FACHAGENTUR
WINDENERGIE AN LAND

SHORT ANALYSIS

Overview
Onshore Wind Energy

Plant Height | Area Requirements | Number of Turbines

Heights of wind turbines in the field of tension between space requirement and number of turbines

The German government has set itself the target of covering 65% of electricity consumption with renewable energies (RE) by 2030.[1] This requires an additional 150 terawatt hours (TWh) of electricity in addition to the »green electricity« already generated today.[2] According to Grid Development Plan Power 2030 (version 2019), scenario B, around 84 TWh are to be provided onshore through wind energy use.[3] The German Onshore Wind Energy Agency (Fachagentur Windenergie an Land - FA Wind) subsequently explains how the construction height of future wind turbine generators (WTG) can affect this objective.

The calculations based on model wind farms (see appendix) show that around 7,000 new wind turbine generators of the 4 megawatt (MW) class will be required by 2030 to generate the additional 84 TWh of wind power if they are erected with overall heights (OAH) of up to 230 metres (m). If the overall height of wind turbine generators were to be limited to 200 m in future, between 8,000 plants (4 MW class) and 11,000 plants (3 MW class) would be required. A height limit of 180 m would require almost 12,000 new turbines of the 3 MW class. Should wind turbine generators in future be subject to a height limit of 150 m, this would not only limit the range of products on offer, since a large proportion of today's WTG in this dimension are no longer offered at all. In addition, almost twice as many new turbines would be required (13,500 wind turbines, 3 MW class) as current turbines without height restrictions.

The following figure1 illustrates that if the height of WTG were limited, the additional generation capacity to be installed would also have to increase significantly in order to generate the forecast additional electricity quantity of 84 TWh in 2030.[4]

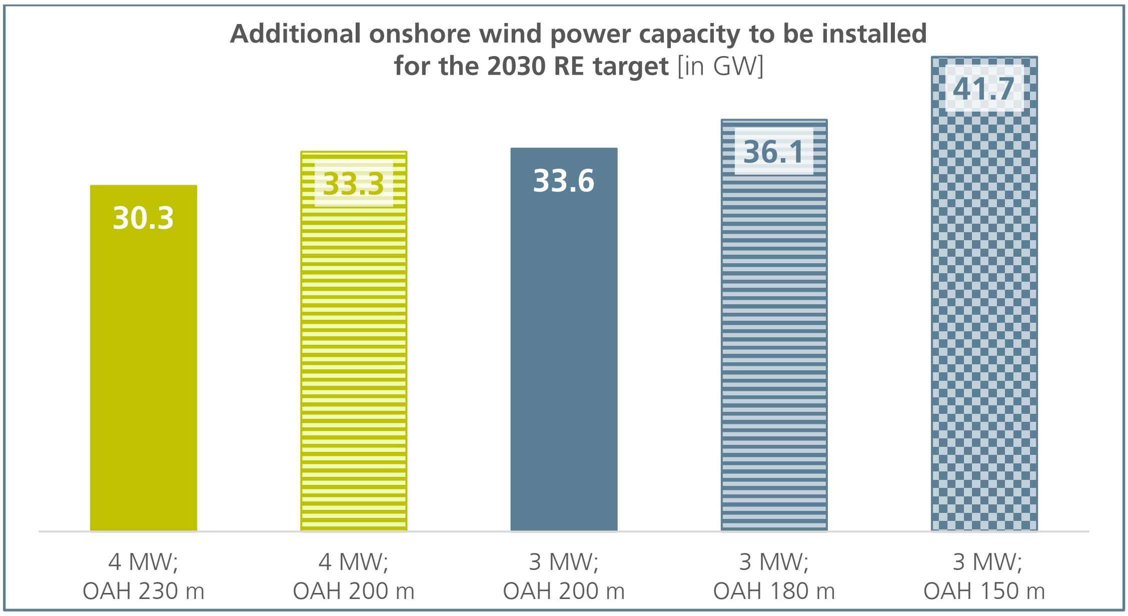

Figure 1: Net onshore wind power to be installed by 2030 in order to achieve the required amount of wind power for the renewable energy share of 65% of gross electricity consumption; graph: FA Wind

