5 ct/kWh. After start-up of an offshore WT, the initial remuneration is prescribed for 12 years. Thereafter the feed-in remuneration is reduced to a base remuneration. Offshore WTs that are brought into operation up to 2017 are remunerated for 12 years with 15 ct/kWh and thereafter with 3.5 ct/kWh. From 2018 onwards the remuneration will decrease each year by 7% [53].

Enhanced initial remuneration. All offshore WTs 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, further 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 initial remuneration period is extended for offshore WTs 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 72 shows the length of the period of initial remuneration as a function of the distance from the shore and water depth [53].

Direct marketing. As for onshore WTs, operators of offshore WTs have the opportunity to utilize direct marketing under the REA [53]. At the end of 2013 all the electricity generated by offshore WTs installed in Germany was directly marketed (see Figure 66).

Benchmarking and efficiency improvement using shared knowledge databases

The development of offshore wind energy has proceeded apace in recent years. Despite this, the whole wind industry is still in its infancy. In order to efficiently utilize the acquired know-how and introduce benchmarking in the wind industry at an early stage, projects have been initiated in both Germany and the UK to set up cross-industry knowledge databases. The Offshore~WMEP project [127] funded by the Federal Ministry for Economic Affairs and Energy (BMWi) is collating detailed operating and event data (troubleshooting and maintenance) on individual WTs in European waters. The SPARTA project in the UK is directed at cross-industry benchmarking of offshore UK wind farms.

The objective of both projects is to give wind farm operators the ability to compare their own results with those of the rest of the wind industry. Besides energy output and downtimes, the frequency of malfunction of the various subsystems of WTs is being collated. Operators will thus be able to see where action is needed and where improvements are being made. The very detailed data being used in the Offshore~WMEP project will also enable a library to be built up of characteristic values for the failure of individual components. This will allow optimization of maintenance schedules and will form the basis for the application of Reliability Centered maintenance (RCM).

In order to maximize the benefit for wind farm operators and minimize the work involved, both projects will used a harmonized set of data and evaluations. This means that operators interested in both projects will only have to prepare their data once.

WIND ENERGY REPORT GERMANY 2013

Special Report

BUSINESS MODEL FOR RENEWABLE ENERGY

Norman Gerhardt, Fabian Sandau, Carsten Pape

The cost of switching to renewable energy

The switchover to renewable energy is currently dominated by the public and political debate about the cost. Much overlooked is the fact that the switchover to electricity generation from renewables is in fact an economically viable and low-risk project. In order to investigate this point, Fraunhofer IWES carried out detailed analyses in an internal project [1].

In order to analyze the "business model for renewable energy", a comparison must be made between the investment in new, capital-cost intensive renewable technologies and the savings from old, operating-cost intensive technologies that use fossil fuels. Future renewable energy supply systems here will be dominated by wind and solar energy. Besides primarily being used for power generation, these sources will also cover the energy requirements for transport and heating. The detailed calculations of Fraunhofer IWES show that the cost of the overall switchover to renewable energy is acceptable, even with very conservative assumptions and even if no increases in fuel costs and no costs for CO_2 emissions are taken into account.

Current imports of energy sources and distribution by sector

Primary energy consumption in Germany in 2011 totaled 3772 TWh, with 285 TWh of this accounting for non-energy usage, namely for material utilization. The annual cost of the energy sources is ca. 96 billion euros. The majority of the energy sources have to be imported. This costs 87 billion euros and hence accounts for ca. 90% of the primary energy costs. Although the share of primary energy requirement for power generation is similar to the shares for heating and transport (see Figure 1), the costs are relatively low. In contrast, oil and gas are expensive and are difficult to substitute. These energy sources are mostly used for transport and heating.

The current cost-benefit debate about the switchover to renewables is strongly focused on the power sector. In the power sector, however, expansion of electricity generation from renewables brings very little cost-saving because mainly coal and nuclear sources are replaced. That is why today there are

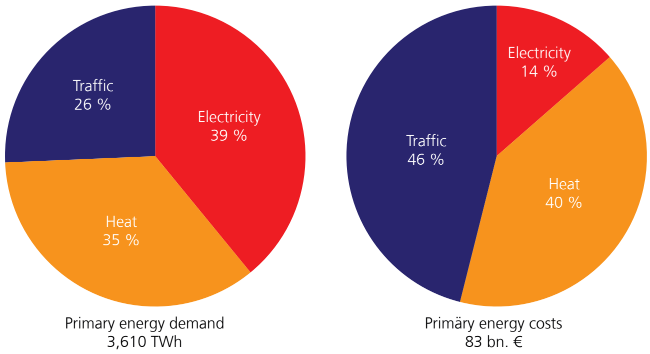


Figure 1: Share and cost of primary energy for power, heating, and transport (temperature-adjusted, excluding non-energetic consumption)

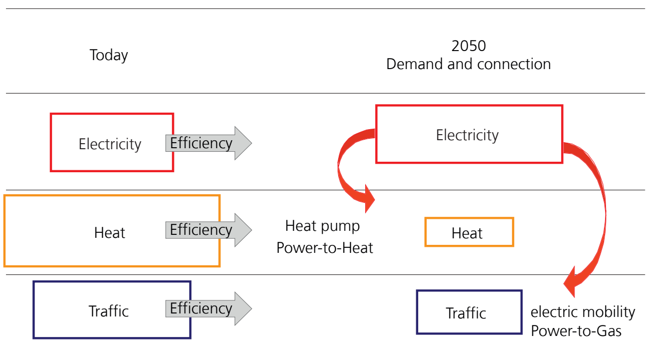


Figure 2: Increasing importance of electricity generated from renewables for heating and transport

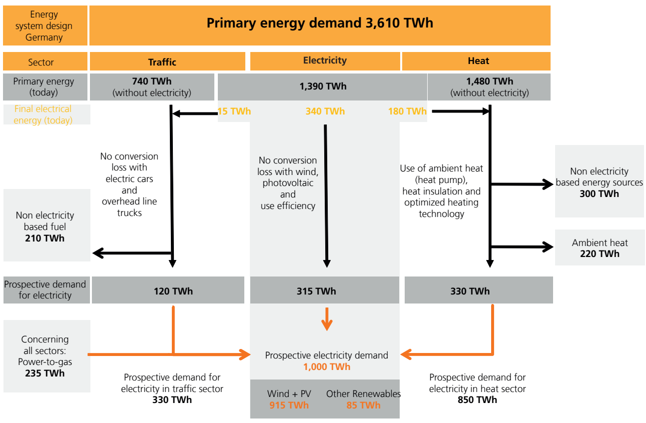


Figure 3: Electricity requirement in a 100% renewable energy scenario (power-heating-transport) without non-energetic consumption

high differential costs (e.g. REA surcharge) – but this argument is too short-sighted.

In the future, wind energy and solar energy will be the primary energy sources and electricity for heating and transport must also be generated from renewable sources (Figure 2).

Holistic consideration of all sectors is hence vital in order to determine the beneficial macro-economic effects of expansion of the necessary infrastructure.

In order to realize these macro-economic benefits, there must be efficient electricity usage for transport and heating in order to replace the high-cost primary energy sources and reduce the differential costs for the power sector. In order to meet the electricity requirements of all sectors, the preliminary investment must focus on dynamic expansion of the power sector. Only by considering all these aspects is it possible to perform a detailed cross-sector cost-benefit analysis.

Derivation of a 100% renewable energy scenario for 2050

A 100% renewable energy scenario for 2050 has been derived for autarchic energy provision in Germany. This scenario fully balanced the application areas and fuel utilization paths (Figure 3). This resulted in an electricity requirement of ca. 1,000 TWh. This requires realization of the potential efficiencies via very high electrification and full utilization of the potential of electric cars and overhead line trucks and very high utilization of heat pumps (75% of the low temperature requirement). In the area of high temperature process heat, high amounts of electricity are used for steam generation (power-to-heat).

The success of electricity generation from renewables also depends on considerable efficiencies being made, such as reduction of traditional electricity consumption by 25%, as specified in the energy scenario [2]. Measures such as insulating buildings, efficiency increases for industrial process heat and in the transport sector, more efficient heating technologies, and substantial utilization of waste heat (see [3]) will allow the primary energy consumption of ca. 3900 TWh (ca. 2400 TWh end energy) to be reduced to 1500 TWh end energy. The residual requirement for chemical energy sources will be covered by power-to-gas (electricity, heating, transport) and by mineral oil (non-energetic consumption).

Scenario for 100% renewable energy in all sectors

Based on the electricity requirement and the available renewable energies, a renewable energy mix was identified which minimized the fluctuations in the residual load and which was able to cover the requirements. A viable energy mix under these conditions was found to be 50 GW offshore wind energy, 180 GW onshore wind energy, and 200 GW photovoltaic energy. Hydroelectric power is already almost fully utilized and only makes a small overall contribution to electricity generation. Biomass utilization is already at a high level. It is assumed here that this remains constant in the power-heating-transport sectors. Based on the quantity of energy, the energy generation from fluctuating renewable sources comprises 22% PV, 26% offshore wind, and 52% onshore wind (Figure 4).

The required energy system infrastructure for the energy consumption and energy generation mix was then determined. The integration of the renewable energy utilized the flexibility of thermal power stations, grids, energy storage systems, power-to-heat converters, and electricity-to-material converters. Depending on the electricity requirement (Figure 3), this also includes E-cars, overhead line trucks, electric heat pumps, power-to-heat systems, local battery storage, and the utilization of power-to-gas.

Required investment

For this scenario, Fraunhofer IWES used literature surveys and its own experience of the power generating sector to determine the differential costs, namely additional costs, compared with continuing the status quo (reference scenario). Summing these costs, taking into account the increase in the number of wind turbines and the repowering necessary up to 2050, indicates that an investment of 1500 billion euros (Figure 5) is required, excluding capital costs.

Industrial-political implications

In order to meet the 2°C target, 100% renewable energy generation must be achieved by 2050. In order to ensure there is also a continuous transition between the construction of new WTs and the repowering of existing WTs, including after 2050, the construction must be largely complete by 2040. Otherwise considerable generating capacity would have to be built to meet the 2050 target which, in the phase after 2050, would no longer require repowering and would lead to unnecessary costs. This situation is clearly shown in Figure 6 for the expansion of onshore wind energy.

In order to operate a 180 GW wind farm continually, assuming a WT service life of 20 years, repowering of 9 GW per year will be necessary in the future (today ca. 3 GW/year). Only be expanding the generating capacity by ca. 2030 to the future requirement of 9 GW/year will a continuous transition between new WT construction and repowering be possible. Likewise, for the expansion of offshore wind energy (service life of 20 years) and photovoltaic installations (service life of

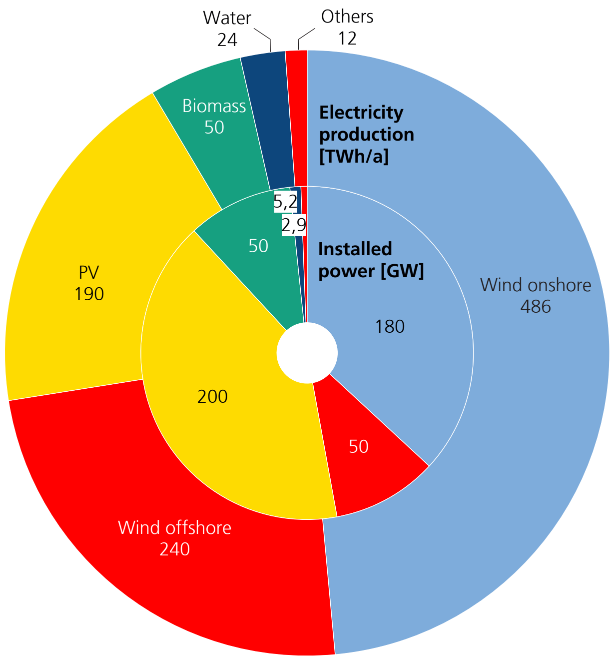


Figure 4: Selected mix of renewables for 100% renewable energy generation (with consideration of partial downpowering of renewable energy installations)

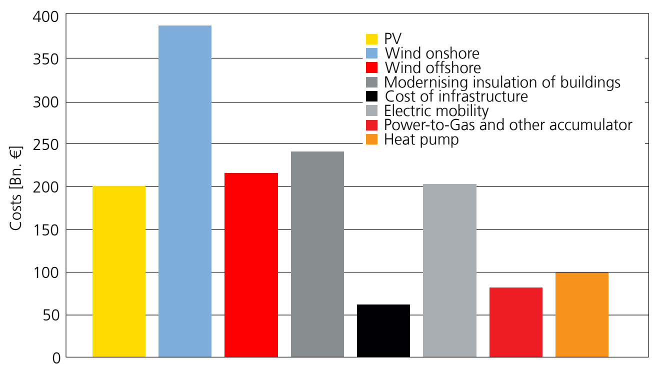


Figure 5: Required investment from 2011 to 2050

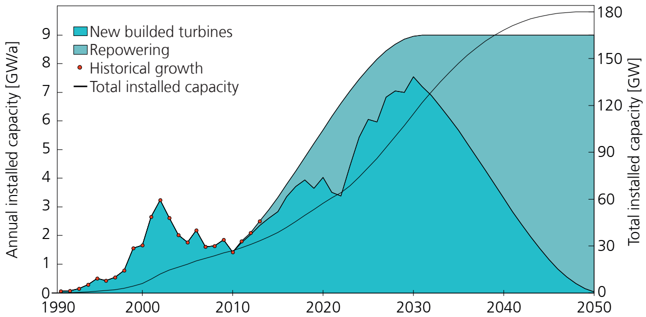


Figure 6: Required new wind turbines and repowering of onshore wind turbines up to 2050

