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Hidden outlaws in the forest? A legal and spatial analysis of onshore wind energy in Germany

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Abstract

Onshore wind power has become one of the most important technologies for renewable electricity production throughout the world, with Germany being one of the global leaders. More than 27,000 wind turbines are currently spinning across Germany. Given the government's ambitious renewable energy targets, their numbers will continue to rise rapidly. It has now become technically and economically feasible to install wind turbines in forested areas. Our interdisciplinary analysis combines legal knowledge with spatial land use and wind power data to analyse the past development of wind farms in German forests and check whether the existing planning instruments successfully steer their spatial distribution. Our results reveal that, since 2011, a growing number of wind turbines are being installed in forests, even if they only account for 5.5% of the total number (8% of the total installed wind power capacity) and are almost exclusively limited to six of the 16 federal states. As there are no nationwide, uniform regulations governing wind turbines in forested areas, the federal states developed their own specific regulations. While some, especially those with high forest shares, generally permit wind farms in forests for reaching their renewable energy targets, others aim to keep their forests clear. So far, planning law and regional planning could successfully steer the hitherto comparatively slow expansion of wind energy in forest areas and ensure that windmills in forests are by no means "outlaws".

1 Introduction

Onshore wind power has become one of the most important technologies for renewable electricity production throughout the world. By the end of 2016, the global total wind power capacity reached nearly 500 GW, with China, the United States, and Germany being the global leaders [1]. In the last 25 years, the German electricity sector has undergone a substantial transformation towards a low-carbon and renewable-based system. The share of renewables in Germany's total electricity consumption rose from 3.1% in 1991 to 31.5% in 2016 [2]. Onshore wind power has become a central pillar of renewable electricity production in Germany. While in 1991, less than 1,000 wind turbines were installed, by the end of 2016 more than 27,000 wind turbines were spinning across the country, producing approx. 66 terawatt hours (one third of renewable electricity production) [2]. Given the German government's ambitious target of reaching an 80% share of renewables in total electricity consumption by 2050, the number of wind turbines is set to rise sharply.

While more and more wind turbines are installed, public acceptance of the further expansion of onshore wind power is decreasing [3-5]. Especially on the local level, aspects such as noise emission, shadow flicker, visual impact, and expected losses in property value are often negatively evaluated and arouse resistance [6-9]. One way of dealing with these acceptance problems, is to establish setback distances from residential areas [10, 11]. In Germany, the 16 federal states are responsible for creating their own guidelines or requirements determining wind turbine siting and setbacks. For example, in Bavaria, the German state with the strictest setback distance regulation, wind turbines have to maintain a minimum distance from residential housing of ten times the total height of the wind turbine (the so-called H10 regulation); as a result, the areas available for wind farms are drastically reduced [12].

Large-scale wind turbines are preferably placed in flat, open landscapes with low amounts of vegetation, offering high wind speeds and low turbulence levels [13]. However, in light of Germany's ambitious expansion targets and the establishment of setback distances, the focus of politicians, planning authorities, and wind farm developers is increasingly on forested areas. In recent years, the rapid progress in wind turbine technology (e.g., hub heights of up to 150 m) has made it technically and economically feasible to locate wind farms in forested areas, e.g. on forested hill tops and ridgelines offering high average wind speeds [14]. Especially in heavily forested countries like the United States of America, Canada, and Sweden, forest wind farms will open up significant new onshore wind potential [15, 16]. For example, nearly 2,000 wind turbines were operating in forests in the United States of America in 2015 (approx. 4% of the total number) [17].

Almost one third of Germany's total surface area is forested (approx. 106,000 km²). Therefore, after agriculture (which accounts for approx. 50% of the total surface area), forests represent the second most important type of land use in Germany [18]. Forests are not only complex ecosystems offering natural habitats for a great diversity of flora and fauna, they also provide a range of ecosystem services (e.g., climate protection, air purification, fresh water provision, recreation and tourism) [19, 20].

In Germany, the specification of areas for wind turbines is legally controlled at the spatial planning level, with planning authorities designating concentration zones for wind turbines. This is mainly regulated by the planning law which is based on federal state legislation and guidelines. However, it is framed and applied differently in the 16 federal states. The planning and approval procedure for

wind turbines in forests is basically the same as on open land but is subject to tighter restrictions regarding species protection and protected area legislation. Many forested areas provide roosting and foraging habitat for specially protected bird and bat species. In addition, some forests with natural and recreational functions enjoy special protection.

Against this background, we conducted an interdisciplinary analysis in which we combined legal knowledge with land use and wind power statistics. We checked whether regional planning is effectively steering the development of wind farms in German forests by analysing spatial data on wind turbines and on land use. Although this study focuses on the development in Germany, its methodological combination of wind power statistics and legal analysis could serve as blueprint for prospective studies in other countries.

2 Methodology and Data

2.1 Legal analysis

For the examination of the legal framework conditions for wind energy planning in forests, the legal and planning requirements were analysed. In addition to the relevant federal laws, the regulations in the 16 federal states in Germany have been examined. These include the current state development plans and/or programmes, wind energy ordinances as well as thematic guidelines or recommendations for the utilisation of wind energy in forests. In most federal states, there is a supra-local planning level (federal and regional planning) and a local planning level (land use and urban land use planning); the decisive supra-local level for wind energy planning is regional planning. For the three city-states in Germany, there are special regulations: Bremen and Hamburg have no supra-regional planning, but only local planning level (where the wind energy planning is done). Berlin has a joint supra-regional planning together with Brandenburg.

2.2 Spatial analysis of the development of wind energy in German forests

2.2.1 Data on wind turbines

There is no official data set on wind turbine locations and characteristics available for Germany as a whole. Therefore, as a first step, we created a nationwide data set by merging data provided by the responsible regional authorities. In Germany, the main development of wind energy started after the passing of the Electricity Feed-in Act (StromEinspG) in 1991. We therefore analysed the period from 1991 to 2016, the most recent year for which a complete data set was available. No spatial explicit data on wind turbines was available for the three city federal states Berlin, Bremen, and Hamburg. Therefore, we limited our spatial analysis to the 13 non-city federal states. In general, the three city states have very low numbers of wind turbines (Berlin: approx. 5 wind turbines, Bremen and Hamburg approx. 60-80 wind turbines, respectively in 2016) [21]. Small wind turbines with a rated power of less than 100 kW (636 wind turbines) were deleted from the data set. Small wind turbines are mostly used in the private and domestic sector and not registered for feed-in tariffs. Accordingly, the statistical coverage and reliability of this data is very limited [22]. Not all data sets were complete regarding certain parameters such as year of installation, power, hub height, and so on. Therefore, we applied multiple advanced algorithms developed by Becker and Thrän [23] to fill the gaps in the data sets.

The administrative boundaries of the 13 analysed federal states were derived by using a shapefile provided by the German Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie, BKG, scale: 1:2,500,000).