In order to achieve the 65% target by 2030, it is not only the number of WTG and the electrical power to be installed that would have to increase significantly due to a comprehensive construction height limitation. The area required for wind farms would also increase considerably. With a maximum (overall) height of 150 m, this would require 18% more space. The additional requirement would be around 300 square kilometres - which is roughly equivalent to the area of Bremen. Figure 2 shows the additional space needed as a percentage depending on the type of WTG used. The area requirement of a

[1] Coalition agreement between CDU, CSU and SPD for the 19th legislative period, p. 71.
[2] 2018 228 TWh of electricity was generated in renewable energy plants. Gross electricity consumption is forecast at 582 TWh for 2030 in the first draft of the Grid Development Plan Power. A share of 65% corresponds to 379 TWh. Less the »green electricity« already generated today, there is an additional amount of electricity to be generated from renewable energies of around 150 TWh.
[3] The first draft of the Grid Development Plan Power 2030 (version 2019) forecasts 173.8 TWh of onshore wind power for the year 2030. 90 TWh per year were generated on average in 2017 and 2018, from which an additional quantity of 84 TWh to be generated is derived.
[4] The wind energy yield is significantly influenced by the swept rotor area of the turbine, the ratio of rotor area to installed power and the airflow, which increases and stabilises with increasing height above ground level.

model wind farm in the 4 MW power class with turbines of 230 m height corresponds almost to the area required for a category 3 MW model wind farm with turbines of a total height of 200 m, but requires around 3,500 more turbines to generate the same amount of electricity.

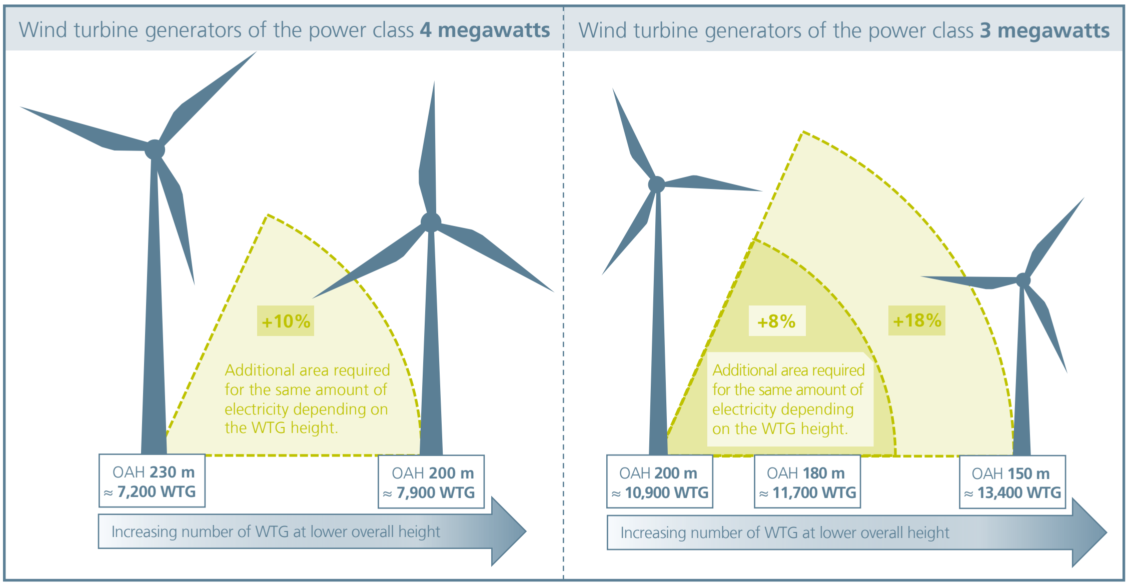

Figure 2: Increase in area and WTG requirements as a function of the overall height and power class of WTG to generate the additional electricity required by 2030; graph: FA Wind

The calculations of the needed WTG were modelled according to the assumptions made in the appendix on the basis of the electricity demand according to the first draft of the 2030 Grid Development Plan.[5] It was not taken into account that in individual regions the electricity supply potential of the wind turbines cannot be fully exploited, at least temporarily, due to a lack of sufficient grid capacities. In these cases, the need for new installations to cover the electricity volumes would still increase until 2030.