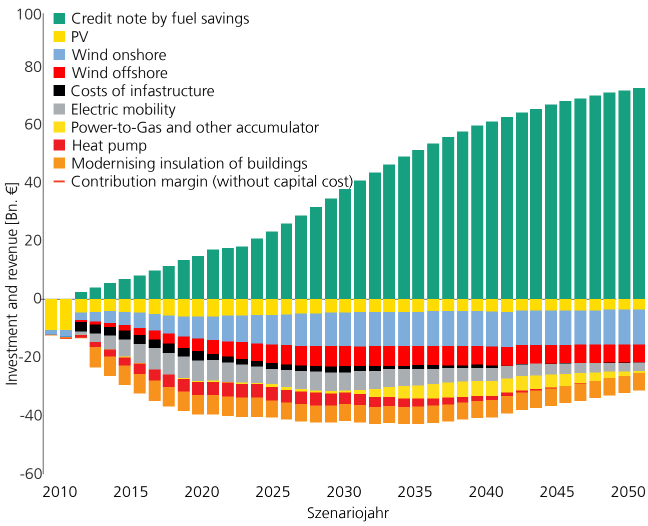


Figure 7: Costs, excluding capital costs, and revenues assuming a constant primary energy price

30 years), new additional generating capacity of 2.5 GW/year and 6.7 GW/year respectively is necessary.

The numbers also suggest that more than 90% of the renewable energy infrastructure must be constructed by 2040. This demonstrates furthermore how little flexibility there is with regard to expansion of renewable energy generation if the 2°C is to be met.

Modeling the cost of the switchover to renewables

Based on the assumptions for the end energy requirement in 2050, a holistic scenario can be derived to describe the energy requirements, generating costs, and investment costs for the new infrastructure for the whole period from 2011 to 2050. To evaluate the economic viability of the overall project, the residual value of the investments in 2050 must also be considered. For this, solely the residual values of the wind turbines and PV installations were considered. This is therefore a conservative assumption.

The expansion of renewable energy generation initially largely replaces fossil fuel based energy generation, which only makes up a small fraction of the primary energy costs. In addition, being relatively new, these technologies still have high investment costs. This means that initially the differential costs are high. In order to realize the macro-economic benefits, there must be efficient electricity usage for transport and heating in order to replace the high-cost primary energy sources and reduce the differential costs for the power sector. There is hence a need to use renewable energy for transport and heating at an early stage. Therefore, the expansion of renewable energy generation for power usage must only be viewed as the initial financing step. Figure 7 compares the annual investment costs for expansion of renewable energy generation (downward bars) and the saved primary energy costs (green, upward bars). The calculated investment costs for the 100% electricity generation from renewables scenario over a period of 40 years indicate that from 2030 (namely after ca. 20 years) there are positive contributions to profit, if interest rates and capital costs are not considered. The required initial financing is 383 billion euros. In 2050 there is significant financial gain because the savings for fossil fuels are many time greater than the ongoing investment for wind turbine repowering.

On taking account of an interest rate on borrowed capital, there is a delay in achieving a positive contribution to profit. Assuming this interest rate is 2%, a positive contribution to profit can be achieved from 2035 onwards (namely after ca. 25 years). The required initial financing is 501 billion euros.

The economic viability of the overall project becomes even more evident if increasing primary energy costs are assumed in the climate protection model of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) [4]. This scenario attains profitability sooner. Positive contributions to profit occur after just 15 years (without considering interest) or 18 years (with consideration of interest on borrowed capital). The required initial financing is 295 billion euros. without considering interest and 356 billion euros taking interest into account.

Results

The conclusion that can be drawn from these initial considerations is that financing the 100% renewable energy project is feasible, even with very conservative assumptions (no increase in fossil fuel prices, no costs for CO_2 emissions). Assuming a constant price for primary energy at 2011 levels and constant residual values, there are interest payments of 2.3% for the full investment (inflation-adjusted). If price increases for oil and natural gas are taken into account, the profitability is enhanced and reaches values of 6.7% (inflation-adjusted) for the price increases specified in the climate protection model.

Even very ambitious climate change goals (requiring 100% energy generation from renewables) are economically feasible, and particularly so if increases in primary energy costs and costs for CO_2 emissions are expected. The "cost of renewable energy generation" should therefore not be the sole factor for political decisions on climate change.

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WIND ENERGY REPORT GERMANY 2013

Special Report

MODELS FOR FUNDING RENEWABLE ENERGY GENERATION

Uwe Leprich / Uwe Klann

Germany is pursuing the goal of making its energy provision more sustainable. In order to achieve this, the last German government defined a target matrix in the autumn of 2010 [1, p 16] for its energy supply. In December 2013 the coalition agreement of the present German government changed and lowered some targets of this matrix. A key goal, however, is still to continuously increase the share of electricity generation from renewables, to at least 40-45% by 2025 [2, p 51].

Funding the future expansion of renewable energy generation

Most scholars are agreed that the expansion of renewable energy generation in Germany cannot indefinitely be funded via the existing submarkets of the electricity sector, namely the wholesale and control energy markets. This is because:

- the prices in the wholesale markets have continuously fallen due, not least, to the increased level of competition, the fall in CO_2 allowances, the stable and favorable price of coal, and the merit order effect of renewable energies and it is not expected that they will increase sharply over the coming years [3, p. 32];
- the prices in the control energy markets have also fallen and the total volume of these markets of less than 500 million euros is anyway very small [4, p 74] compared to the necessary revenues for funding renewable energy installations;
- the market values for wind and solar energy, the fuel-free renewable energies, as the ratio of the specific and average spot market revenues will fall further with continued expansion of these technologies and during windy and sunny periods will thus cannibalize its own revenues [5, p 33; 6; 7].

Contrary to the words of many politicians and media reports, we are not dealing here with “subsidization“ or “sponsoring“ of renewable energies but rather with its financing. The spectrum of potential funding models here is quite straightforward.

Spectrum of funding models for renewable energies

A fundamental distinction can be made between two categories of funding models:

- Technology-neutral models that put all the renewable energies in a pot with the aim of only utilizing the most favorable technology for achieving the given objective;
- Models that differentiate between the individual technologies and possibly take into account other differentiating features, such as regional differences. Besides cost efficiency, these models often pursue other goals such as technology development, retention of technology diversity, and equitable distribution.

This does not follow the commonly encountered categorization based on quantity and price mechanisms [16, p. 895] because these features are not the main differences between the models. With regard to integrating renewable energies into the energy system, two approaches can once again be differentiated:

- Making it compulsory for suppliers to include renewable energies on a pro rata basis in their purchasing portfolios. This approach can be designed as physical turnover in the feed-in remuneration model or as a quota model.
- Marketing the renewable energies in the respective submarkets, either on trust by the TSOs or a third party in a feed-in remuneration model or by direct marketers in the various premium models.

Finally, two approaches can be differentiated for the premium models:

- The market premium is based on the specific market revenue in €/MWh and can be set as a fixed premium ex-ante or as a sliding premium ex-post.
- The capacity premium is ultimately an investment allowance and is specified in €/kW.

Instead of being set on an administrative basis, all premiums can also be determined by competitive auction procedures. Figure 1 gives an overview of the funding models for renewable energies.

<table>
<tr><th colspan="10">Technology specific models / regional different models</th><th colspan="5">Technology-neutral models</th></tr>
<tr><td colspan="2">Feed-in remuneration</td><td colspan="8">Premium models</td><td colspan="4">Premium models</td><td>Quota</td></tr>
<tr><td colspan="2" rowspan="3"></td><td colspan="4">Market premium (ct/kWh)</td><td colspan="2" rowspan="2">Fixed capacity premium (€/kW)</td><td colspan="2" rowspan="2">Fixed market premium (ct/kWh)</td><td colspan="2" rowspan="2">Fixed capacity premium (€/kW)</td><td rowspan="3"></td></tr>
<tr><td colspan="2">Sliding</td><td colspan="2">Fixed (ex-ante)</td></tr>
<tr><td>Adminis-tratively defined</td><td>Auc-tioning Process</td><td>Adminis-tratively defined</td><td>Auc-tioning Process</td><td>Adminis-tratively defined</td><td>Auctioning Process</td><td>Adminis-tratively defined</td><td>Auctioning Process</td><td>Adminis-tratively defined</td><td>Auctioning Process</td></tr>
<tr><td>phys. turnover</td><td>Marketing on trust</td><td colspan="8"></td><td colspan="5"></td></tr>
</table>

Figure 1: Overview of the spectrum of models for funding renewable energies [5, p.53]

Groups of criteria	Criteria / Target
Technical-environmental	Efficiency
	Security of energy supplies
	Environmental impacts and resource conservation
Feasibility / controllability	Conformity
	Continuity
	Flexibility
	Practicability
Embedding into society	Acceptance
	Direct participation
Economic aspects / effects	Dynamic efficiency
	Cost efficiency
	Transaction costs
	Distributional impact
	Strengthening of competition

Figure 2: Criteria for evaluating the funding models for renewable energies [5, p.36]

Evaluation of the different funding models

An evaluation of the different funding models based solely on the economic criterion of cost efficiency is clearly far too inadequate; it is also not certain that this criterion would have priority over all the other criteria. A distinction can first of all be made between the following groups of criteria:

- Technical-environmental aspects
- Feasibility/controllability
- Embedding into society
- Economic aspects/effects

Figure 2 lists many individual criteria that are deemed to be important [8; 9; 10; 11] in the above criteria groups.

In principle, there may be both complementarity and conflict between the criteria. For example, improved cost efficiency may improve the acceptance but can simultaneously reduce the regional value-creation in rural areas – which is taken into account under the "distribution" criterion.

A weighting of these very different criteria is necessarily always subjective and reflects current political preferences. In addition to the cost effectiveness and efficiency of the model, we believe criteria such as practicality, acceptance, and player/technology diversity are of key importance in reality, with the player/technology diversity being derived from a variety of criteria and in particular the intensity of competition.

Deciding on a suitable funding model

We believe the following are salient factors for choosing between the different models:

- The **technology-neutral** funding models are inferior to the technology-specific funding models for two main reasons: Firstly, they are not cost-effective because they do not differentiate the remunerations or premiums and hence give unnecessarily high profits ("producer benefits") [12]. Secondly, they considerably narrow the technology spectrum and run the risk of costly technology advances if the currently utilized technologies become outdated and no replacement technologies are ready. For these reasons alone, these models should only be considered once the costs of an adequately wide technology portfolio have approached one another.
- In principle, the amount of state-organized funding for renewable energies can be administered or auctioned. It is evident from abstract considerations that competitive determination of the premium (**auctioning**) is superior because the market players have better information and have to assess their own risks. In principle, this can contribute to reducing the costs and more precise control of the expansion. For the practicalities of such a system, numerous requirements still have to be fulfilled in order for the expected benefits to be actually realized. These are, in particular, measures for assuring the attainment of the expansion targets for renewable energies and a sufficiently broad range of players and technologies. There must also be measures to prevent avoidable costs being incurred from transaction costs or the exercising of market power in the auctioning. Caution is warranted here given the fundamental considerations involved and the numerous examples of foreign auctioning systems for renewable energies [13, Annex D].

If one disregards for a moment the quota model and auctioning model for the aforementioned reasons, the **feed-in remuneration** does readily fulfill some of the mentioned criteria: the low risk premiums due to the spread of risk and the assurance of a diverse range of players can be mentioned [16, p. 903]. It does not however utilize the potential opportunity for direct marketing. However, it would offer the opportunity for integration of the renewable energies into the energy system via physical turnover of the renewable electricity to the distributors. This goes beyond market integration and incentivizes flexibility that could lead to favorable balance group settlement [14].

All technology-specific and possibly regionally differentiated **premium models** involve marketing the renewable energy in the existing submarkets, and in particular the wholesale markets. They differ in the extent they focus on or promote the utilization of revenues from the marketing activities to fund the installations. Depending on the intensity of the marketing pressure, all premium models have investment risks. These are reflected in risk premiums of differing magnitude and hence the funding becomes more expensive.

If one wishes to optimally promote the marketing of renewable energies – and in particular the fluctuating energies (wind and solar) – then the primary contenders are the fixed market premium model or capacity premium model. In both models the premium is set ex-ante.