2.2.2 Data on land use and protected areas

We determined the area of the three land uses, arable land, pasture, and forest, with the help of shapefiles from the ATKIS database, the official German topographic-cartographic information system provided by the BKG. We used the following feature types of the digital basis landscape model (Basis-DLM, scale: 1:25,000, year: 2012): arable land (object type no. 4101 “Ackerland”), pasture (object type no. 4102 “Grünland”), and forest (object type no. 4107 “Wald, Forst”). The ATKIS object type for forest additionally distinguished between deciduous, coniferous, and mixed forest.

We used shapefiles provided by the German Federal Agency for Nature Conservation (Bundesamt für Naturschutz, BfN) to determine the amount of forest that is protected under the German Federal Nature Conservation Act (BNatSchG). We focused on the six main types of protected areas: nature conservation areas, national parks, biosphere reserves, landscape protection areas, nature parks, and Natura 2000 sites (composed of sites designated under the Birds Directive (Special Protection Areas, SPAs) and the Habitats Directive (Sites of Community Importance, SCIs, and Special Areas of Conservation, SACs)) (designation status: 2016 or 2017). It is important to note that two or more protected areas of different types can overlap or even cover the same area of land.

Depending on the protection purpose and conservation objective, the restrictions on land use vary among the different types of protected area. Nature conservation areas (§ 23 BNatSchG) and national parks (§ 24 BNatSchG) are the two strictest types from a nature conservation viewpoint as they allow very little or no human intervention. Accordingly, the installation of wind turbines is not allowed in these areas, which are excluded in the frame of spatial planning. In the other four types, the installation of wind turbines is not excluded per se. A case-specific investigation decides whether the installation could be allowed.

Accordingly, in our analysis, we distinguished between two groups of protected areas: “strictly protected” (nature conservation areas and national parks) and “less strictly protected” (biosphere reserves, landscape protection areas, nature parks and Natura 2000 areas). In cases where both groups overlapped, we assigned the area to the group “strictly protected”.

3 Results and Discussion

3.1 National framework provides guidelines to concentrate wind power installation

Until the 1990s, the siting of wind turbines was mainly a bilateral process between wind power operators (commercial and private) and approval authorities on the level of local municipalities. As a result, a dispersed placement of wind farms took place [24]. In 1997, § 35 of the German Federal Building Code (BauGB) was amended, declaring wind turbines to be “privileged projects” in the so-called undesignated outlying area (Außenbereich). Since then, the installation of wind turbines is generally permitted in that area, unless public interest stands in the way. As a corrective measure, regional planning authorities and municipalities can steer the construction of wind turbines by designating wind energy concentration zones (§ 35 III 3 BauGB) [25, 26]. In that case, wind turbines may only be erected in those concentration zones.

When defining such concentration zones planning authorities must observe numerous legal and practical framework conditions. Case law summarises these requirements in a phrase that calls for the development of a “coherent overall planning concept”. In practice, the planning authorities work mainly with the exclusion method, a test sequence developed by the Federal Administrative Court (BVerwG ruling of 13/12/2012 - 4 CN 1.11 [27] [24] (Figure 1). In the first step “taboo zones” which are not available for wind energy uses are identified. These taboo zones can be subdivided into “hard” and “soft” zones. Hard taboo zones are areas which for practical or legal reasons are simply not suitable for wind energy use, for example water or settlement areas or nature conservation areas for the protection of bat species. Soft taboo zones are areas on which wind turbines should not be erected due to the intended planning design (e.g. maintenance of green corridors, insufficient wind conditions or heritage protection considerations). The potential areas left over after the deduction of the hard and soft taboo zones must then be related in a further step to the competing uses, i.e. public concerns that oppose the designation of a landscape zone as a concentration zone are to be weighed against the interest of giving wind energy use a chance at suitable sites with adequate wind conditions.

As a result – according to case law – the designation of wind energy concentration zones “must provide substantial space” and this must be based on the ratio between concentration zone areas and the area that was available after deduction of the hard taboo criteria. The objective here is not to reach a certain value; what is decisive is that the legal assessment – wind energy installations in undesignated outlying areas are privileged projects (§ 35 I BauGB, see above) – is taken into account. The smaller the area of the identified concentration zones is, the more likely the selection concept must be called into question and, if necessary, changed by re-determining and evaluating the soft taboo zones.

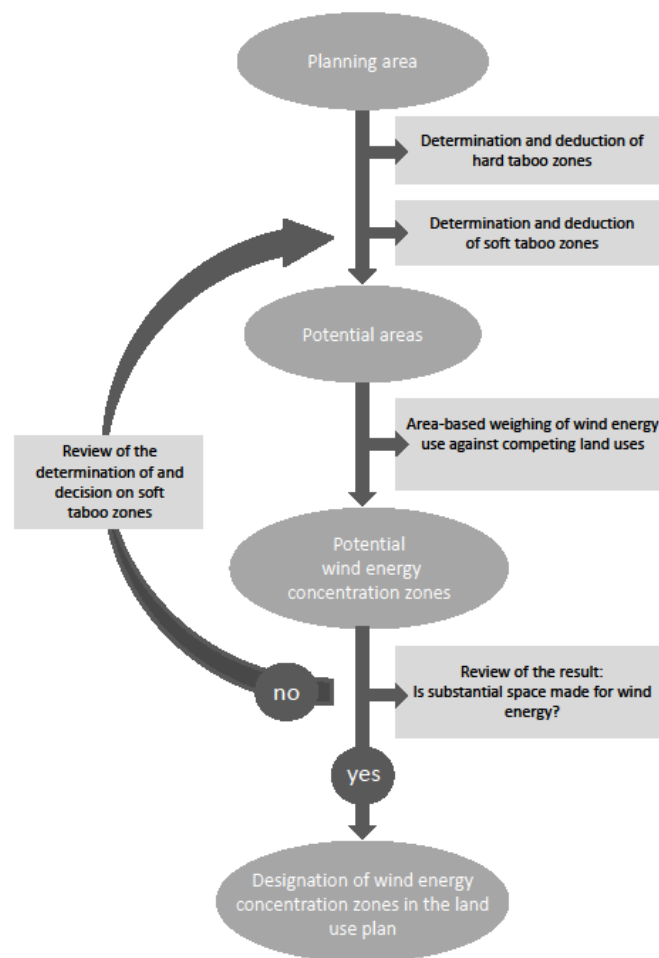


Figure 1: Test sequence for the determination of wind energy concentration zones.

A key aspect which has to be considered when determining concentration zones for wind energy is species protection, especially the prohibition of killing (Art. 12.1a Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora (Habitats Directive); Art. 5 lit. a Directive 2009/147/EC on the conservation of wild birds (Birds Directive)) and the prohibition of deliberate disturbance and destruction (Art. 12.1 b-d Habitats Directive; Art. 5 lit. b – d Birds Directive). According to these directives, member states shall take the requisite measures to establish a system of strict protection for endangered native animals and birds prohibiting all forms of deliberate capture or killing of specimens of these species in the wild and deliberate disturbance of these species, particularly during the period of breeding, rearing, hibernation and migration. In Germany, these requirements of European Union law were implemented in the Federal Nature Conservation Act (BNatSchG).

