Onshore Wind Energy Potential in Germany

Current study by the Federal Environment Agency on the nationwide area and output potential

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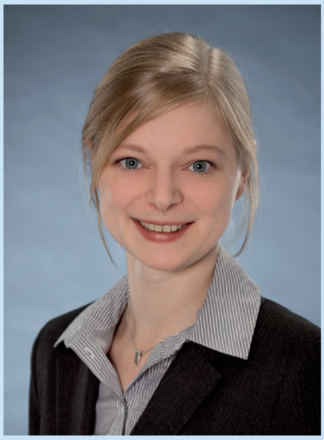

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Summary

A GIS-based study carried out by the German Federal Environment Agency (Umweltbundesamt, UBA) [1] has concluded that in principle, on the basis of the assumptions made and the chosen turbine technology around 13.8 % of the country's territory could be used for wind energy harnessing. This area potential would allow the installation of turbines with a total capacity of around 1,200 GW and an annual power output of around 2,900 TWh. However, within the scope of the study, certain considerations requiring case-by-case analysis could not be reflected in a sensible way. The technical-ecological potential of the onshore generation of wind energy, which must above all also take aspects of special protected species conservation into account, is therefore considerably lower. Even lower is the actually realisable potential, due to additional impact factors such as economic framework conditions or local acceptance levels. Nevertheless, it becomes clear that onshore wind energy generation confirms its key role in the renewable energies portfolio. There are sufficient sites which, in combination with state-of-the-art turbines, promise even power feed-in through maximum capacity utilisation. Considered at a national level, the determined potential also allows the conclusion that initially, the development of sites that are as little conflict-provoking and as cost-efficient as possible could be considered for a future expansion of onshore wind energy production. To what extent the existing potential can ultimately be exploited is a matter of social and political decisions, and also spatial planning considerations at various levels.

Introduction

Germany aims to increase the share of renewable energies in the country's energy supply to at least 35 % by 2020. The harnessing of wind power plays a decisive role here. It already makes a considerable contribution to the energy supply in Germany today. Of all the renewable energies, wind power harnessing has the highest potential for cost-efficient expansion in the short and medium term.

In 2010, the UBA released a study [2] in which the power supply system of Germany based on 100 % renewable energies was modeled. For onshore wind energy, an installed capacity of 60 GW and an annual power output of 180 TWh was defined by approximation as a lower limit of the technical-ecological potential. In order to get a clearer picture of the importance of the role wind energy can play in facilitating Germany's energy shift, the UBA has now deter-

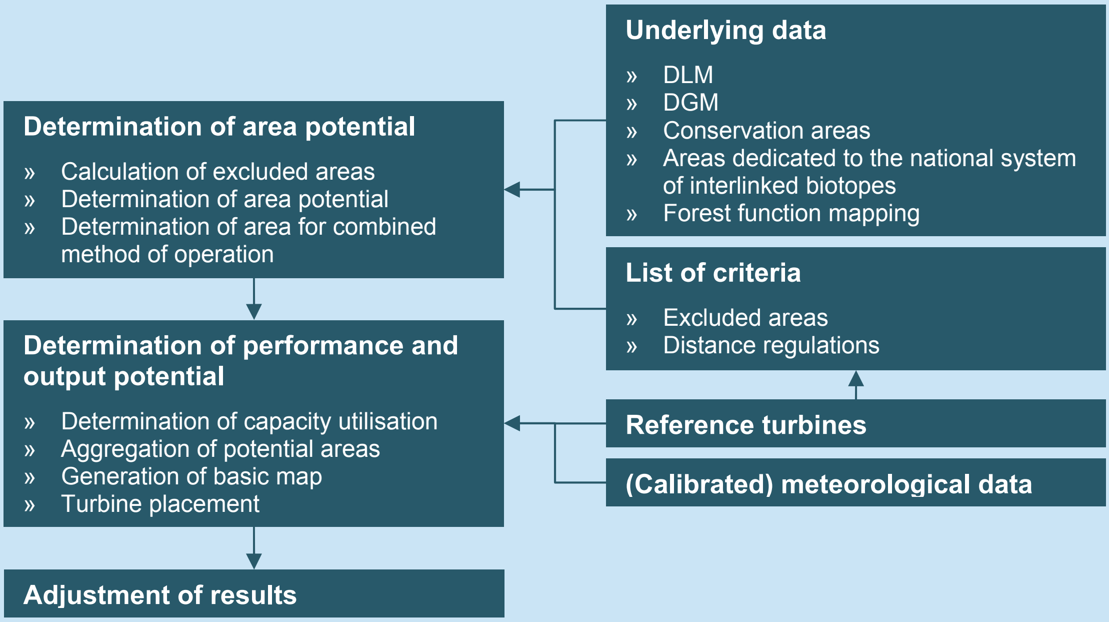

Fig. 1 Methodological approach

mined the country's area potential for onshore wind harnessing, and the respective capacity potential more precisely, by way of a study. The modelling and calculations, which were carried out by the Fraunhofer Institute for Wind Energy and Energy System Technology (IWES), were based on state-of-the-art turbine technology and the most detailed digital national geodata available.