Plus points of the **fixed capacity premium** are that:

- it provides an incentive, even for spot electricity prices of zero, to search for alternative markets, for example the heating sector, thus letting the price affect the operation of renewable energy installations free from distortion and maximizing marketing opportunities;
- it lowers the demand-risk for operators and as such it counters the higher risks of this model compared to feed-in remuneration and the associated costs.

Plus points of the **fixed market premium** are that:

- only if the spot electricity prices are very negative does it make commercial sense to stop generating the renewable energies and as such the feed-in priority for renewable energy is largely retained;
- there is less damping of negative prices and the flexibility incentives in the system are virtually unchanged.

Depending on the political objective, one or other of the other premium model must be prioritized if marketing the energy is opted for; no clear recommendation can be given here on a scientific basis.

The current **sliding (ex-post) market premium** can be considered to be a mixture of feed-in remuneration and a fixed (ex-ante) market premium. It largely cushions the marketing risks, but means there is no big incentive to comprehensively test marketing strategies. Overall it leads to higher costs which must either be borne by the electricity consumers or the installation operators, without the additional benefits compared to feed-in remuneration being really persuasive [15].

Recommended funding models for different renewable energy technologies

Figure 3 shows there is a need to have different funding models for different renewable energy technologies. Figure 3 lists selected characteristics of the different renewable energy technologies.

The following conclusions can be drawn from this regarding the individual technologies:

Biomass utilization is already well-established from a technical point of view, meaning that technology development here does not play a major role. At the same time, the capital requirements are relatively low which limits possible cost increases and risk increases – and further negative consequences thereof – due to direct marketing. As such, direct marketing is even recommended for smaller installations which have relatively high specific transaction costs for marketing. The funding model must taken into account that CHP utilization of biomass is obligatory for efficiency and hence environmental reasons. It must also be heeded that the displacement of power from biomass CHP installations by fossil fuel fired power plants is not desired from a climate policy standpoint.

Geothermal energy is controllable but differs from biomass by the fact that for specific project development there are high technical risks. The technology is not yet established and the capital costs are high. The resulting investment risks, which are viewed as a considerable obstacle, can be reduced by, for example, an investment subsidy paid during the project development to effectively lower the capital costs. Simultaneously, direct marketing could be considered in order to benefit from the controllability.

If one considers the non-controllable renewable energies, then **offshore wind energy** stands clearly out: The technology is highly capital intensive and has high risks, including technical risks, and we are only at the beginning of the learning curve. Due to the high plant costs it is assumed that only large companies will be able to make the required investment. The

	PV	Wind Onshore	Hydroelectric	Wind Offshore	Biomass	Geothermal
Controllable with assured availability	No	No	Teilweise und eingeschränkt	No	Yes	Yes
State of the art	Already achieved strong learning effects	Already achieved mean learning effects	Fully developed	At the begin-ning of the learning curve	Mostly developed	Not yet maste-red routinely
Costs of technical risks of the investment	Low	Low	Low	High	Low	Very high
Capital intensity	Very high	Very high	Very high	Very high	Less high	Very high
Size of the plants	Very small to large	Small to very large	Small to very large	Very large	Small to large	Large

Figure 3: Characteristics of renewable energies [5, p.74]

	PV	Wind Onshore	Hydroelectric	Biomass	Wind Offshore	Geothermal
Feed-in remuneration	X	X	X			
Fixed market premium						
* Administratively defined				X		
* Auctioning Process						
Capacity premium						
* Administratively defined	X	X	X	X		
* Auctioning Process					X	
Mandatory direct marketing	X	X	X	X	X	X
Investment grant						X
(Bail)						X

Option A: Model citizen
Option B: Integration model

Figure 4: Recommended funding models for different renewable technologies [5, p.9]

high capital costs, high risk, and long planning times make it very difficult today for government bodies to give a reliable estimate of the long-term costs in order to define the feed-in remuneration or capacity premium. From an investor point of view, the prescribed reduction in statutory remuneration rates for the start-up period also represents a high risk due to the planning uncertainty. A procedure here which discloses the cost estimates of potential operators for specific installations – namely an auctioning process – removes relatively large uncertainties. Large energy companies normally have experience with auctioning processes and with the marketing of the energy. As only large companies operate in this sector, the number of players will probably be further reduced by auctioning and compulsory direct marketing. Provided market power can be suppressed in the auctioning, the disadvantages of auctioning for this technology (in particular the related transaction costs) are deemed to be relatively low. The major advantage is the disclosure of the cost estimates of the investors.

The other non-controllable renewable energies – **PV, onshore wind, and hydroelectric** – have similar main features: The technological risks are low, they are very capital intensive, and the power generated by the installations varies enormously from small to very large. These similarities mean these three technologies can be discussed together. As already mentioned above, direct marketing has greater uncertainty for investors compared to feed-in remuneration, depending on the design of the relevant premium model. This greater uncertainty must be compensated by risk premiums which means that investors will demand higher returns. This increases the electricity generation costs. The cost increase is relatively high for the non-controllable renewable energies, compared for example to biomass, due to the higher capital investment. In addition, small installations are also operated and planned for all three technologies. For smaller installations with a fixed (ex-ante) premium, the greater uncertainty could lead to rationing in the capital market because investors will demand greater certainty and smaller players will struggle to provide this. There is also the fact that direct marketing will be more costly due to the higher, non-diversified risk and due to fixed costs. A fixed premium model with compulsory direct marketing therefore brings with it the danger of marginalizing smaller investors and reducing the number of players.

In order, however, to nevertheless utilize the potential opportunities of direct marketing without endangering the current wide range of players, it seems sensible here to have an options model which gives investors a choice that takes into account the different attitudes to risk and also market knowledge. For smaller, risk-averse investors requiring lower returns, a feed-in model as before seems optimal and ensures continuity. For professional investors open to more risk and wanting greater returns, the fixed capacity premium model offers the opportunity to test out all the marketing options and to integrate the renewable energies further into the total system.

Figure 4 summarizes our recommended funding models for the different renewable energy technologies.

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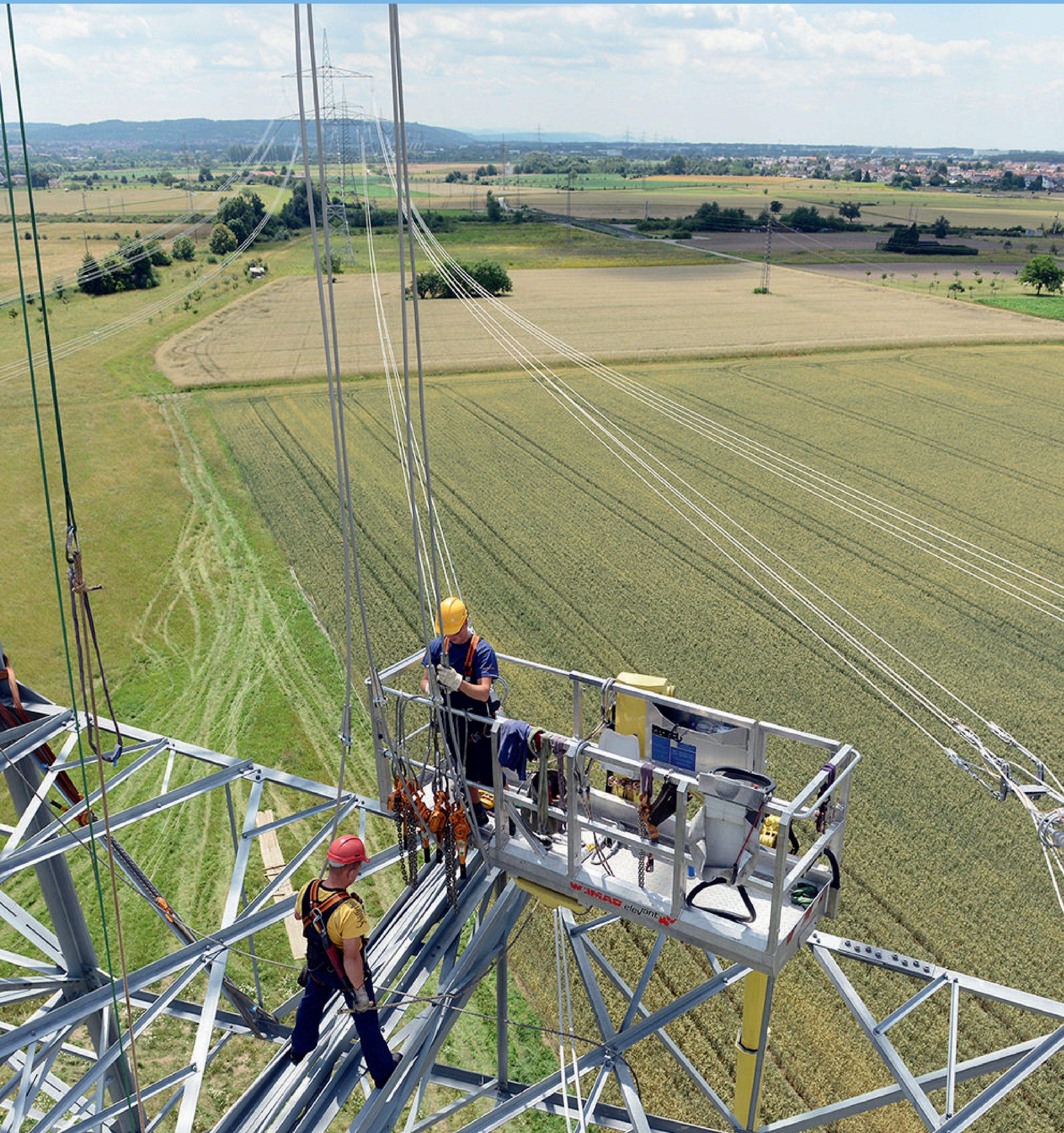

Special Report

TECHNICAL GRID ASSESSMENT BY THE FEDERAL NETWORK AGENCY

Dr. Swantje Heers, Thomas Dederichs und Achim Zerres

Challenges for grid planning and grid assessment during the switchover to renewable energy generation

The switchover to renewable energy generation requires major changes to the infrastructure for the transmission and distribution of electrical energy. For example, under EU Regulation 2009/72/EC and the amendment to the Energy Industry Act (EnWG) of 2011 a grid planning procedure was embraced which puts high requirements on transparency and accountability and is unrivaled. An annual grid development plan is drawn up by the German transmission system operators (TSOs) and then assessed by the Federal Network Agency (BNetzA). This is keenly monitored by market participants and the public.

Objectives of energy provision and grid assessment

There is wide consensus today that the construction of electricity grids is vital for efficient and environmentally compatible energy provision. However, both the construction and assessment of grids is not without controversy. Due to the associated costs, the utilization of land, and the actual or feared impact on the quality of life and assets of residents, grid expansion is far more than just an engineering issue.

The demands of the public with regards to grid planning have thus changed enormously in recent years. Driven by a classical attitude of "as much as necessary, as little as possible", other factors have now come to the fore. For example, when planning grids there are a series of competing goals including:

- Appropriateness with regard to the negative impact on other legal assets
- Effectiveness for reaching the objectives
- Realization in the prescribed time period
- Objectivity
- Transparency
- Comprehensiveness
- Robustness with regards to future energy industry developments that differ from the expected plans

Differences between grid planning and assessment

According to § 12b paragraph 1 of the Energy Industry Act (EnWG), the grid development plan must specify the required grid expansion for the next 10 years. This task is being undertaken in a multi-step development process, which is being repeated every year and at the end of which will be the grid development plan [2,3]. Based on an approved scenario [4,5,6] for regionalization and market simulation, the inflow and outflow of electricity are determined for every hour of a year (e.g. for 2023 in the grid development plan 2013). The feed-ins from renewable energies and conventional power stations to the individual grid nodes, the electricity demand, and the in/out balances at the interconnections define each hour a so-called grid utilization case (GUC). Based on stationary grid analyses (namely load flow calculations), the load on the so-called starting grid can be determined for each GUC. The starting grid, by definition of the Federal Network Agency, is the current transmission system plus planned or ongoing construction measures and projects under the Electricity Grid Expansion Act (EnLAG).

The TSOs determine the necessary measures for the German extra-high voltage grid to alleviate bottlenecks and guarantee efficient grid operations. Their decisions are based on the loads on the starting grid as well as consideration of their responsibilities for the system and their planning principles [1].

Besides assuring electricity provision, the assessment of the Federal Grid Agency must also ensure that the grid expansion measures are proportional, economically viable, and robust. It must take account of the fact that the ten year forecasts for electricity production and demand may change. As such, the necessary grid expansion may change from one grid development plan to the next. It must also be avoided that measures fluctuate from one year to the next due to approval and then non-approval.

Grid extension

Assessment of the grid development plan by the Federal Network Agency

The Federal Network Agency assesses the grid expansion measures proposed by the TSOs to check whether the TSOs have correctly applied their own planning rules and to check the measures against the above-mentioned additional criteria. For the assessment, the Federal Network Agency have defined the criteria "effectiveness" and "required" as follows [7,8].