According to the core energy market data register (Marktstammdatenregister) 6,600 wind turbine generators were installed nationwide between August 2014 and December 2018.[6] 1,800 of the turbines (28%) have total heights of up to 150 m; three quarters of these were erected in northern Germany (MV, NI, SH). In the southern federal states (BW, BY, HE, RP, SL) only 27 of 1,700 wind turbines (1.6%) with an overall height of up to 150 m were erected. In particular, the so-called light-wind turbines suitable for southern Germany have larger rotor diameters and thus larger overall heights.[7] These would therefore be particularly affected by the negative effects of a general limitation of WTG construction height.

As a result, a »flat-rate« height limitation would lead to a significant increase in the nationwide area requirement, the number of WTG and the capacity to be installed in order to provide the additional wind power required to achieve the 65% renewable energy target in 2030. In addition, according to WindGuard[8] calculations, turbines with larger overall heights generally have lower electricity generation costs. This is likely to intensify in the case of the latest generation of WTG, which have been further optimised in terms of electricity generation costs due to cost pressure within the tendering system introduced by the RES Act 2017. In addition, a blanket limit on height could jeopardize the development of technology on the German lead market and put it at a competitive disadvantage in an international context.[9]

A planning limitation of wind turbine heights, in particular by determining the degree of structural use within the framework of urban land-use planning, is in principle possible if the protection of sufficiently important legal interests justifies this.

[5] Approval of the scenario framework 2019 - 2030 for the Grid Development Plan Power 2030 of 16th June 2018.
[6] BNetzA, publication of EEG register data (period 08/2014 to 01/2019) of 28th February 2019.
[7] According to WindGuard availability of turbines with a low specific area output below 150 m overall height is severely limited, »since maximized rotor diameters are usually accompanied by increasing hub heights«.
[8] Cf. WindGuard, Economy of different hub heights of WTG, June 2017.
[9] Cf. to this: VDMA, Achieving Acceptance and Efficiency of the Energy Turnaround with Wind Energy in Germany, Position Paper, March 2019, p. 7.

Appendix: Procedure for calculating the needed area for onshore wind energy use in 2030

In the following, the assumptions and calculations made by FA Wind to determine the area required for wind energy use in 2030 are outlined. At the first, the required quantities of electricity to be generated onshore by wind turbine generators in the year 2030 are determined. Subsequently, the area required and the number of wind turbines for generating these electricity quantities are determined on the basis of a model wind farm design.

1. Assumptions on the electricity supply situation in 2030

This analysis is based on the scenario framework 2019-2030 for the Grid Development Plan Power 2030 approved by the Federal Grid Agency (Bundesnetzagentur – BNetzA) in June 2018 and the first draft of the Grid Development Plan Power 2030 (version 2019).

The scenario framework uses various scenarios to describe the probable development of electricity generation capacities and consumption in the target years 2030 and 2035. The scenarios differ in terms of the dimensions of the sector coupling and the design of the electricity generation structures and also take into account the energy policy objectives agreed in the coalition agreement of the current federal government.

The forecast values for the level of gross electricity consumption for the year 2030 in the scenarios range from 556.8 terawatt hours (TWh) in scenario A 2030 to 616.7 TWh (scenario C 2030).[10] For this analysis, the value of 582.7 TWh according to scenario B 2030 is used. Scenario B is generally regarded as the development path with the greatest probability of occurrence.

In the first draft of the Grid Development Plan Power 2030 (version 2019) a target value of 173.8 TWh onshore wind power is set for scenario B 2030. Based on the forecast gross electricity consumption in 2030, this corresponds to a share of 29.8 percent.[11] A comparable result can be achieved by extrapolating the average development of the annual onshore wind power volume from the energy turnaround year 2011 to the year 2030. The calculations are based on a share of 30 percent of gross electricity consumption in 2030 (582.7 TWh). Deducting the wind power quantities already generated today (the average for 2017 and 2018 was 91 TWh), there is a difference of 84 TWh, which must be generated by the additional wind turbine generators to be realised by 2030. It is assumed that the existing facilities currently connected to the grid will still be fully available in 2030. The required net addition is therefore determined. Should there be considerable plant shutdowns by then, e.g. as a result of the phasing-out of funding provided by the RES Act, the demand for additional wind turbines to be built would continue to rise.