Since birds and bats have been identified as main wildlife groups affected by wind turbines [28-30], there are additional regulations for them: The so-called “Helgoland Paper”, which is a technical guideline [31], was developed for the protection of birds in Germany. For bats, there is no

nationwide guideline. Instead the federal states, independently of one another, have developed their own guidelines with varying degrees of detail and binding effect [14].

The planning process for wind energy projects is strongly influenced by judicially developed criteria and the guidelines of each federal state. Increasingly, the fulfilment of these criteria is proving to be a balancing act for planning authorities. For example, the distinction between hard and soft taboo criteria required by case law is difficult; on the other hand, it is not clear how space for wind energy should be made in a “substantial way” because there is no uniform or definitive quota that has to be fulfilled. With regard to the technical guidelines on species protection, case law stresses that while it can offer important pointers for the determination of a violation of the prohibition of killing (keyword “significant increase in risk”), it nevertheless always comes down to a case-by-case assessment. For this assessment, the competent authority is granted a margin of discretion for its own expert judgment (BVerwG ruling of 15/09/2009 - BN 25.09, BVerwG ruling of 24/01/2008 - 4 CN 21.07) [24, 26].

3.2 No uniform procedure for concentration zones in forested areas in the federal states

In the meantime, all of the federal states have positioned themselves on the topic of wind energy in forested areas in laws, plans or guidelines (Table 1, Figure 3d). A comparative examination (cf. Kress [14], FA Wind [32]) shows that there are federal states in which wind energy in forested areas is generally permitted, being prohibited only in specifically designated forests which enjoy a certain protection status, such as protected forest (Bannwald), forest reserves (Schonwald) or recreational forest (Erholungswald). These are: Baden-Württemberg, Bavaria, the joint state planning authorities of the federal states of Berlin & Brandenburg, Hessen, North Rhine-Westphalia, Rhineland-Palatinate, Saarland and Thuringia (Table 1a). In the four federal states Bremen, Mecklenburg-Vorpommern, Lower Saxony and Saxony the situation is different; here wind energy is generally prohibited and only permitted in exceptional or individual cases (Table 1b). In these federal states, woodland areas are assigned special natural and recreational functions and should not be used for wind energy. When it comes to the question of whether and to what extent concentration zones for wind energy in forests are determined, the plan initiators have so-called planning discretion. For a legally watertight plan, however, they must prepare a “coherent overall planning concept” and at the end of the day their land-use planning must, in a substantial way, make space for wind energy (Sec. 3.1) [3]. In this respect, planners in all of those 13 federal states have the option to designate concentration zones in non-excluded forest types. In the four federal states in which wind energy in forested areas is permitted in exceptional cases only, however, planners are confronted with a high administrative burden as they have to justify the exception.

In three federal states wind turbines may not be erected in forests (hard taboo zone) (Table 1c). In Saxony-Anhalt the conversion of forest for the construction of wind turbines is not permitted (§ 8 I 3 Forest Act of Saxony-Anhalt (LWaldG LSA)) and in Schleswig-Holstein the conversion of forest for the construction of wind turbines with a height of over 10 metres is not permitted (§ 9 III 3 Forest Act of Schleswig-Holstein (LWaldG SH)) [33, 34]. As a result, in both of these federal states, by law, it is a legal impossibility to designate wind turbines in forests because their construction would not be realisable due to the lack of a forest conversion permit. In the city-state of Hamburg, as a result of a directive, forests along with an additional buffer zone of 200 metres are excluded from wind energy use.

Table 1: Forest regulations in the federal states (as at June 2018). An explanation of the different forest types can be found in the appendix.

a) Wind energy in forests is generally permitted and prohibited only in specific types of forest	
Federal State	Regulation
Baden-Württemberg	According to a technical guideline (WEE BW 2012) wind turbines are excluded from protected forests (Bannwald) and forest reserves (Schonwald) (§ 32 Forest Act of Baden-Württemberg (LWaldG BW)) and a minimum distance of 200 metres is recommended in order to avoid significant impairments through wind turbines. In specially protected forest areas (soil conservation forests, protective forests which safeguard against harmful environmental impacts, recreational forests) the planning procedure is subject to certain restrictions.
Bavaria	Protective forests (Schutzwald) and protected forests or recreational forests and natural forest reserves (Art. 10, 11, 12, 12a Forest Act of Bavaria (BayWaldG)) are excluded from wind energy development. According to a technical guideline (BayWEE 2016), in forests with old tree stocks (> 140 years) as well as in forests whose structure is particularly rich in deadwood and biotopes with near-natural tree species composition, planners must establish in a case-by-case decision process whether and why the impacts on nature and the landscape are justifiable in the overall assessment of competing interests.
Berlin/Brandenburg	Berlin and Brandenburg have a joint supra-regional planning. Wind turbines are excluded from protective forests and recreational forests according to § 12 of the Forest Act of Brandenburg (BbgWaldG). For Brandenburg, under the wind energy decree (BbgWEE 2011), restrictions apply to structurally rich deciduous and mixed forest areas (larger than 100 hectares) with a high proportion of fallen trees and the presence of at least 10 bat species or species of high importance for the reproduction of endangered species. In respect of the existing animal ecology concerns in these areas, certain spacing criteria apply (TAK 2012).
Hessen	According to a technical guideline (WKA 2012), wind turbines are excluded from protective forests (Schutzwald) and protected forests (Bannwald) (§ 13 Forest Act of Hessen (HWaldG)); areas with a very high conflict potential (including the nursery roosts and winter quarters of bat species worthy of protection as well as old forest stands) are to be conserved.
North Rhine-Westphalia	According to the wind energy decree (WEE NRW 2018), wind turbines may be installed in forested areas as long as essential functions of the forest are not significantly impaired. Accordingly, a forest conversion permit can generally not be granted for site-appropriate, structurally rich deciduous forests with high biotope value, natural forest cells, process protection areas, seed stocks, sites used for long-term forest field studies and historically important forest sites. A forest conversion permit can, however, generally be granted in coniferous forests with poor structure and on forest areas without tree stands due to abiotic or biotic factors such as storm, ice throw or ice damage, insect damage.
Rhineland-Palatinate	According to the 2017 state development programme (LEP RLP 2017),