Effectiveness. A measure is classed as effective if:

a. it ensures the (n-1) reliable operation of the grid in accordance with the planning regulations [1];
b. it avoids disproportional work to relieve overloads in lower grid levels;
c. it leads to the desired increase in cross-border transport capacity to other countries;
d. it significantly reduces undesired physical loop-flows across other European countries.

Points (b) – (d) will not be discussed further in this report (see [7,8]).

To test the effectiveness of a measure in the sense of (a), it is determined to what extent efficient grid operation is possible with and without the measure. First of all the measure under test is removed from the grid planned by the TSOs ("target grid"), namely the grid expansion is assessed without the measure but with all other expansion measures. With the help of the base load flow and (n-1) failure cases, the resulting line loads are determined in the German grid.

If there are no line loads of > 100% (overloads) in either the base case or in the failure situations, then the necessity for the measure is not clear and it is consequently not effective for relieving an overload. The (n-1) cases under consideration generally include the failure of lines in the surrounding grid zones which have base utilization of more than 50%.

In contrast, if overloads are found, the same tests are carried out with the measure. The measure is effective if all the (considered) overloads are relieved or considerably reduced.

For assessing the measures, overhead electricity line monitoring was taken into account, namely the weather-dependent operation of extra-high voltage lines to increase the current carrying capacity, as laid down in the planning regulations of the TSOs [1]. Depending on the weather, the maximum permissible line load in the three wind zones can significantly increase, namely in central and southern Germany (up to a maximum of 115% of the line load), in the northern German lowlands (maximum 130%), and in the coastal regions (maximum 150%).

In addition, topology changes (namely switching measures) are allowed for alleviating possible breaches of hardware limit values and small breaches of the total exchange capacity with other countries are allowed. A detailed description can be found elsewhere [7,8,9].

The Federal Network Agency was given a grid data set for each measure. The grid data set contains the specific electricity feed-in and consumption for an hour of scenario B2023 (grid utilization case). Each data set contains the node-level topology of the entire German extra-high voltage grid and simplified models of the grids in neighboring countries and German distribution grids. The grid data were evaluated using Integral software. The grid comprises ca. 6600 grid nodes, 5500 circuits, and about 1850 transformers. Also included in the data set are line parameters, electrical data of the coupling transformers, generators, and extra high voltage direct current installations, busbar utilization and the switching states of the lines and active grid elements.

Example of effectiveness assessment for project 72, measure 50: Lübeck region – District of Segeberg. The measure involves the construction by the TSO of a 380 kV line along the route of the existing 220 kV line between Lübeck region and the District of Segeberg and is deemed necessary to enhance the grid. In the District of Segeberg the construction of a new 380 kV substation is also necessary.

The TSOs deemed the measure necessary due, amongst other things, to grid overload on failure of one of the lines between

Lübeck and Hamburg/Nord. It often arises that the Baltic Cable, connected in Herrenwyk, which connects the German and Swedish grids can either not be operated or not operated at full capacity.

The base load case was assessed with and without measure 50. In the hour that was assessed (3204, 13.05.2023, 12:00), the base case gave 71% utilization of the lines between Lübeck and Hamburg/Nord without the measure.

To simulate the (n-1) case, Figure 1 shows the Hamburg/Nord (HAMN) and Lübeck (LBEC) transformer stations in detail. If one of the two systems between Hamburg/Nord and Lübeck fails, the rest of the system is overloaded (118%). The overloading cannot be relieved by switching measures.

The next step involves undertaking the same assessment but with the new planned measure. Figure 2 shows measure 50 in operation and the 220 kV systems between Lübeck and Hamburg/Nord switched off. If now one of the two 380 kV systems between Lübeck and the District of Segeberg fails, the parallel system is 45.5% utilized. Measure 50 enables the situation to be prevailed with (n-1) certainty, as assessment of other failures does not lead to overloads. Measure 50 was hence classed as effective.

Necessity. Measures that are approved in the grid development plan must generate benefits for the grid even if the boundary conditions change. Examples of the latter are changes to the statutory requirements or assumptions in the scenario about the planning timescale. A measure is consequently necessary if it has a certain robustness to changes to the grid development plans, and even to changes to the starting parameters.

To quantity the necessity, the maximum utilization of a measure during a year was determined. The line utilization in an hour (hi) here is defined as the ratio of the electricity load ($I(h_i)$) to the nominal maximum load of the line (I_r) (see equation (1)).

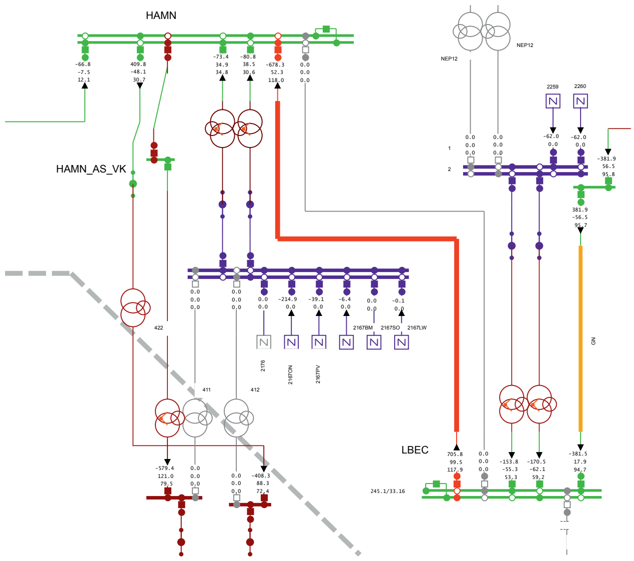

Figure 1: Lübeck (LBEC) and Hamburg/Nord (HAMN) transformer stations with (n-1) situation without measure 50.

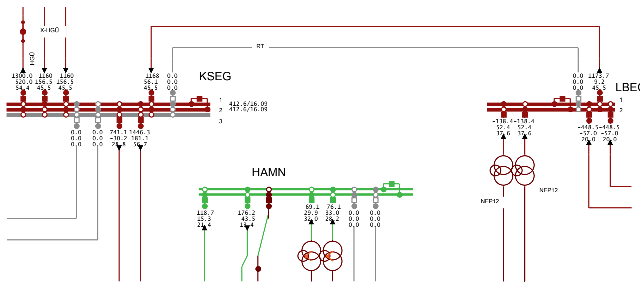

Figure 2: District of Segeberg (KSEG), Lübeck (LBEC), and Hamburg/Nord (HAMN) transformer stations with (n-1) situation. Measure 50 is active.

$$p\%(h_i) = \frac{I(h_i)}{I_r} \cdot 100\% \quad (1)$$

For the assessment, a measure is deemed necessary if its maximum utilization was at least 20% (see (2)).

$$\max_{i=1}^{8760} (p\%(h_i)) \geq 20\% : \quad (2)$$

The choice of a limit load of 20% was made for the following two reasons:

The required minimum line load must not be chosen too high so as to be impractical for subsequent grid operation if there are operation-related shutdowns or other such events. High line loads are generally not able to absorb the failure of other operating systems.

The utilization limit must also not be chosen too low so as to make the measure necessary under changed boundary conditions. The value of 20% was chosen because below this value it is also possible for grid expansion in lower level grids or other technical variants. The necessity criterion only gives meaningful results for alternating current measures, because there the utilization follows from the physical principles of the network grid. For direct current measures (HVDC), the utilization can be set by controlling the converters. Here the Federal Network Agency has embraced the results of the expert report of TU Graz [10] for the grid development plan 2012 and the grid development plan 2013. The report comes to the conclusion that "the necessity and benefits of controllable transport corridors is evident", but that "assessment of the utilization of the four extra-high voltage corridors proposed by the TSOs shows that a solution with a fewer number of corridors would be preferable."

The assessment of the necessity was undertaken using a data set of the "target grid", which shows the planned expansion of scenario B2023 in the normal state of operation and which the Federal Network Agency received for assessment in addition to the individual grid utilization cases. Using the target grid, the annual utilization curves for the specific measures were determined by calculating all 8760 grid utilization cases and evaluating the necessity of the measures in the grid development plan. The line utilization for project P72 M50 Lübeck – District of Segeberg is shown in Figure 3. The maximum utilization is 30.6%. The measure is therefore necessary.

Further development of assessment methods

The Federal Network Agency will trial various improvements for grid assessment over the coming years. Some will have a major effect on the currently used procedures and are difficult to implement.

Selection of grid utilization cases and weather years. Despite increasing the grid utilization cases to 8760 hours per scenario, only a two-digit number of the (n-1) calculations is relevant for the design of the grid. It must be checked whether a selection of individual hours or selected time periods (e.g. weeks) from long weather time series is appropriate.

More scenarios / sensitivities. The procedure up until now puts the reference scenario to the fore, knowing however that the future will not be exactly like this. There is more uncertainty, however, in the range of the grid utilization cases and the choice of selection criteria. Various contributions to consultations and scientific studies [11] have urged greater consideration of further scenarios. This does not necessarily lead to greater legitimacy of the assessment results because no scenario can accurately forecast actual future developments. With regard to the comprehensiveness of the methodology demanded by the legislator, a compromise must also be found between complexity and manageability.

Time periods versus points in time. A further key point is the focus on a point in time 10 years hence (and also to a lesser extent on a point in time 20 years hence). The same studies [11] provide reason for more continuous assessment over shorter time periods. It is not disputed that procedures over short time periods, considering a lot of points in time, are more suitable for avoiding a so-called "lock-in". With regard to transmission grid planning, however, there has up until now been no indication that local optima provide significantly lower efficiency with respect to technical or economic assessment standards.

Status-dependent assessment criteria. In order to be robust, an abnormal parameter set for already approved lines is also conceivable. Taken from control technology, the term hysteresis would be suitable for this. This was so prevent an often changing assessment result for lines whose necessity is only just justified. Instead, stricter requirements would be put on lines that are not (yet) approved. In principle, approved lines would only be subject to limited assessment in the following years.

In addition, there remain other considerations such as the dependence of the scope of the assessment on the size of the project (should the same criteria apply for a short AC grid expansion and an HVDC electricity highway) and the matter of procedural dependence of the solution (to what extent is a "very good" long-term solution overlooked because "good" solutions are approved in the short-scale iteration steps of the grid development plan).

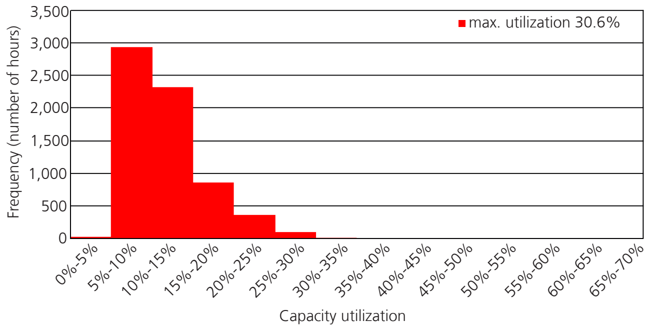

Figure 3: Line utilization for measure 50 over 8760 hours

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WIND ENERGY REPORT GERMANY 2013

Special Report

RECYCLING OF WIND TURBINES

Prof. Dr.-Ing. Henning Albers, Dipl.-Ing. (FH) Saskia Greiner M.Sc.

Introduction

When new technologies are introduced, it is nowadays endeavored to consider the whole life cycle of installations from the very outset, namely at the development stage. It is clear, however, that key questions regarding recycling are still not being satisfactorily answered. Consider, for example, the recycling of end-of-life wind turbines. This concerns various types of materials:

- traditional bulk materials such as concrete and steel
- large quantities of modern materials such as glass fiber reinforced plastics from rotor blades
- smaller quantities of valuable materials such as heavy metals and rare earth metals

These materials have either to be disposed of as waste or processed into second-life products. Up until now there have been no efficient systems in place, either from technical and organizational standpoints, for all these materials and some systems have developed out of necessity or by accident. There is enormous uncertainty about responsibilities, handling procedures, and technical solutions, and particularly so regarding the options for recycling components and materials.

Boundary conditions and state of knowledge

Fundamental questions. It is often claimed that the materials used in these newer energy generation technologies should be recycled. The example of photovoltaic installations demonstrates that these ideas are becoming part of the European and national legislation processes but that there are still many unanswered questions. An overview has been given by Wambach (2013).

The setting up and operation of recycling processes and technologies requires the following questions to be answered to facilitate decision-making:

1. What objectives, tasks, and responsibilities have the individual participants in the process chain?
2. At the end of the life cycle, what waste materials arise from what components and in what quantities and qualities?
3. What recycling routes must be available for the various renewable energy technologies?
4. What markets and uses are there for the recyclates?

Responsibilities and organization. There are still major uncertainties regarding Question 1. Up until now, the legislator has not availed of the provision in the Waste Management and Recycling Act (Kreislaufwirtschaftsgesetz (KrWG)) to lay down responsibilities for products, in accordance with § 23, by statutory order [BUND 2012]. As wind farms are generally designed for a service life of at least 20 years, the waste problem is not yet topical. For the few wind farms that are nearing the end of their lives, discussions about recycling are ongoing between component manufacturers, WT manufacturers, and wind farm owners. There are in principle suitable existing recycling systems for many materials used in WTs. As far as the authors are aware, decisions have up until now been taken on a case by case basis. At present there is no established, optimized system. There is apparently deemed not be sufficient need at present given the small quantities of materials. Clear though, from the answer to Question 2, is that the need for action on Question 1 will increase.