Calculations of the electricity yields of the various types of plants are based on published reference yield values (Referenzertragswerte in accordance with Annex 2 RES Act 2017).[12] Where no reference yield values are published for individual WTG types, these were directly inquired of the manufacturers. For the assumption, which average site quality should be used as a basis for the model wind farms, findings from WindGuard were used.[13] According to their calculations, a quarter of all wind turbine sites had a site quality of 70 percent in 2013. On a cumulative basis, more than half of the plant locations at the time achieved a site quality of up to 70 percent. A quality factor of 70 percent is therefore assumed for the electricity quantity calculations of the model wind farms.

2. Assumptions for the calculation of area requirements

The required area was determined on the basis of model wind farms in two power classes (3 and 4 MW respectively), whereby the wind farms each consist of five turbines of one model type. A model type corresponds to an average of comparable plant types.

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[10] Approval of the scenario framework 2019 - 2030, p. 150, table 38.
[11] Grid Development Plan Power 2030 (version 2019), first draft, p. 94 (figure 36).
[12] Cf. FGW, publication of reference yield values according to new reference site yield (RES Act 2017 - Annex 2).
[13] Cf. WindGuard, Cost Situation of Onshore Wind Energy – Update, figure 10, December 2015.

The model type was formed on the basis of comparable characteristics such as hub height, rotor diameter and rated power. In addition, only one type per manufacturer should be included in the selection in order to take into account the widest possible range of models. The choice of model for the B model wind farm takes into account the models in the 3.0 to 3.3 MW output range that have been frequently implemented in Germany in recent years.[14] The turbine assembly in model wind farm A includes wind turbines of the new generation in the power class 4.1 to 4.5 MW with rotor diameters up to 150 m. Both model wind farms are each considered with two different overall heights. An additional consideration was made for systems with up to 150 m total height. However, since not all types in model wind farm B are offered in this dimension, a variation »Wind farm B.1« was required, in which a turbine type was changed. Table 1 shows the types of turbines considered in the model wind farms and their characteristic values.

Table 1: Types of wind turbines of model wind farms with two power classes

Model wind farm A (4 MW class)			**Model wind farm B** (3 MW class)			**Model wind farm B.1** (3 MW class; OAH ≤ 150 m)		
WTG type	**power**	**height**	**WTG type**	**power**	**height**	**WTG type**	**power**	**height**
Enercon E-138	4.2 MW	200 m/ 230 m	Enercon E-115	3.0 MW	180 m/ 200 m	Enercon E-115	3.0 MW	150 m
Nordex N149	4.5 MW	200 m/ 230 m	Nordex N117	3.0 MW	180 m/ 200 m	Nordex N117	3.0 MW	150 m
Senvion 4.2M148	4.2 MW	200 m/ 230 m	Senvion 3.2M114	3.2 MW	180 m/ 200 m	Senvion 3.2M114	3.2 MW	150 m
Siemens DD-142	4.1 MW	200 m/ 230 m	Siemens 3.0-113	3.0 MW	180 m/ 200 m	Siemens 3.0-113	3.0 MW	150 m
Vestas V150-4.2	4.2 MW	200 m/ 230 m	Vestas V126-3.3	3.3 MW	180 m/ 200 m	Vestas V112-3.3	3.3 MW	150 m

In order to be able to determine the area required for the net construction of the wind turbines to achieve the 65% target in 2030, assumptions had to be made about the average size of the wind farm. According to a market analysis by the Leipziger Institute for Energy (IE Leipzig), more than half (53%) of the wind farms operated in Germany in 2014 comprised up to five turbines.[15] On this basis, the model wind farms were each based on five turbines for the calculations of the space requirement. As recommended to avoid turbulence influences, a distance of 5 times the rotor diameter in the main wind direction and 3 times the rotor diameter in the secondary wind direction is maintained between the wind turbines. The area required for the energy generation of a model wind farm is measured, in simplified terms, from the area inside the external wind turbines. This is based on the tower of the turbine; the rotor protrudes beyond the required area. Area requirements that arise for other reasons are not taken into account in the model calculation of net areas. Figure 3 shows the schematic area load, whereby the net area requirement is shown in green.