	wind energy use is prohibited in large areas of contiguous deciduous forest (older than 120 years). Delimitation is based on a minimum area of old wood of approx. 10 hectares which may include, at most, small areas (less than 1 hectare) of younger trees, conifers or forest clearings.
Saarland	Wind energy planning in forested areas is generally possible (LEP SL 2011). As of September 2017, the installation of wind turbines in the historically old forest areas (forest since at least 1817) of the state forest is prohibited unless there is an overriding public interest in the construction. An overriding public interest exists when the average wind power density above ground at the site of installation is at least 321 W/m ² at a height of 150 metres and the site is already developed or the site and the areas required to develop the site are already impacted (§ 28 I no. 6 Forest Act of the Saarland (LWaldG SL).
Thuringia	Wind energy development is prohibited in protective forests (Schutzwald) and in recreational forests (§ 9 I Forest Act of Thuringia (ThürWaldG)). In addition, the state's wind energy decree (ThürWEE 2016) recommends a safety distance of 100-300 metres, depending on the protective purpose in question. Forests that serve a particular function (e.g., forests with a soil protection function or scientific study sites) are classified as "soft taboo zones" and may, in individual cases, be approved.
b) Wind energy in forests is generally prohibited and permitted only in exceptional cases	
Bremen	In view of the special importance of forests for nature and recreation and the small area of forest in Bremen, wind turbines are not to be built in forested areas (FNP HB 2014).
Mecklenburg-Vorpommern	According to a technical guideline (RL RREP MV 2012), the erection of wind turbines in contiguous forest areas of 10 hectares or more is prohibited as forest is one of the most valuable natural assets and, as such, must be protected, developed, maintained and managed; also, only 23 % of the state's surface area is covered by forest (Figure 3c).
Lower Saxony	According to a principle in the state's regional development plan (LROP-VO 2017), due to its diverse functions, and in particular because of its importance for climate and ecology, forests may not be used for wind energy development. Areas within forests may be used in narrowly defined exceptional cases when no other potential areas are available on open land and the area in question contains technical installations or has been impacted by construction (e.g., industrial and commercial areas and wastelands, post-mining landscapes or former landfill sites).
Saxony	According to the 2013 state development plan (LEP SN 2013), the use of forest areas should be generally avoided. This applies in particular to forest areas with protected status under nature protection legislation and to areas with selected forest functions.
c) The installation of wind turbines in forest is prohibited	
Hamburg	At the land-use planning level (FNP HH 2013), Hamburg excludes forests for wind energy use with an additional buffer zone of 200 metres.
Saxony-Anhalt	The conversion of forest for the construction of wind turbines is

	prohibited in Saxony-Anhalt (§ 8 I 3 Forest Act of Saxony-Anhalt (LWaldG ST)).
Schleswig-Holstein	The conversion of forest for the construction of wind turbines with a height of more than 10 metres is prohibited (§ 9 III 3 Forest Act of Schleswig-Holstein (LWaldG SH)).

3.3 Strong annual variation of newly installed wind turbines

According to our database, 25,155 wind turbines (approx. 43 GW installed capacity) were installed in Germany between 1991 and 2016. The numbers of newly installed wind turbines show a strong annual variation in the last 26 years (Figure 2). In 1991, the adoption of the Electricity Feed-in Law (StromEinspG) set in motion a steady development of wind power during the 1990s by guaranteeing wind energy producers access to the electricity grid and obliging power companies to purchase wind energy at 90% of the average tariff for final customers [35]. After the introduction of the Renewable Energy Sources Act (EEG) in April 2000, the numbers of newly installed wind turbines nearly doubled, up to 2,200 per year (Figure 2). The EEG provided wind energy investors with favourable long-term conditions, for example, by guaranteeing stable feed-in tariffs for up to 20 years. From 2002 onwards, the feed-in tariff decreased annually by 1.5% for new wind installations, explaining the very high numbers of new installations in the first years after the adoption of the EEG. After the “hype” of the first EEG years, the numbers of annual installations declined again, mainly due to the decreasing availability of suitable sites (Figure 2) [36]. With the EEG amendment in 2014, the German government decided to end the “classical” system of a fixed feed-in tariff and to oblige operators of new renewable energy plants to market their electricity directly [37, 38]. However, wind turbines that were approved until the end of 2016 and commissioned in 2017 and 2018 could still apply for a feed-in tariff specified in the amended EEG 2014. This transitional provision might be the reason for the sudden increase in the numbers of wind turbine installations after 2013 (Figure 2).

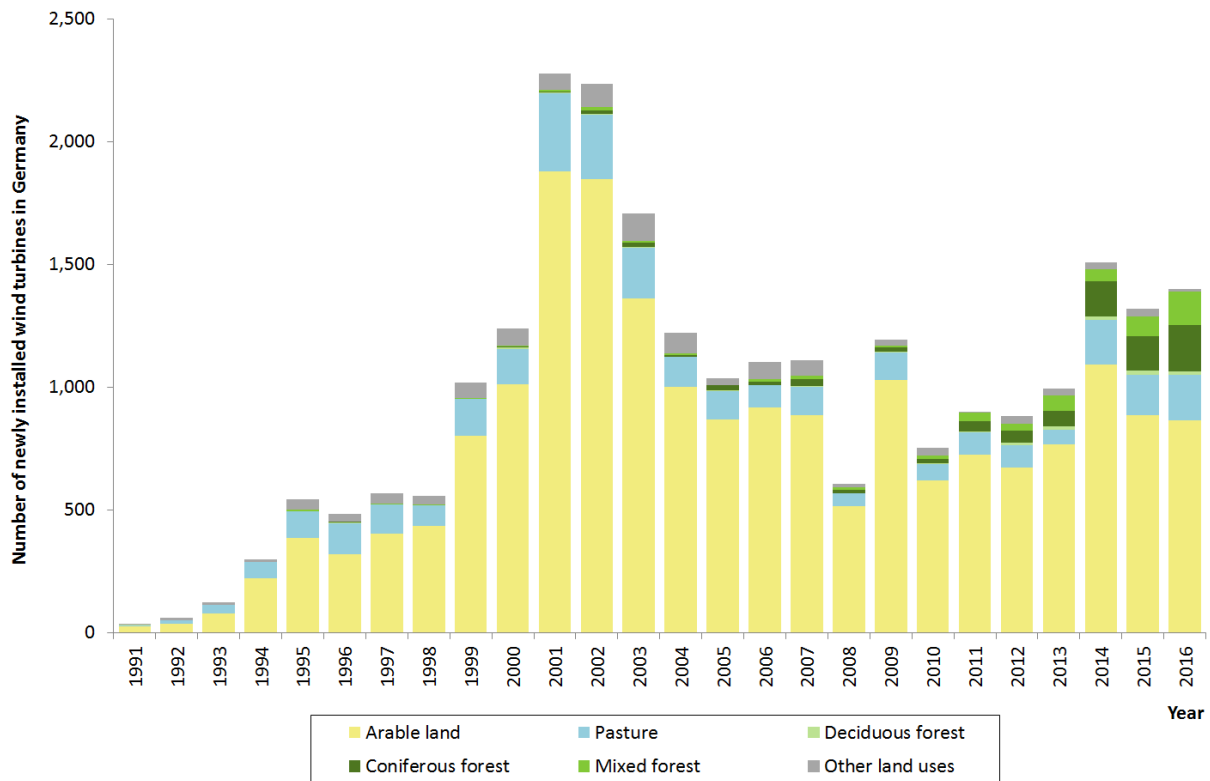


Figure 2: Number of newly installed wind turbines in Germany per year and land use category.