Estimation of future material flows. The composition of WTs can be estimated using the data of Seiler/Henning (2013) as shown in Figure 1. To be remembered here is that onshore WTs have steel towers. The steel content of offshore WTs is much higher due to the submersed steel support structures.

The main materials are concrete and steel (including cast iron) in various qualities.

A more detailed breakdown based on the nominal power of WTs is also possible, but generally has to be derived from secondary data as data from manufacturers are often not available. Albers/Greiner (2013), for example, assumed 10 Mg rotor blade material per 1 MW nominal power.

Material	Share [Masses-%]
Concrete	60 – 65
Steel	30 – 35
Fibre composite material	2 – 3
Electrical components	< 1
Copper	< 1
Aluminium	< 1
PVC	< 1
Liquids	< 1

Figure 1: Typical percentages of materials in onshore wind turbines [Seiler/Henning 2013]

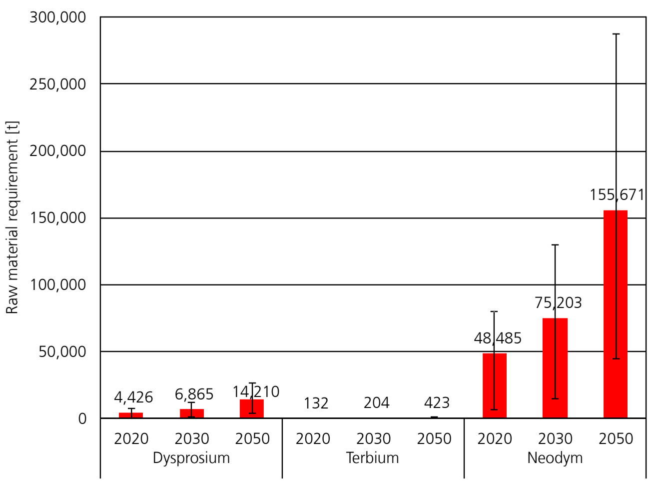

Figure 2: Forecast requirement for rare earth metals, showing scenario 2 and the range between scenarios 1 and 3 [Pehlken/Garcia Sanchez 2013]

This base data can be used for expansion scenarios, as shown in Figure 2. This compares worldwide expansion scenarios onshore and offshore, plus technology and market trends for permanent magnet generators.

The raw material requirements for wind energy different expansion scenarios are shown using the examples of dysprosium, neodymium and terbium. Independent of the scenarios, the raw material requirements will at least double every ten years. Between the worst case and best case scenarios the requirement can vary by a factor of 12. The requirement is hence considerable. These materials will in principle be available for recycling at the end of life of a WT.

Besides this coupling to expansion scenarios and data for the number of WTs, estimates of the service life of WTs are needed in order to be able to answer Question 2. Additional boundary conditions must be included here:

- the dismantling of old WTs before expiry of the intended service life and their replacement by more powerful WTs, so-called repowering;
- the upgrading of old WTs and their use as second-life WTs in emerging and developing countries;
- further operation beyond the planned service life.

Although the latter point is already under discussion, but in the opinion of the authors is nigh impossible to estimate due to the lack of practical experience, fundamental trends are evident with regards to the two other boundary conditions. Specific and comprehensive data relating to these issues are however not yet available.

The REA amendment [BUND 2011] accelerated the dismantling of older WTs in 2012, largely due to the improved boundary conditions for repowering [Neddermann 2013]. Figure 3 shows there was a doubling of the repowered WTs within a year. Most of the WTs that were repowered were 10 to 15 years old. Up until now it is unknown what happened to the dismantled WTs: Were they upgraded and reused as second-life WTs? Were they stored whole or as components? Were the materials recycled or sent for disposal?

Taking account of the above-mentioned boundary conditions, scenarios were developed to roughly estimate the flows of waste materials. Figure 4 shows by way of example the potential waste for recycling in the current decade based on the following assumptions: Repowering after 10 to 15 years in service, recycling (and intermediate storage) about 90%. The results for GFRP were firstly compared to a "traditional approach" that considered a standard service life of 20 years and then disposal. The data in Figure 3 for the disassembled WTs were then linked to the specific values of Albers/Greiner (2013) for the mass of rotor blades. It could not be determined whether and to what extent this mass was actually recycled or sent for disposal.

Figure 4 clearly shows that the material flows will significantly increase by the end of the decade. Compared to other waste flows, however, the material flows here will be rather small.

Question 2 can hence only be answered with many assumptions and estimates, but orders of magnitude can be given. This means that preliminary conclusions about the required recycling capacities can be drawn.

Recycling technologies. Question 3 can at present also only be answered generally. For most components such as electronic parts and steel and concrete from the tower there are established return and recycling systems. There are therefore relatively high recycling quotas for WTs, estimated to be 80-90% by Seiler/Henning (2013) and more than 90% by Pehlken/Garcia Sanchez (2012). The question arises here whether there are any customized disassembly, dismantling, cutting and crushing technologies adapted for WTs which allow efficient recycling of type-pure materials. In the opinion of the authors, this matter is unresolved for the previously mentioned smaller quantities of valuable materials such as heavy metals and rare earth metals. Figure 5 shows the fundamental disposal options as outlined by the Waste Management and Recycling Act (Kreislaufwirtschaftsgesetz) [BUND 2012].

For the glass fiber reinforced plastics in the rotor blades and nacelle housing, namely the main waste flow in Figure 4, there

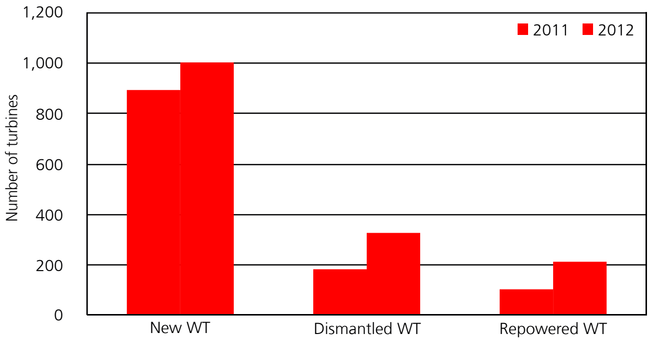

Figure 3: Overview of the newly constructed, dismantled, and repowered wind turbines in 2011 and 2012. Data sources: [Ender 2012 / Ender 2013]

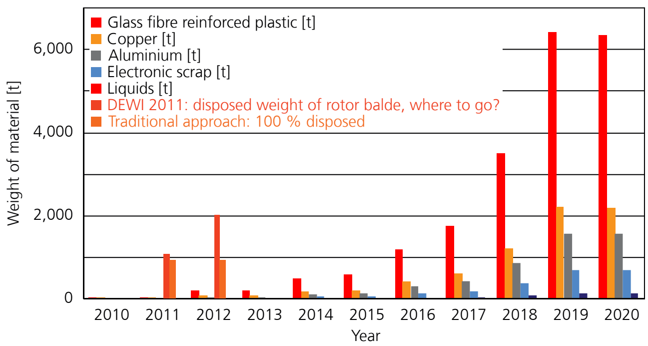

Figure 4: Estimated masses of materials from wind turbines [Albers et al. 2012]

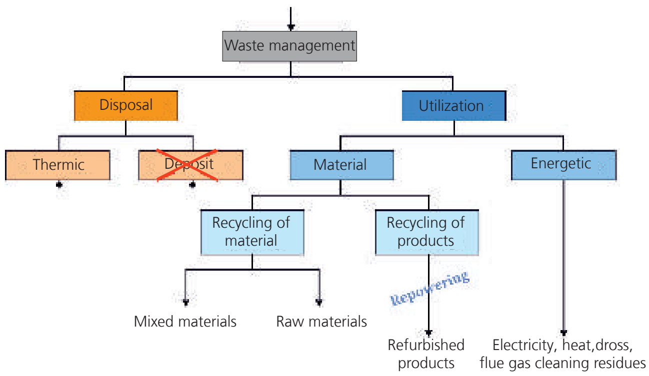

Figure 5: Disposal options for waste from wind turbines [Albers et al. 2009, amended]

are few recycling options thus far. Thermal treatment in incinerators is a common option for smaller material flows. Currently the most widely used and most established technical solution appears to be customized cutting/crushing and subsequent material recycling, combined with energy utilization, in cement factories of Zajons and Holcim [Hinrichs 2012]. Further options for material utilization, namely involving the "true" recycling of materials, have not yet become established. It is unclear whether this is due to the technical challenges or due to the lack of market opportunities. Technologies for separating composites and purifying the materials are currently being researched. Seiler/Henning (2013) show examples of technologies being used for GFRPs.

Markets and uses for recyclates. Question 4 can at present only be answered for the small number of large-scale recycling options that have been realized. Only after answering Questions 1 to 3 will qualified statements about Question 4 be possible.

Need for action

The wind energy industry provides "green" energy. It must reflect on how efficiently it uses materials and what recycling options it provides for products at the end of their service lives. In this regard, the four main questions raised here have up until now not been satisfactorily answered. As the sizes of the material flows will increase over the coming years, there is a need for action to develop and implement best-practice solutions, designed with both the environment and market in mind. This task is not only a technical environmental issue but also a resource management issue with a series of unanswered organizational matters. Particularly unclear is what decisions need to be made by what players and on what basis, in order to make optimum solutions available. The first results are available but these must be given more detail and consolidated.

Answering Question 2 about the waste materials (timing, mass flows, qualities) and Question 3 (treatment/purification technologies) appears to be the top priority at the moment because the results will provide the basis for answering Questions 1 and 4. For this, reliable data from the manufacturers about the material composition of WTs are required. Product passports and product data sheets can help here. In addition, the information about the assembly and disassembly of WTs must be supplemented with qualified statements about the recycling or disposal of components and the reutilization of components or whole WTs within the context of "second-life" activities.

The wind industry has up until now had little to say in relation to Question 1 concerning objectives, tasks, and responsibilities. The experience with other technologies such as solar energy is that the industry must either meet its responsibilities or be prepared for regulations to be laid down by the legislator.

Summary

At the end of the life cycle of a WT, the materials used in that WT can be either recycled or disposed of as waste. A further option is to upgrade the WT and use it as a second-life WT. Established and optimized systems for recycling all materials are not available at present. Some existing recycling systems are utilized.

The masses and qualities of materials for recycling and the moment of recycling have to be estimated, and often only secondary data are available. Material and WT specific technologies are only in their infancy. The potential markets and uses for some recyclates are unknown.

Acknowledgment

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WIND ENERGY REPORT GERMANY 2013

Special Report

TEST-BASED DEVELOPMENT OF WT CONTROL SYSTEMS

Martin Shan, Dr. Boris Fischer

The automation systems used today for controlling and monitoring WTs and wind farms are highly complex.

- The control of a wind farm involves a hierarchical system comprising wind farm control system, WT control systems, and intelligent subsystems (e.g. pitch system, generator system). When designing the system a large number of boundary conditions must be considered. For example the permissible load limits of the mechanical components must not be exceeded and defined feed-in to the grid must be guaranteed.
- For each WT this involves several hundred I/Os and complex subsystem interfaces. A variety of subsystems from different manufacturers must therefore be integrated into a functioning total system.

The automation systems are also very important for the safety and reliability of the WTs and also the electricity feed-in: The automation system monitors the functioning of all the subsystems of the WT and in the event of malfunction must guarantee that the WT transfers to a safe operating state (generally this means shutdown). Due to the large loads associated with a hard emergency stop, the trend here is towards a staggered response of the safety system depending on the relative malfunction.

The automation system itself must efficiently operate under all WT operating conditions; its failure necessarily leads to the WT shutting down. It is also directly responsible for ensuring there is observance of the operating parameters of the subcomponents, and in particular observance of mechanical loads. Ensuring there is efficient observance of the design loads under all operating conditions is vital if a WT is to have a long service life.

The automation system is also responsible, to a certain extent, for the feed-in characteristics of the WT and wind farm. Besides the aspect of grid quality, another key factor here is correct action in the event of grid malfunction in order to guarantee the grid stability.

Maintaining the required reliability with the given system complexity requires complex quality assurance measures during the development process. A key aspect of this is systematic testing of the hardware and software of the subsystems and total system. Similar problems and solutions are known in other industries, including the car manufacturing industry [1]. Automated test procedures have been a key part of the development process in those industries for many years. They are used there, for example, for quality management and for seamless integration of components from different manufacturers.