Independent of commercial considerations and already existing wind farms, the aim of the study was to show the total potential for wind power harnessing in Germany available once technical and ecological aspects are taken into account. However, certain considerations requiring case-by-case analysis (above all the protection of species but also, for example, radar installations) could not be reflected within the scope of the study in a sensible way. The technical-ecological potential of the onshore generation of wind energy, which must above all also take aspects of special protected species conservation into account, is therefore considerably lower than the potential determined within the scope of the study. Furthermore, any interpretation of the results should take into account that these are determined by the quality of the data used as the basis and the assumptions made to a considerable degree. For example, the reference turbines selected are an important factor, as their hub heights, rotor diameters and rated capacity have direct influence on power output and capacity utilisation. The low noise emissions of the turbines chosen also have a direct effect on the distance which must be kept to housing prescribed in the *Technische Anleitung zum Schutz gegen Lärm (TA Lärm)*, the German law regulating permissible noise pollution levels, and therefore also on the determined area potential.

Research Strategy

The national potential for onshore wind power harnessing was determined in two main stages: The first stage involved the determination of the area potential with the aid of geodata that was as detailed as possible by defining non-usable open country and forested areas and excluding these from the calculation. The second stage involved the determination of the capacity and output potential on the basis of state-of-the-art reference turbines and meteorological data (cf. Fig. 1).

Using the basic digital landscape model (Basic DLM) meant that the most detailed digital data on national area usage available was used to determine the area potential. This allowed the inclusion of splinter settlements and individual buildings located outside settlements. In addition, data records on conservation areas and areas dedicated to the national system of interlinked biotopes as well as the federal states' forest function maps were taken into account. All types of area usage were defined as either allowing wind power harnessing or not. As far as the areas that do allow the generation of wind energy were concerned, any additional prescribed distances were also taken into account. In addition, areas that are too steeply inclined were excluded on the basis of the digital terrain model (DGM 25). The assumptions made with regard to areas to be excluded and distances for protection reasons are shown in Tab. 1.

The requisite distances to housing were calculated on the basis of the emission limits defined in the *TA Lärm*, and the emissions of the reference turbines chosen. By way of example, two different turbine configurations were considered. The resultant minimum distances were subsequently applied across the board, although independent of the configuration of the turbines installed. The resultant distances to housing were comparatively short as low noise emission levels had been a reference turbine selection criterion, and the assumptions had been based on lower noise emission levels during night-time operation. For example, in low-noise mode of operation, the reference turbines already comply with the night-time emission limit of

	Exclusion	Distance from foundations in m
Settlements		
Industrial and commercially used areas	Yes	at least 250
Residential areas	Yes	at least 600
Health resorts	Yes	at least 900
Infrastructure		
National motorways	Yes	100
Other roads	Yes	80
Rail traffic	Yes	250
Funiculars	Yes	300
Airports	Yes	approx. 5000 +/- 50 to 100*
Airfields	Yes	1760
Overhead power lines	Yes	120
Ecologically sensitive areas		
National parks	Yes	200
Nature conservation areas	Yes	200
Special protection areas (EU birds directive)	Yes	200
Special areas of conservation (EU habitats directive)	Yes	-
Special areas of conservation dedicated to bat protection	Yes	200
Ramsar sites (Wetland as defined by the Ramsar Convention)	Yes	-
Biosphere reserves (core area and buffer zone)	Yes	-
Biosphere reserves (transition zone)	-	-
Landscape protection area	at least 75 %**	-
Protected landscape elements	Yes	-
Nature parks	-	-
Areas dedicated to the national system of interlinked biotopes	Yes	-
Forests		
Forests in federal states with less than 15% forest coverage	Yes	-
Soil protection forests	Yes	-
Forest planted for visual impact reduction purposes	Yes	-
Climate protection forests (local and regional)	-	-
Recreational forests (category I and II)	at least 75 %**	-
Forests planted for emissions pollution reduction purposes	-	-
Forests planted for noise pollution reduction purposes	-	-
Bodies of Water		
Watercourse, river, stream (1st order); canal (navigable)	Yes	65
Watercourse, river, stream (2nd and 3rd order)	Yes	5
Canal (water management)	Yes	-
Lake	Yes	5
Other		
Incline	> 30°	-

* Dependent on length of runway
** max. 25% of a landscape protection area or a recreational forest per federal state are taken into account as a potential area