3.4 Expansion of German wind power shows clear north-south divide

Our results show that the expansion of wind energy was not equally distributed across Germany, but rather resulted in a clear north-south divide. The majority of wind turbines are in operation in the north of Germany, in the federal states of Lower Saxony, Brandenburg, North Rhine-Westphalia, Schleswig-Holstein, and Saxony-Anhalt (approx. 70% of total installed wind power capacity) (Figure 3a). The highest wind turbine density in relation to total surface area is found in Schleswig-Holstein, which has approx. 0.19 wind turbines per km², followed by Saxony-Anhalt, Lower Saxony, and Brandenburg with 0.13, 0.12, and 0.12 wind turbines per km², respectively (Figure 4). Even combined, the most southern federal states, Bavaria and Baden-Württemberg, only account for 7% of the total installed wind power capacity. Due to their comparably large total surface area, Bavaria and Baden-Württemberg have a very low wind turbine density of 0.014 and 0.016 wind turbines per km², respectively (Figure 4). The remaining 23% of the total installed wind power capacity is distributed over the centre of Germany. The north-south divide is mainly due to better wind conditions in the northern German plains and coastal regions compared to the southern part of Germany, which is primarily characterised by lower average wind speeds and more complex terrain [23, 36].

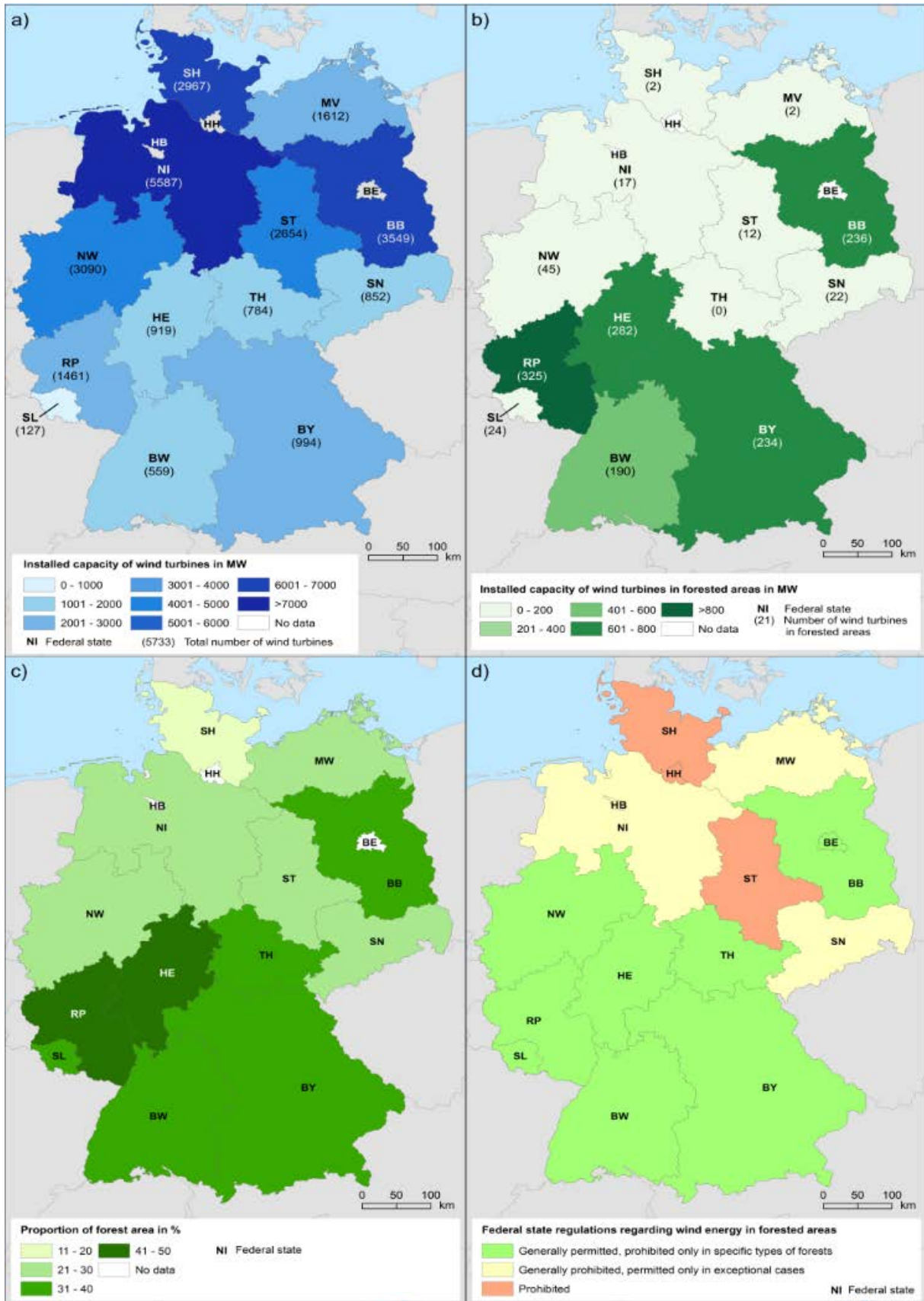


Figure 3: a) Installed capacity (in MW) and total number of wind turbines and b) installed capacity (in MW) and number of wind turbines in forested areas installed between 1991 and 2016, c) proportion of forest area, and d) federal state regulations regarding wind energy in forested areas in the 16

German federal states (in alphabetical order of abbreviation; BB: Brandenburg, BE: Berlin, BW: Baden-Württemberg, BY: Bavaria, HB: Bremen, HE: Hessen, HH: Hamburg, MW: Mecklenburg-Vorpommern, NI: Lower Saxony, NW: North Rhine-Westphalia, RP: Rhineland Palatinate, SH: Schleswig-Holstein, SL: Saarland, SN: Saxony, ST: Saxony-Anhalt, TH: Thuringia).