Hardware-in-the-Loop (HiL) systems allow the systematic and automated testing of hardware and software from a wide range of automation components for WTs and wind farms [2]. HiL in the context of wind energy means that a real component of a WT or wind farm is tested under realistic conditions with the help of a real-time simulator. These test components can, for example, be the generator or WT control system (see Figure 1). The simulator mimics the behavior of the total system from the viewpoint of the test components. If, for example, the WT control system is being tested, then a real-time model of the whole WT – apart from the WT control system – and the grid connection runs on the simulator. The simulator and control system hardware are connected via real interfaces. The interactions between the total system and the test component/system are realistically mimicked.

HiL systems have a number of advantages. The ambient conditions under which the test component/system is tested can be chosen and can be exactly reproduced as often as desired. Whilst one must wait when carrying out tests on real WTs until certain wind conditions prevail or until there are suitable access conditions (wave height), the HiL simulator can simulate these at the press of a button. Extreme situations or malfunction scenarios can be mimicked which occur very rarely in the field or which should not be tested on real WTs for safety reasons, and yet which must be able to be dealt with by the WT control system. Difficult wind conditions and simultaneous grid failure can be readily mimicked on the simulator without risks to safety. The simulation of critical states and the reconstruction of accidents and malfunction scenarios are also possible.

V112-3.0 MW

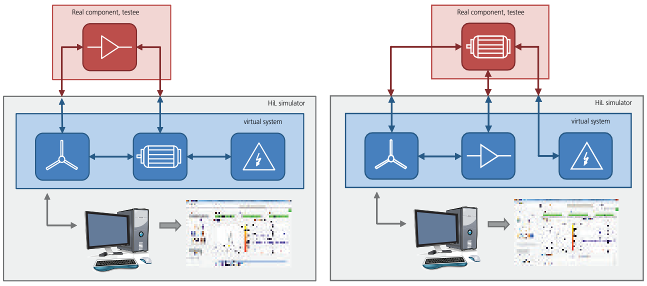

Figure 1: Schematic representation of the HiL test stands for wind turbine controls (left) and generators (right). The virtual total system with all components relevant from the viewpoint of the test component/system is calculated with the help of special simulation hardware. A desktop PC manages the testing process and evaluates the data.

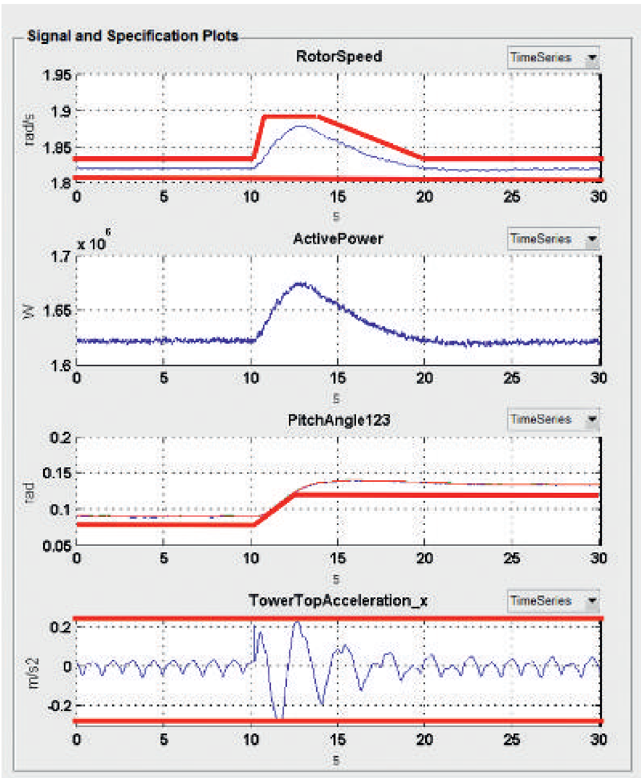

Figure 2: Example signal curves and signal-specification curves (red, bold) for testing the dynamic behavior of the speed control for a wind turbine.

Detailed HiL simulation in this way reduces the start-up time in the field, which is particularly expensive for offshore WTs. At the production stage, HiL simulations also provide a valuable service, for example for detecting wiring/cabling errors via end-of-line testing.

HiL simulation is used today by many WT manufacturers. The simulation models used are often those used to calculate loads. For example, HiL modules for software such as GH Bladed and FAST are also available. A disadvantage of this procedure is however that the simulation codes were optimized for load calculation. For HiL simulation they are hence often too inflexible, if for example different components must be taken from the model and run in-the-loop for different scenarios (see Figure 1).

Block-based modeling approach

For this reason the test systems for WT components developed at Fraunhofer IWES in Kassel are essentially based on a library of real-time submodels. Here, each component of the WT or wind farm is modeled in an independent block with clearly defined interfaces. In general, several implementations of a submodel at different levels of detail are available for adaptation to the relevant test task. For example, to test the main control computer a very simplified generator model with a typical sampling time of 10 ms usually suffices, whilst for testing the electrical behavior in the event of grid failures a considerably more detailed generator model is required with shorter sampling time. For a given testing task, the total model is obtained by combining the relevant submodels.

A total model is in general tested and optimized at a simulation level as a first step. If necessary, manufacturer-specific submodels can be adapted or newly developed. The adaptation to a specific HiL scenario is easy to realize in the second step: The block, which represents the real component to be tested, is removed from the simulation model and the relevant interfaces are externally connected.

Several HiL test stands have already been developed and constructed using this methodology: for testing WT and wind farm control systems (Figure 2) and for testing pitch systems. The validation of the simulation models is carried out by comparison with the software packages GH Bladed, Flex5, and FAST and with the help of field test data.

Simulink simulation software from MathWorks is used for the modeling. This platform allows clear, graphic programming of the model. It also offers an interface for automatic code generation for any target systems. This means that the program code, which the computer system of the HiL simulator executes, is generated directly from the graphic models. Such a procedure is well-established for programming control units for cars and medical equipment, because it guarantees high software quality.

Real-time system and hardware interfaces

An important aspect is the so-called hard real-time capability of the simulator. Hard real-time means that calculating the models is achieved within a fixed time frame – the real component does not wait until the simulator has carried out time-consuming calculations before responding.

The real-time test systems are being realized based on industrial automation systems such as Beckhoff and B&R. These systems offer the ability to execute the C-code modules generated from the Simulink models in hard real-time. They also offer high versatility with regards to the hardware interfaces. A large number of standard I/Os are available and can be combined as desired. It is particularly beneficial if the simulator is realized with the automation system available at the respective WT manufacturer. That is generally SPS with the relevant programming environment. Developers can utilize their own know-how when using this software and hardware for servicing the HiL test stand and so reduce the costly start-up process.

Different time frames are appropriate depending on the component being simulated. For the turbulent wind field it usually suffices if new values are available to the simulator ten times per second. For testing generators, however, the model for grid connection must under some circumstances be calculated more than a thousand times per second. That means that real-time capability for a specific case depends on the physical characteristics of the submodel being simulated. For the modeling a good balance must therefore be found between model accuracy and calculation time.

Automated testing process

Defined test packages can be run automatically for systematic development and quality assurance applications. In each case there is automatic generation of test documentation at the end of the process.

Each test package consists of a large number of test cases. A test case reflects a specific operating situation of the simulated WT. This is described firstly by external parameters such as wind field and grid status, and secondly the occurrence of specific component failures or grid failure can be defined.

In addition, the expected behavior of the system can be specific for each test case. This is carried out using so-called signal-specification curves. In the simplest case here, the upper and lower limit curves, which may not be exceeded, can be defined for each output signal of the real-time model. An example is shown in Figure 2. With the help of these signal-specification curves it is possible to give a yes/no decision for each test case as to whether the expected system behavior was observed. This so allows fast and clear documentation and evaluation of the test results, even for a large number of test cases. If an already defined test process is repeated following a software update then, if there was suitable definition of the test cases and signal-specification curves, it will quickly be clear whether the WT shows, as before, the desired system behavior. The HiL test stand, being part of the quality management system, can thus make a key contribution to enhancing quality assurance.

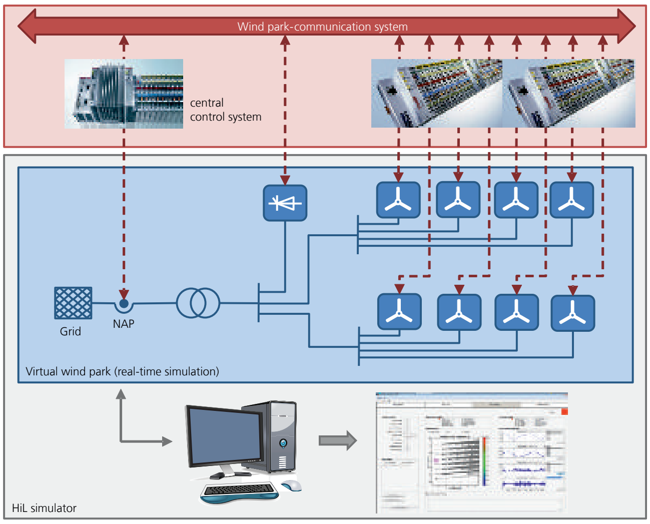

Figure 3: Schematic representation of the "virtual wind turbine" HiL test stand. Wind farm control systems and communication systems are the real test components.

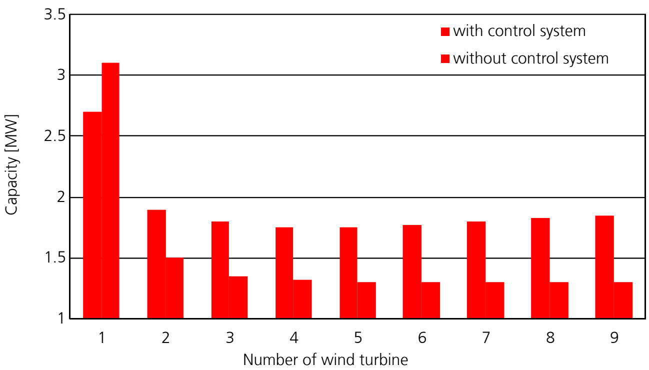

Figure 4: Performance of nine in-line wind turbines with and without a central wind farm control system (WFCS). If the power output of the front-most wind turbine is reduced, the overall power output increases.

Application example: wind farm control system

A central wind farm control system is vital for large wind farms. This ensures that the wind farm complies with the applicable grid connection regulations, for example using a reactive power control system. Depending on the measured values at the grid connection point, it controls the individual WTs and if necessary additional balancing units via the wind farm communication system. The delays in communication can sometimes have a major influence on the quality of the control, so a test that includes the control and communication hardware is highly recommended.

Fraunhofer IWES (Kassel) and Areva Wind GmbH are carrying out a joint project funded by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) to develop an HiL test stand for testing a wind farm control system, including the communication system [3]. Figure 3 shows a schematic representation of the "virtual wind farm". The base total model describes the behavior of the WT, wind farm grid, grid connection, etc. The test stand allows critical situations such as massive disturbances in the grid due to different weather conditions to be simulated in the laboratory.

The wind farm model also takes account of the wind field in the park and shadow effects between WTs. This enables the wind farm control system to be optimally configured. Figure 4 shows this effect for nine in-line WTs. The central wind farm control system reduces the power output of the first WT so that more wind "remains" for the other WTs. The net effect of this measure is that the wind farm produces more power overall.

Certification of wind turbine and wind farm control systems

In addition to the already mentioned uses for product development and quality assurance, HiL systems may also in the future play an important role in the certification of WT and wind farm control systems.

The standard current practice for individual WTs is document-based certification. For this the WT manufacturer must make a wealth of documentation about the control system available to the certification body. The documentation must be such that the certification body can mimic the loads on the control systems and so check the load specifications of the manufacturer.

The amount of documentation has risen with the growing complexity of the WT control systems and hence so has the complexity of the certification procedure. The manufacturers must also disclose some of their key know-how to the certification body by giving them an accurate description of the control algorithm. For these reasons and at the behest of the WT manufacturers (GL guideline 2010) an alternative procedure was introduced, a key aspect of which is functional testing using HiL systems. Less emphasis here is put on the documentation for the control system and more emphasis on the development process for the control system. This requires the introduction of quality management procedures for the development process, including detailed testing of the software and hardware using HiL systems [4].

Today, the certification of the electrical characteristics of wind farms involves a combination of field tests on individual WTs and wind farm simulations. The certification process here may in the future make use of HiL tests. This would allow more systematic testing of generator systems under different operating and grid situations in an HiL environment in the laboratory [5]. As mentioned above, the certification of wind farm control systems should include the hardware components for the control and communication systems.

The advantages of test-based certification are several-fold, the one disadvantage is that there are high one-off costs for establishing QM methods for developing control systems. The development and manufacturing processes are being continuously optimized due to the intense competition and ever increasing requirements being put on system reliability. It is thus only a matter of time before test-based certification procedures becomes established in the wind energy industry.

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WIND ENERGY REPORT GERMANY 2013

Special Report

FLOATING-LIDAR SYSTEM

Julia Gottschall, Gerrit Wolken-Möhlmann, Thomas Viergutz, Claudia Rudolph, Bernhard Lange

Introduction

A general challenge for offshore wind resource assessments is the lack of suitable data for prospecting purposes. Offshore meteorological (met.) masts at future wind farm sites are scarce, and if new masts are erected, they pose a significant capital and logistical commitment for the developers. Moreover, the installed masts rarely reach the hub heights of future offshore WTs, which results in additional uncertainties when vertically extrapolating the mast measurements.