[14] Frequently realised WTG types from 08/2014 to 12/2018 in Germany: Enercon E-115 (863 WTG); Vestas V112 (736 WTG), V126 (434 WTG); Nordex N117 (636 WTG); Senvion 3.2M114 (292 WTG) and Siemens SWT 3.0-113 (83 WTG).
[15] Cf. IE Leipzig, Market Analysis – Onshore Wind Energy, February 2015, p. 24.

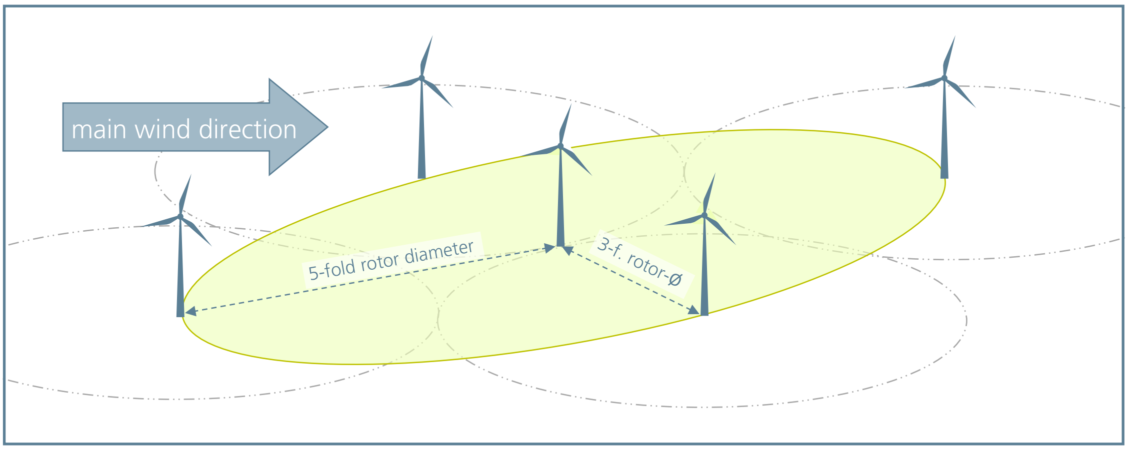

Figure 3: Arrangement of WTG within a model wind farm and area taken into account; graph: FA Wind

The following steps are used to calculate the area required for the necessary new wind turbine generators expansion up to 2030:

1. Area requirement of an individual WTG type in the model wind farm:

   $A_{WTG} = \pi * 5d * 3d$ (A = surface; d = rotor diameter of the WTG)

2. Average area requirement of the five WTG within the model wind farm:

$$A_{WTG_{\bar{x}}} = \frac{A_{WTG_1} + A_{WTG_2} + A_{WTG_3} + A_{WTG_4} + A_{WTG_5}}{5}$$

3. Need for new WTG for additional wind power quantity until 2030 (30% of gross power consumption):

   $n_{WTG} = \frac{E_{WTG\_expansion\_2030}}{E_{WTG_{\bar{x}}} * 0.7}$ (Required additional wind power quantity 2030 ÷ reference yield value of a WTG in the model wind farm with 70% site quality)

4. Calculation of the net area requirement for the required new WTG installations by 2030:

   $A_{expansion\_2030} = n_{WTG} * A_{WTG_{\bar{x}}}$ (New WTG requirements * average area requirements of an individual WTG)

Further information (in German):

FA Wind: Overview of the distance recommendations in the federal states for the designation of wind energy areas, February 2019

FA Wind: Legal evaluation of the height limitation of wind turbines against the background of the invitation to tender, May 2018

WindGuard: Economic efficiency of different hub heights of wind turbine generators, prepared in the context of preparation and support of the preparation of a field report according to § 97 RES Act 2014, on behalf of the Federal Ministry of Economics and Energy, June 2017

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