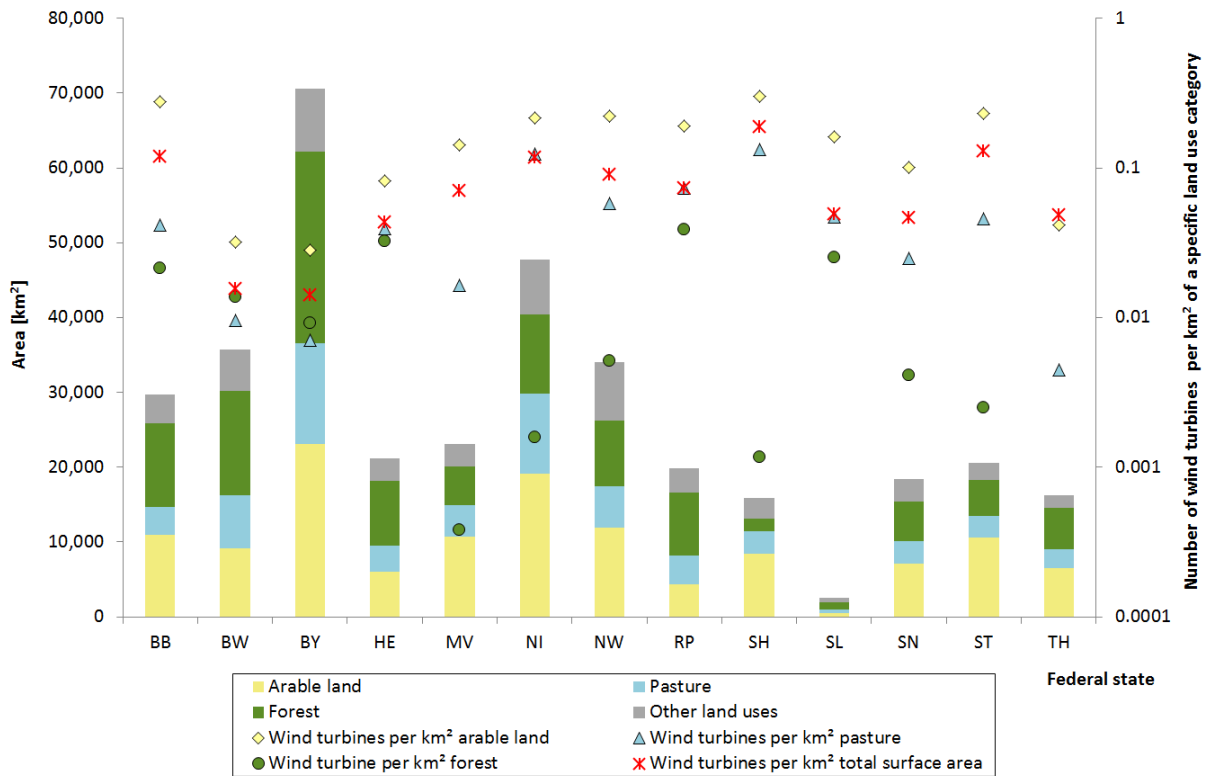


Figure 4: Area of a specific land use category and number of wind turbines per km² of a specific land use category (in logarithmic scale) for the investigated 13 federal states. Please note that there are no wind turbines in forested areas in Thuringia.

3.5 Increasing number of wind turbines in forested areas

Between 1991 and 2016, the great majority of wind turbines were installed on agricultural land (78% of the total number, approx. 33 GW installed capacity). A small share of approx. 12% was erected on pasture. Since 2011, more and more wind turbines are placed in forested areas (2010: 35 wind turbines, 2011: 81, 2012: 90, 2013: 140, 2014: 207, 2015: 237, 2016: 341) (Figure 2). In 2010, only 5 % of new wind turbines were installed in forest, compared to 24% in 2016. According to our dataset, at the end of 2016, 1,391 wind turbines (3.5 GW) were in operation in German forests (5.5% of the total number and 8% of the total installed capacity), three quarters of those having been installed after 2010.

Our spatial analysis shows that according to the ATKIS land use data more than half of the wind turbines in forested areas were erected in coniferous forest (57%), followed by mixed forest (35%)

(Figure 2). Only 8% are in operation over deciduous forest. This result may be explained by the fact that coniferous forest is the dominant forest type (48%) in the 13 investigated federal states, followed by mixed forest (35%) and deciduous forest (17%). Furthermore, especially old stocks of deciduous forest with high structural diversity are considered as deserving special protection. In the wind energy decree of Rhineland-Palatinate, for example, wind energy use is prohibited in areas with larger contiguous deciduous forest (120 years or older) (hard taboo zone) (Sec. 3.2, Table 1a). Other states, e.g. Bavaria and Baden-Württemberg, also make statements on the special worthiness of protection of this type of forest, where interferences in structurally rich, old deciduous forest generally tend to be regarded as more serious than interferences in less valuable habitats (soft taboo zone). In North Rhine-Westphalia, on the other hand, forest conversion permits are generally not granted for site-appropriate, structurally rich deciduous forests with high biotope value. One reason for the special protection of deciduous forest is that it is a suitable habitat for wind energy-sensitive bat species [39].

3.6 Installation of wind turbines in forested areas mainly in six federal states

Our results for wind turbines in forested areas reveal strong regional differences that do not show the same north-south divide found for the spatial distribution of wind turbines in total (Figure 3). The installation of wind turbines in forested areas is almost exclusively limited to six federal states (Rhineland-Palatinate: 325 wind turbines (approx. 820 MW), Hessen: 282 (approx. 760 MW), Brandenburg: 236 (approx. 620 MW), Bavaria: 234 (approx. 600 MW), Baden-Württemberg: 190 (approx. 460 MW), North Rhine-Westphalia: 45 (approx. 110 MW); representing approx. 94% of the wind turbines in forested areas) (Figure 3b). These results are in line with the findings of our legal analysis where we identified these six federal states as states that generally allow the installation of wind turbines in forested areas (Sec. 3.2, Table 1a).

With 325 wind turbines and approx. 820 MW installed capacity in forested areas, Rhineland-Palatinate is the front runner state in terms of wind energy development in forested areas. Already since 2011, every year, 30-50% of new wind turbines are placed in forested areas (Figure 5). The state government of Rhineland-Palatinate aims to cover its total electricity consumption with renewable energy sources by 2030. Two-thirds is supposed to come from wind power. Rhineland-Palatinate has the highest proportion of forest of all the federal states (approx. 42% of its total surface area, approx. 8,400 km², Figure 3c and 4). Accordingly, planning authorities are asked to make available not only at least 2% of the total area of Rhineland-Palatinate for wind power concentration zones, but also at least 2% of its forest area (LEP RLP 2013). Even though this statement was moderated in 2017 (LEP RLP 2017) - for both provisions the phrase "at least" is now deleted - this is a unique statement in Germany regarding wind energy.

The state governments of Hessen, Baden-Württemberg, and Bavaria also emphasise the need to place wind farms in forested areas in order to reach their renewable energy targets. Like in Rhineland-Palatinate, since 2011, an increasing number of wind turbines is installed in Hessian forests, reaching its peak in 2016 with 93% of the new installations (100 of 107 wind turbines) (Figure 5). A main reason for that might be a political decision from the year 2011, when it was recommended to cover 2% of the Hessian land area with concentration zones for wind energy (LEP Hessen Änderungsentwurf 2012). Also in Baden-Württemberg, 72-75% of the new wind turbines in 2015 and 2016 were erected in forested areas. At the end of 2016, in Hessen and Baden-Württemberg, one third of the total wind turbines are spinning in forested areas, in Rhineland-

Palatinate and Bavaria around 20%. Brandenburg has the third-highest number of wind turbines in forested areas, however, representing only approx. 7% of the total number. The wind turbines in forested areas in North Rhine-Westphalia account for less than 2% of the total number in this federal state (Figure 3a and b).



Figure 5: Number of newly installed wind turbines per year (2005-2016) and land use category for the six German federal states with more than 40 wind turbines in forested areas.

The remaining federal states have negligible numbers of wind turbines in forested areas and, so far, show no ambition to increase their numbers (Saarland: 24 wind turbines, Saxony: 22, Lower Saxony: 17, Saxony-Anhalt: 12, Schleswig-Holstein: 2, Mecklenburg-Vorpommern: 2, Thuringia: 0) (Figure 3b).