In this connection, floating lidars represent a cost-effective alternative to an offshore met. mast, lowering first of all the CAPEX of the project. Additional benefits are a shorter process of approving in terms of lower requirements for a corresponding marine licence application, a significantly smaller disturbance of the environment, and a greater flexibility of the system enabling a deployment at different locations.

A (buoy-based) floating lidar system is here defined as a lidar device integrated in or installed on top of a buoy. The offshore environment corresponds to a major challenge to the lidar instrument but also to the complete system: the harshness of the environment sets requirements on all system components, its non-stability (with changing water depths, wave conditions and ocean currents) requires a certain adaptability, and the limited access affects the availability, and finally also the reliability, of the system. Power supply may be a critical issue, and needs to be ensured by a technically mature approach – similarly as data storage and communication.

Furthermore, the quality of the lidar measurements – in terms of accuracy and precision – is affected by the motion of the buoy. Platform-typical motions, including up to six degrees of freedom, may cause systematic measurement errors, appearing e.g. as a wrong projection of the wind velocity vector, a confused wind direction measurement, added velocity components, increased lidar turbulence intensity or a wrong measurement height.

The development of suitable and for an application in the offshore wind industry optimized floating-lidar systems has made considerable progress during the last few years, and has resulted in realisations that vary not only in the adapted lidar and buoy technologies but also in the used concepts for installation or data handling, and in particular the consideration of motion effects on the recorded data.

R&D project “Offshore Messboje“

Fraunhofer IWES has been engaged in the development of floating-lidar concepts since 2009. An own correction algorithm for motion compensation was developed and tested both in simulations and first onshore motion tests. In 2011 the R&D project ‘Offshore Messboje’ was granted by the BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) within that an own and novel floating-lidar system, were to be designed, built and tested.

The prototype of the Fraunhofer IWES Wind Lidar Buoy was completed in May 2013, and as a start tested in the inner harbour near the Fraunhofer IWES buildings in Bremerhaven for a couple of weeks. The final performance of the system was verified in an offshore test next to the met. mast FINO1 in the German North Sea from August to October 2013. After concluding the test campaign, the Fraunhofer IWES Wind Lidar Buoy was introduced and presented to the offshore wind industry at the EWEA Offshore event in Frankfurt in November, and the project was successfully completed by the end of the year 2013.

Wind Lidar Buoy next to FINO1 met. mast

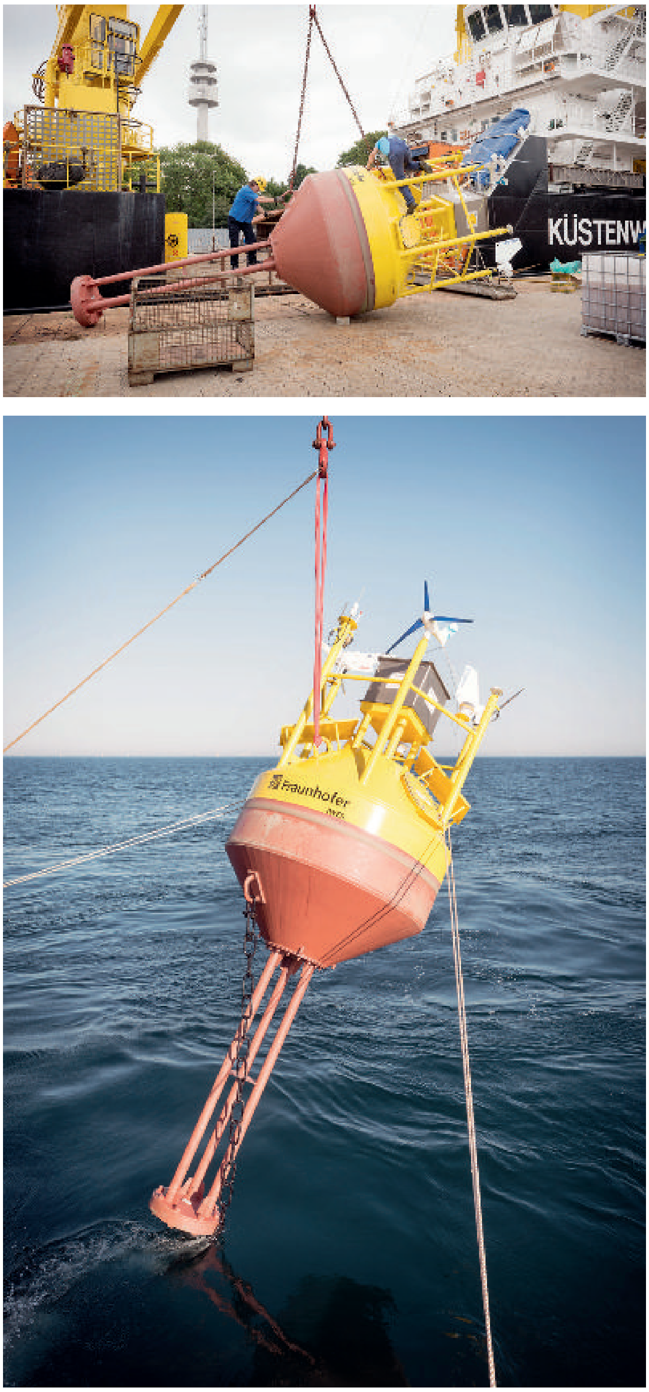


Figure 1: Fraunhofer IWES Wind Lidar Buoy before and during its first offshore trial. (Photographs: Caspar Sessler, Fraunhofer IWES))

Technical specifications of the system

The Fraunhofer IWES Wind Lidar Buoy – see figure 1 for pictures from the first offshore trial – is a floating-lidar system integrating a Windcube® v2 lidar device in an adapted marine buoy.

The basic components of the system are:

- the body of the buoy with an overall height of 7.2 m, a diameter of 2.55 m, and a weight of 4.7 t, that is designed according to the dimensions of a standard 'Leuchtfeuertonne' (LT81);
- the lidar device, measuring the wind vector for up to 12 range gates between 40 m and approximately 250 m with a data sampling rate of 0.7 s, in a custom-made housing;
- an autonomous power system based on three micro-WTs, PV panels and AGM batteries for energy storage;
- a data transfer protocol comprising a wireless connection (with a range of up to 300 m) for data transfer and a satellite connection for the transfer of selected status data and alarms;
- the integration of additional sensors as e.g. motion sensors, a weather station for measuring different meteorological parameters and a bottom-based AWAC current meter for measuring waves and currents.

The correction of the recorded lidar data, using the simultaneously measured data from a satellite compass and an AHRS (Attitude Heading Reference System), was implemented as part of the post-processing of the data.

Offshore test next to FINO1

The performance of the Fraunhofer IWES Wind Lidar Buoy was tested in a nine-weeks offshore measurement campaign in an environment that is representative for the later application – next to the research platform FINO1 located in the German North Sea about 45 km to the north of the East Frisian island Borkum. The water depth at the location is approximately 30 m. The prevailing wind direction is South-West. The direction of the sea currents is governed by the prevailing tide.

The Fraunhofer IWES Wind Lidar Buoy was installed on 2 August 2013 at the location N 54° 01.00' E 6° 34.89', i.e. north-west of the met. mast in a distance of about 450 m. The bottom-based AWAC system, recording in parallel the prevailing sea conditions, was installed during the first visit for inspection on 28 August 2013 at the location N 54° 00.99' E 6° 34.63'. Both systems were recovered according to plan on 6 October 2013.

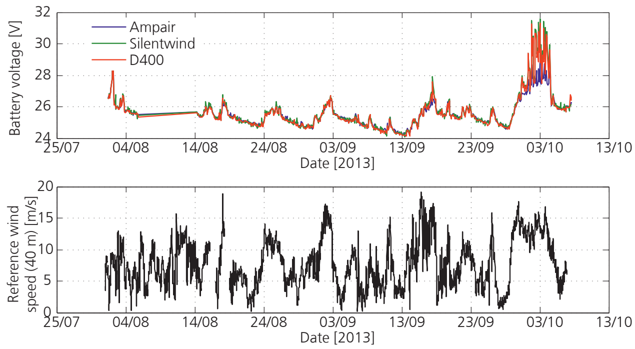


Figure 2: Transmitted status data (voltages of battery banks assigned to micro-WTs) during offshore test next to FINO1, in relation to reference wind conditions.

The status of the floating-lidar system during the offshore trial was monitored on the basis of the satellite messages that were transmitted every two hours, and included data on the amount of available stored energy (voltages from the three battery banks, one attached to each micro-WTs as essential energy generators) and a few additional signals indicating the operability of the system. Figure 2 shows the transmitted voltage data in relation to the prevailing wind conditions, reference wind speed at 40 m height measured at the FINO1 met mast. The battery voltages clearly go up and down with the changing wind speed but never reach their pre-defined minimum level, ensuring the operation of the floating-lidar system for the complete test period.

For an assessment of the accuracy and precision of the floating-lidar wind measurements, recorded 10-min-mean horizontal wind speeds were compared with the corresponding reference values from the mast, measured by cup anemometers at the same height – see figure 3 for the data measured at 100 m height. The relevant valid measurement sector had to be reduced due to significant mast effects to the wind direction range 280° to 350°, all other data were filtered out. A linear regression of the remaining data shows a very good correlation, similar to the results of an onshore lidar-mast comparison, where no additional motions affect the measurements and the distance between mast and lidar device is typically only a few meters.

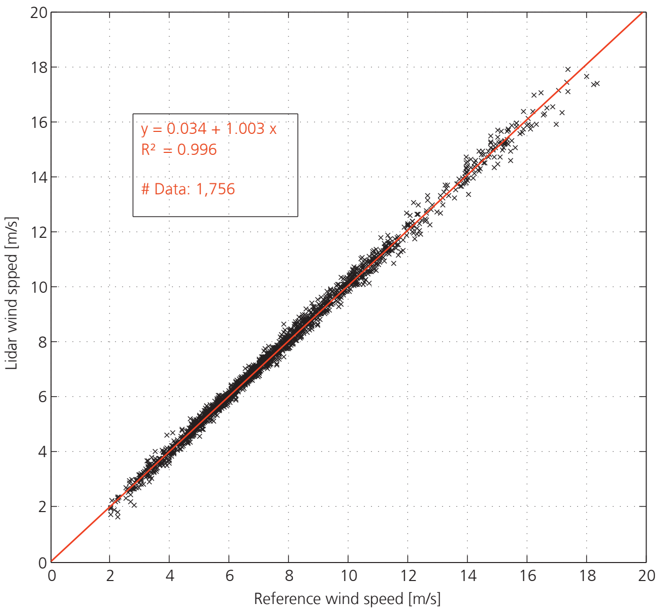
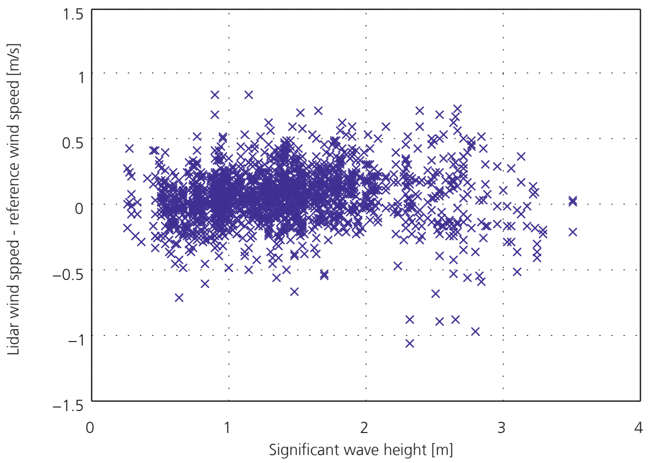


Figure 3: Correlation between measured 10-min mean wind speeds from floating-lidar device and reference cup anemometers at 100 m measurement height.



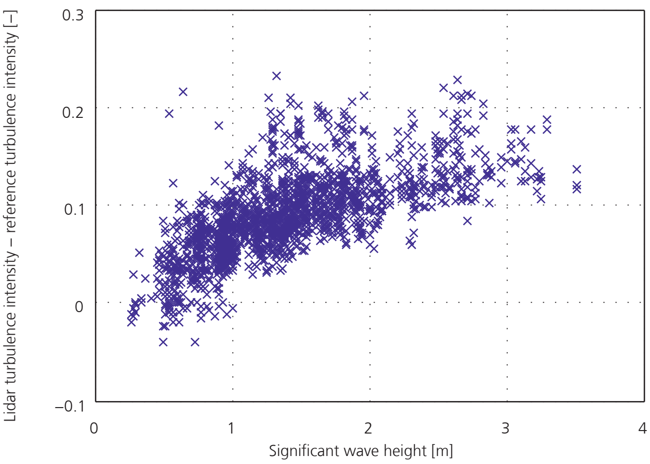


Figure 4: Deviation in measured (a) 10-min-mean wind speeds and (b) TI values from floating lidar and cup anemometer versus simultaneously recorded (30-min-mean) significant wave height – for 100 m measurement height.