Tab. 1: Summary of the excluded areas and protective distances taken into account in the course of potential determination

	Area potential		Capacity potential	Output potential	Mean full load hours
	[km²]	Share	[GW]	[TWh]	[h/a]
North Berlin, Brandenburg, Bremen, Hamburg, Mecklenburg-Western Pomerania, Lower Saxony, Saxony-Anhalt, Schleswig-Holstein (= 38.9 % of German territory)	22,851	16.4 %	526	1,378	2,621
Central Hesse, North Rhine-Westphalia, Rhineland-Palatinate, Saxony, Thuringia (= 30.7 % of German territory)	11,200	10.2 %	287	728	2,540
South Baden-Württemberg, Bavaria, Saarland (= 30.4 % of German territory)	15,310	14.1 %	375	791	2,108
Germany overall	**49,361**	**13.8 %**	**1,188**	**2,898**	**2,440**

Tab. 2: Wind energy potential for Germany determined by the UBA study

Minimum capacity utilisation of turbine designed for weak winds		None	1.600 h/a	2.200 h/a	2.800 h/a
Installable capacity [GW]	North	526	526	524	338
	Central	287	286	254	100
	South	375	349	148	9
	Germany overall	1,188	1,162	930	450
Potential output [TWh]	North	1,378	1,378	1,375	889
	Central	728	728	662	270
	South	791	755	363	27
	Germany overall	2,898	2,862	2,407	1,191

Tab. 3: Impact of assumption of a minimum capacity utilisation of turbines designed for weak winds on the capacity and output potential (Illustrated is the overall output of strong and weak wind turbines; however, the criterion of minimum capacity utilisation was only applied to sites with weak wind turbines as adequate wind conditions were assumed for sites with turbines designed for strong winds.)

Distance to residential areas	600 m	800 m	1,000 m	1,200 m	2,000 m
Area potential	13.8 %	9.1 %	5.6 %	3.4 %	0.4 %
Proportion of determined area potential	100 %	66.3 %	40.9 %	24.8 %	2.8 %

Tab. 4: Influence of distance to residential buildings on the area potential

40 dB(A) currently applicable in areas with housing [1] if they are separated from this housing by a distance of as little as 600 metres. Corresponding buffer zones were applied to all types of usage that require night-time turbine operation in low-noise modus due to noise pollution concerns.

Superimposition of all excluded areas and separation zones then revealed the nationwide area potential. This includes areas where night-time operation in low-noise modus must be envisaged for reasons of noise pollution prevention. On the basis of the area potential, the nationwide wind harnessing capacity and output potential was subsequently determined with the aid of the reference turbines and the meteorological data.

In order to assume the development of potential sites whose development would make sense within the scope of the current framework conditions, the modelling was based on two different reference turbines. As of a mean wind speed of 7.5 m/s at a height of 140 m, a turbine

[1] In view of the requisite distances to housing, simplification measures had to be taken as the Basics-DLM does not differentiate between the various types of building usage as detailed as the *TA Lärm* does. A night-time emission limit of 40 dB(A) was therefore assumed for all areas near housing, even though the *TA Lärm* prescribes varying limits of, for example, 35 dB(A) for purely residential areas, 40 dB(A) for general residential areas and 45 dB(A) for village areas.

designed for strong winds, with a hub height of 100 m, a rotor diameter of 104 m and a rated capacity of 3.4 MW, was used as the basis for the assumptions. Where there were lower wind speeds, a turbine with a hub height of 140 m, a rotor diameter of 114 m and a rated capacity of 3.2 MW was assumed.
The output calculations were based on the German National Meteorological Service's COSMO-DE model[2] analysis data, which was calibrated in a separate research project with long-term reanalysis data from the "ERA interim" project carried out by the European Centre for Medium-Range Weather Forecasts (ECMWF). This allowed a combination of the advantages of both weather models – high level of accuracy in the illustration of wind speeds at high altitudes on the one hand as well as illustration of climate variability through long-term data record series on the other.
For the capacity and output potential model, the first step was to produce a grid map with the potentially achievable full load hours for each grid point. This grid map then served as the decision-making basis for optimum-output placement of the reference turbines. On each potential area, the grid point with the highest number of full load hours was used first. After that, all grid points within the requisite minimum distance between turbines were excluded. For simplification purposes, a radial minimum distance of four times the rotor diameter was assumed for this. These steps were repeated until the area was completely covered. The capacity and output potential was calculated from the information about installed capacity and potential output for the turbines when placed at this particular grid point. And finally, the determined output was reduced by 10 % to account for aerodynamic losses, plus another 3 % for wind turbine non-availability.