The federal state of Saarland has by far the smallest total area of the 13 investigated non-city states (approx. 2,600 km², approx. 37% forested, Figure 3c and 4). Wind turbines in forested areas account for approx. 19% of the total number of installed wind turbines. This is in the same range as the other federal states which generally allow the installation of wind turbines in forested areas (Table 1a). To date, the expansion has taken place mainly in Saarland’s state forests. As a result of a legislative amendment in September 2017, however, the installation of wind turbines on historically old forest sites in state forests is only allowed if an overriding public interest in the installation is present (Table 1a). Because historically old forest sites make up almost the entire state forest, we expect that future wind energy development in Saarland’s forests will be strongly impeded.

The low number of wind turbines in forested areas in Saxony, Lower Saxony, and Mecklenburg-Vorpommern is consistent with the results of our legal analysis where we found that these federal states generally prohibit wind turbines in forested areas and only allow them in exceptional cases (Sec. 3.2, Table 1b). Accordingly, the planning authorities only very cautiously define concentration zones for wind energy development in forests, so that hardly any turbines are installed there.

Since it is not possible to obtain a forest conversion permit for wind turbines in Schleswig-Holstein and Saxony-Anhalt, we did not expect to find any wind turbines in forested areas in these federal states. However, our spatial analysis found two wind turbines in Schleswig-Holstein and 12 in Saxony-

Anhalt. In both federal states, the legislations that prohibit the conversion of forest for wind turbines were first adopted in 2016. So, up to that time it was possible to apply for such a permit, so that in the period up to two years ago it was still possible to install wind turbines in forests. It should be noted that the 12 wind turbines in forested areas in Saxony-Anhalt are all installed on forested area which, however, was previously impacted by construction (e.g., a decommissioned military airport or the spoil heap of a former surface mining area). This clearly indicates that up to that point Saxony-Anhalt also issued forest conversion permits, although not for high-value forest areas.

It is somewhat surprising that we found no wind turbines in Thuringian forests, although Thuringia generally allows them (Table 1a). However, the federal state of Thuringia only took a clear position on wind energy in forested areas in 2016. The new wind energy decree definitively suspended an action recommendation issued to the planning authorities in 2007 by the Thuringian Ministry for Construction, Regional Development and Transport. In this recommendation, forest was included in the list of exclusion criteria for wind energy use. The regional planners stuck to this action recommendation until, in 2014, the higher administrative court (Oberverwaltungsgericht) in Thuringia regarded the action recommendation as a binding planning specification and, in reference to the Law on Forests, clarified that a legal obstacle to the use of wind energy only exists for forests protected by ordinance (ThürOVG, Decision of 8 April 2014 – 1 N 676/12). Due to the current change in the legal regulation, it seems likely that the number of wind turbines in Thuringia's forested areas will increase in the coming years.

3.7 Majority of wind turbines in forested areas in unprotected forested areas

The majority of the 1,391 wind turbines in forested areas (approx. 62%) was erected in forested areas without any protection according to the BNatSchG. Approx. 38% are spinning in forested areas that we classified as “less strictly protected” (mainly in nature parks and/or landscape protection areas; only 7 wind turbines in biosphere reserves and 75 wind turbines in Natura 2000 areas). According to our dataset, no wind turbines were installed in “strictly protected” forested areas. In general, the ratio wind turbines in forested areas in “not protected” to “less strictly protected” (62% to 38%) corresponds to the ratio forest areas that are “not protected” to “less strictly protected” (63% to 30%). Only approx. 7% of the forested areas in the thirteen federal states are “strictly protected” as parts of nature conservation areas or national parks and, therefore, no-go areas for wind farms.

For all thirteen federal states, the majority of the forest is protected by the BNatSchG, ranging from approx. 61% in Brandenburg up to more than 90% in Saarland and North Rhine-Westphalia, respectively. By far the largest forest area without any BNatSchG protection status has Bavaria (approx. 9,200 km², approx. 36% of the forested area), followed by Brandenburg (approx. 4,300 km², approx. 39% of the forested area) (Figure 4 and Figure 6). Saarland, North Rhine-Westphalia, and Schleswig-Holstein have hardly any forest areas without protection status (approx. 80 km², 500 km², and 600 km², respectively).

In Brandenburg, Bavaria, Rhineland-Palatinate, and Baden-Württemberg, the majority of the wind turbines in forested areas was installed in “not protected” forested areas (approx. 92%, 77%, 66%, and 52%, respectively), although, “not protected” forested areas represent the minority of the forested areas in these federal states (approx. 39%, 36%, 21%, and 26%, respectively) (Figure 6). In Hessen, approx. 63% of the wind turbines in forested areas are spinning in “less strictly protected”

areas, which cover approx. 64% of the Hessian forests. In North Rhine-Westphalia, nearly all wind turbines in forested areas (approx. 98%) are in “less strictly protected” areas, which is not surprising due to the fact that approx. 76% of the forests in North Rhine-Westphalia are “less strictly protected” and approx. 18% “strictly protected”, leaving only approx. 6% with “no protection” status. In Saarland, all 24 wind turbines in forested areas are in “less strictly protected” forested areas, which represent approx. 77% of the total forest area of the Saarland (approx. 14% “strictly protected”, approx. 9% “no protection”).