In figure 4a the same data are shown, this time as a difference lidar wind speed minus reference mast wind speed, in relation to the simultaneously recorded significant wave height. Wave data were recorded as 30-min-mean data and assigned to the respective 10-min-mean wind data. The plot shows no trend or significant dependence of the measured mean wind speeds from the floating-lidar system on the prevailing wave conditions. Though significant wave heights, averaged over 30 min, of up to 3.5 m do not correspond to severe winter storms, the results definitely give a positive and promising indication.

Figure 4b shows the recorded difference in Turbulence Intensity (TI) between lidar and reference mast measurements again in relation to the prevailing significant wave heights. This time a clear trend, depicting a larger positive deviation of the lidar values from the reference for higher wave heights, is visible for the uncorrected floating-lidar data. This significant influence of the sea conditions can be compensated by applying the motion correction algorithm developed by Fraunhofer IWES. Figure 5 shows the correlation between lidar and reference TI for different stages of motion compensation, including different sets of degrees of freedom. The correction that considered the most detailed information on the motions of the system gives the best results and a correlation that is more than acceptable for a lidar-mast comparison in terms of turbulence.

Best practices for the application of floating-lidar systems

As floating-lidar systems become more and more interesting for the offshore wind industry – holding out the prospect of less expensive offshore wind measurements, more accurate and precise wind resource assessments and better yield estimations resulting in benefits with respect to the financing of offshore wind projects – there is a need for best practices and more detailed protocols for the application of the technology. In 2012, as part of the IEA Wind Task 32 on Wind Lidar Systems for Wind Energy Deployment, a working group was formed to collect experiences that are made with the technology and their application, and prepare a first version of a Recommended Practices document by the end of 2014. The working group consists of or is supported by basically all relevant players on the market for floating-lidar applications and is coordinated by Fraunhofer IWES. In parallel, the Carbon Trust together with the partners of the Offshore Wind Accelerator have developed a roadmap for the commercial acceptance of floating LIDAR technology that was for the first time published in November 2013. The two working groups are collaborating to a certain level and exchange information regularly.

Conclusions

The Fraunhofer IWES Wind Lidar Buoy is a floating-lidar system integrating a Windcube v2 pulsed lidar device in an adapted marine buoy. The concept of the system was developed within the BMU-funded R&D project 'Offshore Messboje'. A first prototype was completed in 2013 and tested in an offshore test next to the FINO1 met. mast from August to October.

The results of the nine-weeks test show a very good correlation for the recorded mean wind speeds for the floating-lidar device with the met mast data. Measured turbulence intensities are significantly influenced by the system motions, the effects can be corrected for with the motion-correction algorithm developed by Fraunhofer IWES however.

Floating- lidar is a promising technology for the offshore wind industry, with the potential of saving significant costs in the project development and planning phase, and the Fraunhofer IWES Wind Lidar Buoy was proven to be a suitable concept for this task meeting the requirements of a high data accuracy and a good system availability offshore.

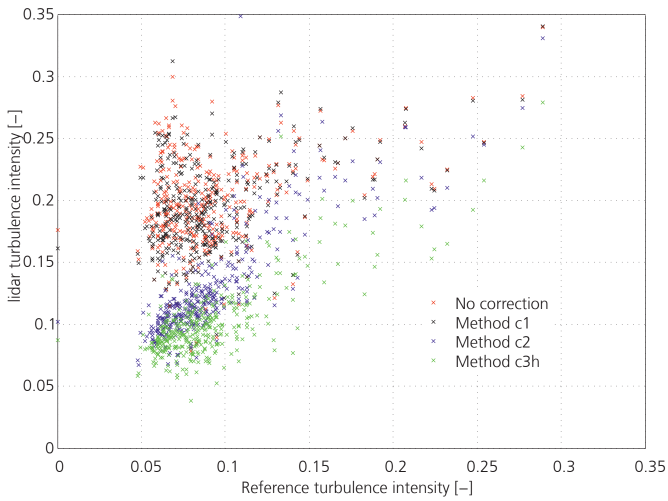


Figure 5: Correlation between measured Turbulence Intensity (TI) from floating lidar and reference cup anemometers at 100 m measurement height for different correction approaches. Method c1 only considers the recorded yaw angles for the correction of the lidar data, c2 additionally the horizontal tilt angles, i.e. roll and pitch, and c3h in additon the heave of the buoy.

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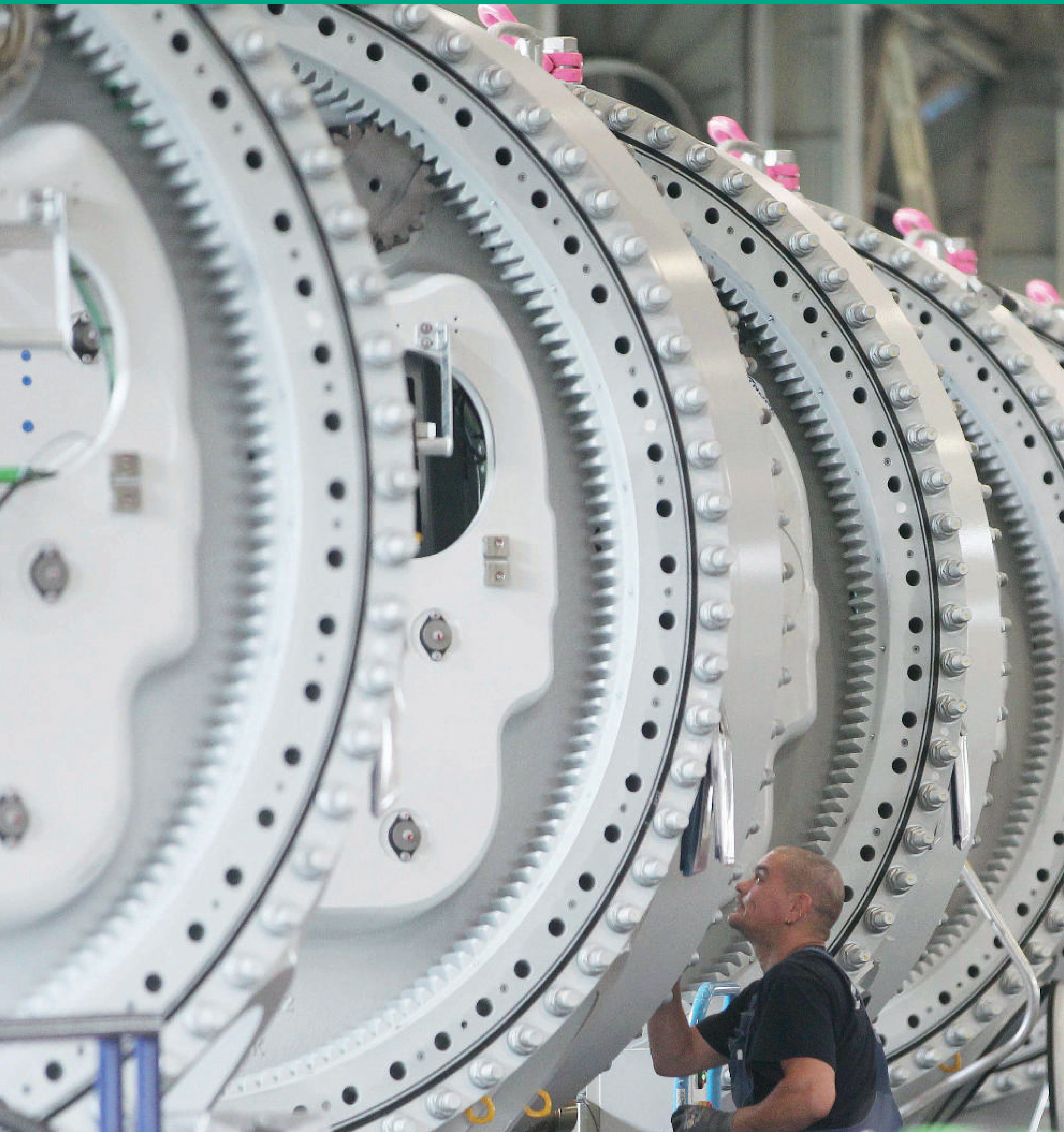

APPENDIX

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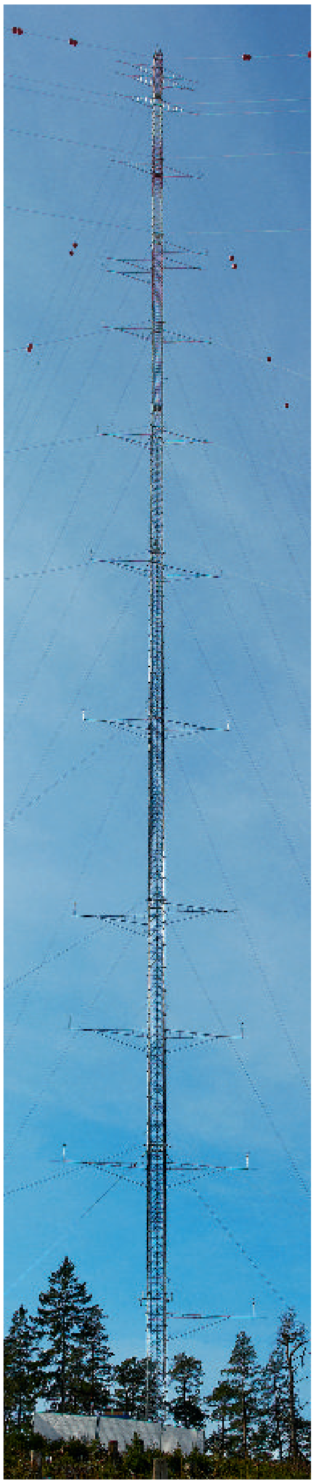

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Fraunhofer IWES. The research of the Fraunhofer Institute for Wind Energy and Energy System Technology IWES includes the entire spectrum of the wind energy and the integration of renewable energies in power structures.

The Fraunhofer IWES was founded in 2009 from the merger of the former Fraunhofer Center for Wind Energy and Maritime Engineering CWMT in Bremerhaven and the Institut für Solare Energieversorgungstechnik ISET e.V. in Kassel. The Fraunhofer IWES currently has a workforce of about 500 people.

The Fraunhofer IWES works very closely with the organized in ForWind composite universities in Hanover, Oldenburg and Bremen. Further intensive cooperation exists with the Universities of Kassel and Stuttgart.

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

Main research:
- Technology and operational management of WTs and wind farms
- Dynamics of WTs and components
- Component development for rotors, drivetrains, and foundations
- Test and evaluation methods for WTs 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 experiment facilities, laboratories and equipment facilities. The specialization extends as far, that new test facilities and procedures were developed and implemented. Together with the expertise of the scientists, the Fraunhofer IWES provides its customers and partners a forward-looking research and development infrastructure which goes far beyond the usual. The main facilities are:

- Competence center for rotor blades
- Offshore ageing sites
- Wind measurement network and 200 meter measuring mast
- Laboratory for control systems for large WTs
- 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
- Nacelle test bench

Roller test bench for electromobility at Fraunhofer IWES, © Fraunhofer IWES

Test center for rotor blades at Fraunhofer IWES, © Fraunhofer IWES

List of abbreviations and units

List of abbreviations

BSH	Bundesamt für Schifffahrt und Hydrografie (Federal Maritime and Hydrographic Agency)
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit
BMUB	Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (Federal Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safet)
BDEW	Bundesverband der Energie- und Wasserwirtschaft (German Association of Energy and Water Industries)
BGBI	Bundesgesetzblatt (Federal Law Gazette)
BMVBS	Bundesministerium für Verkehr, Bau und Stadtentwicklung (Federal Ministry of Transport, Building and Urban Development)
BMWi	Bundesministerium für Wirtschaft und Energie (Federal Ministry of Economic Affairs and Energy)
DiBT	Deutsches Institut für Bautechnik (German Institute for Building Technology)
EnWG	Energiewirtschaftsgesetz (Energy Act)
EWEA	Europäischer Windenergieverband (European Wind Energy Association)
KfW	Kreditanstalt für Wiederaufbau
PV	Photovoltaic
RE	Renewable Energy
REA	Renewable Energy Act
StrEG	Stromeinspeisungsgesetz (Electricity Feed-In From Renewables Act)
TSO	Transmission grid operators
UK	United Kingdom
WT	Wind turbine
WMEP	Wissenschaftliches Mess- und Evaluierungsprogramm (Scientific Measurement and Evaluation Program)

List of units

kW	Kilowatt
kWh	Kilowatt hour
MW	Megawatt
MWh	Megawatt hour
GW	Gigawatt
GWh	Gigawatt hour
TW	Terawatt
TWh	Terawatt hour
m	Meter
km	Kilometer
ct	Cent (Euro-Cent)

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