Findings

On the basis of the assumptions made and the turbine type selected, the UBA study concludes that 49,361 km², or 13.8 % of the country's territory, are in principle suitable for wind energy use (cf. Tab. 2). This area potential would allow the installation of turbines with a total capacity of 1,188 GW and an annual power output of around 2,898 TWh.
As expected, the biggest potential is in the northern German federal states, although a major potential was also calculated for the central and southern parts of Germany. In contrast, significant differences were noted in the median full load hours of the reference turbines as placed, with a national average amounting to 2,440 full load hours. Whilst with 2,621 and 2,540 full load hours respectively, the average capacity of wind energy plants in northern and central Germany is above average, only 2,108 full load hours are achieved in the south. However, this is still considerably higher than the median capacity utilisation of 1,700 full load hours over the past five years in Germany.

[2] In contrast to the micro-scale models used at federal state level for potential determination, this meteorological data has a comparatively rough horizontal resolution of 2.8 km. It can therefore illustrate local wind conditions, especially in mountainous regions, only to a limited extent. However, the level of data accuracy is adequate for nationwide potential determination.

Two sensitivity analyses were carried out to be able to assess the study results better. One focused on assessing the level of impact the assumption of a certain minimum capacity utilisation of wind energy plants has on the capacity and output potential. It only took sites where low wind systems were positioned into account, as it was assumed that wind conditions would be adequate on sites where turbines designed for strong winds had been positioned. The outcome was that at a minimum capacity utilization of 1,600 full load hours for weak wind turbines, only a very marginal proportion of sites is excluded (cf. Tab. 3). At a minimum capacity utilisation of 2,200 full load hours, on the other hand, a significant proportion of the potential is already no longer present. Once at least 2,800 full load hours are assumed, the majority of sites across all federal states are excluded. There are then hardly any usable sites left in the southern federal states.

The second sensitivity analysis carried out looked at the impact of the distance to housing on the area potential. This was done because settlement areas and the requisite protective distances have the biggest influence on area potential. It showed that even a 200 m increase of the minimum distance to residential areas to a total of 800 m decreases the area potential by a third (cf. Tab. 4).

Doubling the distance to 1,200 m reduces the determined area potential by 75 %. At a distance of 2,000 m, all that remains is 0.4 % of Germany's territory. It must also be taken into account that the study does not reflect any considerations that would require case-by-case decisions in the event of practical application, and that the realisable potential must be assumed to be considerably lower.

Classification of results and conclusions

A high potential for onshore wind energy harvesting was determined within the scope of the UBA study. Any interpretation of the results must therefore consider the fact that the technical-ecological potential is considerably lower than the determined potential, because various considerations that would require case-by-case decisions in the event of practical application (above all the protection of certain species but also, for instance, radar installations) could not be taken into account in the potential determination. The technical-ecological potential cannot be determined with the currently available nationwide GIS data, and in view of a respectively necessary case-by-case analysis.

It was also not this study's objective to determine a realisable onshore wind harvesting potential. Important impact factors which were not taken into account but can in practice hinder the realisation of wind energy projects are, for example, the economic framework conditions in individual cases, or the acceptance level amongst the local population. The realisable potential is therefore only a small proportion of the determined potential.

Furthermore, the results of the potential study also depend to a great degree on the assumptions made. For example, the high area and capacity potential is very much also a result of the wind energy generation system technology selected. Due to high hub heights and large rotor diameters, this technology also allows the development of inland sites as well as, due to low noise emissions, compliance with the requirements for the prevention of noise pollution near housing. If, for instance, longer distances were planned for acceptance reasons, this would also result in a respectively lower potential.

However, the results of the study clearly show that onshore wind energy harvesting confirms its key role in the renewable energies portfolio. Should electricity consumption increase in future, for example as a result of use in the heating sector or an increase in electric vehicles, this could be compensated. There are sufficient sites which, in combination with state-of-the-art wind turbines, promise even power feed-in through maximum capacity utilisation.

It can also be generally stated that considerations at a national level show that there are sufficient areas available so that the development of sites that are as little conflict-provoking and as cost-efficient as possible should be considered first of all for a future expansion of onshore wind energy production. Regardless of the study results, substantial space for wind energy can possibly only be created in individual planning spaces if the criteria for the designation as a wind harvesting area are adapted accordingly.

To what extent the existing onshore wind energy potential can ultimately be exploited is a matter of social and political decisions, and also spatial planning considerations at various levels.

References

[1] Please follow this link to download the study: www.umweltbundesamt.de/uba-info-medien/4467.html An English version, which will also be published on the UBA homepage, is currently in preparation.

[2] Klaus, T.; Vollmer, C.; Werner, K.; Lehmann, H.; Müschen, K.: Energieziel 2050: 100 % Strom aus erneuerbaren Quellen. Dessau-Roßlau 2010. Please follow this link to download the study: http://www.umweltbundesamt.de/uba-info-medien/3997.html

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