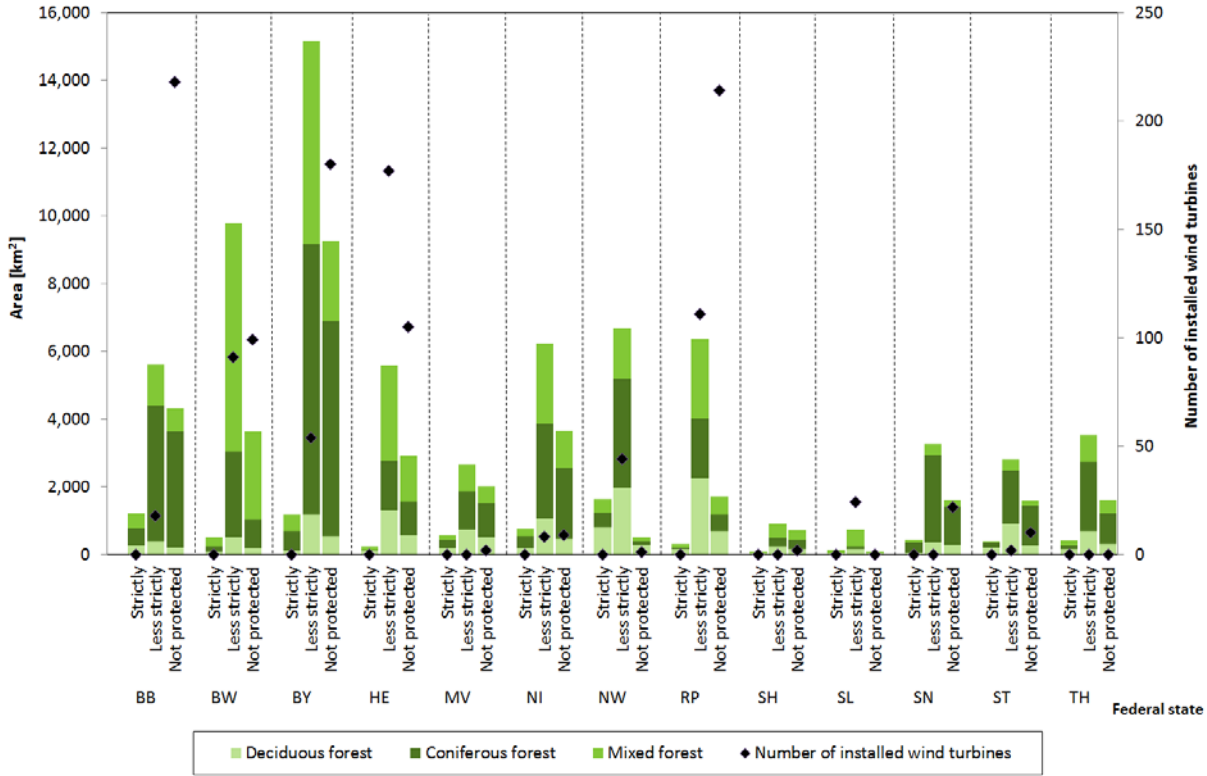


Figure 6: Area of deciduous, coniferous or mixed forest and number of wind turbines distinguished by the different levels of protection and federal state.

4 Conclusions

At the end of 2016, more than 27,000 wind turbines were spinning across Germany, producing one third of renewable electricity production. Given the German government’s ambitious target of an 80% share of renewables in total electricity consumption by 2050, the number of wind turbines will continue to rise sharply. So far, the great majority of wind turbines have been installed on agricultural land. However, in recent years it has become technically and economically feasible to place wind farms in forested areas due to advances in the technology. Forested hill tops and ridgelines not only offer high average wind speeds, but are also far removed from residential areas; a major advantage, considering the increasing establishment of setback distances.

Our results show an increasing number of wind turbines being placed in forested areas since 2011. While in 2010, only approx. 5 % of new wind turbines were installed in forests, that share increased to approx. 24% in 2016. According to our dataset, 1,391 wind turbines were in operation in German forests at the end of 2016 (5.5% of the total number and 8% of the total installed wind power

capacity). Unlike the spatial distribution of all wind turbines, where the northern federal states show the highest expansion figures, the expansion of wind turbines in forested areas is almost exclusively confined to the five southern federal states (Rhineland-Palatinate, Hessen, Bavaria, Baden-Württemberg, and North Rhine-Westphalia) as well as the federal state of Brandenburg, which is located in the north-east. This result is reflected in the findings of our legal analysis: there are no nationwide, uniform regulations governing wind turbines in forests; instead, the individual federal states handle the issue very differently. While some federal states, especially those with high shares of forested areas, emphasise the need to place wind farms in forested areas to reach their renewable energy targets, other federal states aim to keep their forests clear of wind turbines by prohibiting them or permitting them only in exceptional cases.

A comparison of the spatial and legal analysis of the planning of concentration zones for wind turbines in forested areas shows that planning law and regional planning, respectively, have a visible and powerful steering effect: If a federal state provides for restrictive planning, this will lead to little or no expansion of wind energy in forested areas. Whereas if the legal regime of a federal state permits the construction of wind turbines in forested areas, the wind energy concentration zones designated by the planning authorities will also be used by the plant operators. Moreover, the importance and effect of policy objectives for the expansion of wind energy is highlighted. Rhineland-Palatinate is the federal state with the highest number of wind turbines in forested areas, and it is the only federal state where planning authorities are asked to earmark not only 2% of the state's total area for wind power concentration zones, but also 2% of its forest area (LEP RLP 2017).

But our results also show that the political and spatial planning assessment of wind power development in forested areas is subject to change. In Thuringia, for example, forested areas were in the past excluded from designation as a concentration zone for wind energy due to an action recommendation issued in 2007. The situation changed in 2016 when a new wind energy decree suspended that action recommendation and generally allowed the construction of wind turbines in forests. In North Rhine-Westphalia, in contrast, an opposite trend emerged. In April 2018, the government of the state of North Rhine-Westphalia passed an amendment to its state development plan (LEP NRW 2018) which abolishes the existing possibility of constructing wind turbines in forests. The main reason that the state government carried forward this amendment is that in large parts of North Rhine-Westphalia the extensive expansion of wind power is increasingly arousing reservations among the population. In addition, the previous target, which aimed at achieving a 15% share of all electricity production from wind energy, was also removed.

In general, in the public perception, forests are considered to be "closer to nature" than cleared, intensively used agricultural landscapes [40, 41]. Over the last centuries, European forests have been significantly altered by human activities, resulting in severe habitat loss, degradation and fragmentation, and a consequent loss of biodiversity [42, 43]. The German Federal Agency for Nature Conservation estimates that for every wind turbine, about 0.2 to 1 hectare of forest will be required, not only for the construction of the wind turbine itself, but also for its supporting infrastructure (e.g., turbine base, crane pads, access roads, cables) [44]. Accordingly, the German Federal Agency for Nature Conservation and important NGOs like Greenpeace, WWF and NABU are concerned that the installation of wind farms might put additional pressure on the already stressed forest ecosystems and demand that they be limited to commercially used forests with low biological diversity [44-47]. Wind turbines in commercial forests are compatible with timber production and represent an additional income for forest landowners [48].

With regard to legal aspects, the planning and approval procedures for wind turbines in forested areas have to comply with a higher intensity of species protection and protected area legislation than wind turbines in open landscapes [49]. This becomes particularly clear when we look at the example of bats. All bat species occurring in Germany are strictly protected by the European Habitats - Directive, which means that all forms of deliberate capture or killing of specimens or deliberate disturbance of these species, particularly during periods of breeding, rearing, hibernation and migration are prohibited (Art. 12.1a Habitats Directive; implemented in Germany in § 44 BNatSchG). Forests are one of the most important, if not the most important, habitats for bats, providing roosting and foraging opportunities for many species [50]. Accordingly, there are concerns that bat activity, and therefore collision risk, is higher at wind turbines in or close to forested areas compared to those on open land. Furthermore, more bat species could be affected due to the higher bat species richness in forests [39]. However, so far, knowledge of the impacts of wind turbines on the forest ecosystem is still very limited and further research is needed before the associated risks can be more clearly understood [15, 51].

The results of our study show that there is no “one” answer to the question of whether and to what extent German forest areas should be used for the generation of electricity from wind. When it comes to potential wind farm sites, the individual federal states have their own very different natural conditions. Especially those federal states with only few (remaining) free open spaces but large areas of forest with good wind conditions which are not protected under the BNatSchG, like Bavaria, Brandenburg, Baden-Württemberg and Hessen, are reliant on driving forward the expansion of wind energy in forests if they want to meet their renewable energy targets. This has also been recognised by the policy-makers and planners in the different federal states and a legal framework has been established for the expansion with diverse state-specific and regional planning requirements. On this basis, planning law and regional planning could successfully steer the hitherto comparatively slow expansion of wind energy in forest areas and ensure that windmills in forests are by no means “outlaws”.

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