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Key factors influencing onshore wind energy development: A case study from the German North Sea region

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ABSTRACT

The aim of this paper is to identify facilitating and hindering factors for onshore wind energy development near natural conservation regions, in particular in Lower Saxony's Wattenmeer region. An applied research approach was deployed to connect individual aspects of wind energy technology and establish a cross-disciplinary perspective on the expansion of wind energy. To this end, relevant facilitating and hindering factors were identified and then validated by a group of academic experts. The main factors were grouped within the framework of Strengths, Weaknesses, Opportunities and Threats. In a subsequent step, a sample of experts in the wind power sector evaluated the relative importance of the key factors, using an Analytic Hierarchy Process. The results show that factors positively influencing wind energy expansion exceed the hindering factors. Wind electricity is likely to benefit from opportunities such as climate change and from industry-specific strengths, for instance the competitiveness of wind in the German electricity market. Barriers and uncertainties that influence the further development of the sector relate to strict ecological protection laws and limited spatial opportunities for new projects. Finally, basic policy strategies were formulated which aim at fostering strengths and opportunities of wind energy development and at reducing weaknesses and threats.

1. Introduction

Globally, growing understanding and awareness of the potential consequences related to global environmental change is driving the necessity for governments to rapidly decarbonise their economies (Hodbod and Adger, 2014). With the energy sector accounting for three quarters of global greenhouse gas emissions, the provision of clean energy is at the heart of all actions (IEA, 2021). One key measure to keep track with the worldwide efforts to limit global warming to 1.5° is the doubling of solar photovoltaics (PV) and wind deployment in the next ten years (IEA, 2021). Thereby, many countries have embarked on a complex transformation of their socio-technical systems in pursuit of long-term climate neutrality by 2050 (Geels et al., 2017b). Transitioning requires deep systemic changes on multiple levels such as technologies, infrastructures, organisations, markets, regulations and user practices. Of all targeted sustainability transformation areas, shifting from fossil fuelled power to the generation of renewable electricity is perhaps the most significant (Croonenbroeck and Hennecke, 2020). At the same time, reconfiguring existing energy systems poses a large-scale challenge, as their elements and layers have co-evolved and aligned over time rendering them resistant to change. However, socio-technical transitions can be triggered by facilitating mutually reinforcing processes that ultimately strengthen innovations and weaken overhauled systems (Geels et al., 2017b). Energy transitions usually comprise a set of policies and economic incentives that ultimately lead to substantial improvements in green energy technologies, growing support from industry, positive cultural meaning and a favourable policy environment (Geels et al., 2017a). A favourable policy environment often includes the provision of feed-in-tariffs. In several countries the introduction of attractive subsidies led to a widespread adoption of renewable energy technologies, e.g., in China (Mori, 2018), Austria (Brudermann et al., 2013) or in the Czech Republic and Spain (Gürtler et al., 2019). In general, transitions gain momentum when socio-technical innovations and layers of interaction interlink and amplify each other's impacts on existing systems (Dóci et al., 2015; Geels et al., 2017a, 2017b). Policy making on national levels plays crucial roles in such transitions, e.g., in the United States (Stokes and Breetz, 2018), in Japan (Mah et al., 2013), in Taiwan (Lin et al., 2020) or in Mexico (von Lüpke and Well, 2020). The transition towards the use of low-carbon energy systems however is a slow process. Despite the increased use of renewable technologies, it

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remains unclear whether a complete substitution of fossil fuels is possible within acceptable time spans (Leipprand and Flachsland, 2018). This is especially problematic in the light of economic growth in the global south and in China, which comes along with fast extensions of fossil fuel infrastructure. In times of growing energy demand, energy security is prioritised over sustainability aspects or climate change concerns (Zaman and Brudermann, 2018). While emission reductions from the energy sector therefore are still on the rise on a global level, at least some progress in terms of decarbonisation can be recognized in higher-income countries.

1.1. The role of wind power in the German energy transition

The German sustainable energy transformation has progressed considerably with the introduction of the Renewable Energy Act in 2000 and the 20-year long provision of attractive feed-in tariffs positively affected the growth of wind and solar (Unnerstall, 2017). The law statutorily prescribes that all generated and consumed electricity should be greenhouse gas neutral in Germany by 2050 (EEG, 2021), thereby demanding that 65% of the electricity consumed in 2030 is provided by renewable sources. According to the Fraunhofer institute, renewable energies accounted for 50.9% of the German electricity mix in 2020 (Energy-Charts, 2021). For the first time, wind, solar and other renewable energy sources have surpassed fossil fuelled power (STROM-REPORT, 2021). At 27%, wind energy illustrates the largest green energy contributor, which generated more than a quarter of Germany's total electricity in 2020. By the end of 2020, there were 31,109 installed wind turbines in Germany, roughly three times more than in 2000 (Bundesregierung, 2021). Due to the naturally more favourable wind conditions, most wind parks[1] are located in Germany's Northern region. (Jung et al., 2018). Particularly Lower Saxony has by far the largest share with 6352 installed wind turbines (Statista, 2021). Albeit yearly growing wind energy shares on the total electricity mix, Germany's annual wind energy expansion in terms of net newly built turbines reflects less optimistic figures. The annual growth in wind turbines has fallen dramatically since 2017, the year when tendering processes were introduced. A tendering scheme is a competitive mechanism by which authorities publicise installation capacities for wind power plants available for bidding by wind energy businesses (Bundesnetzagentur, 2021). According to Deutsche WindGuard (2020), 75% fewer turbines were connected to the grid in 2020 compared to 2017. This drastic development slowdown is threatening the long-term target of climate protection (Guan, 2020) and thus requires deeper investigation into what factors hinder and facilitate the development and expansion of wind energy.

The scientific literature is extensive with respect to wind energy expansion as an essential driver of the *Energiewende*. It can be characterized as a highly debated and multidisciplinary field of research. Energy scholars consider onshore wind as a promising green energy source which directly competes with fossil fuels in terms of production costs (Masurowski et al., 2016, Croonenbroeck and Hennecke, 2020). However, as will be discussed in the following, there are several challenges yet to be solved. Consequently, experts from several scientific disciplines have set out to investigate specific areas and parameters of onshore wind energy development in Western countries. Roughly, three wind energy research foci can be denominated that cover a broad set of potentials and challenges associated with the German case.

First, research on economic aspects of wind energy expansion analyses monetary opportunities and downsides, while technical perspectives focus on technological and material features. For regulatory purposes, wind turbines need to be reassessed regularly and typically have a lifespan of 20–25 years, after which electricity output decreases substantially and maintenance costs grow (Grau et al., 2021). Two options present themselves to wind park operators, namely the choice of modernizing and repowering wind turbines or searching for new site selection (Jung et al., 2018). Additionally, the wind energy sector has seen considerable improvements in technology and costs. For instance, compared to 2011, the average electricity cost of wind power had been reduced by 12% in 2015 (Chang et al., 2021).

Second, environmentally focused scientific investigations are oriented towards examining the impact of wind energy expansion on natural systems. The growing production of wind energy and the resulting widespread construction of wind parks can lead to strong negative impacts on biological communities and biodiversity (Bose et al., 2018). Subsequently, new conservation issues emerge. Besides the collision of birds and bats through direct contact with the turbine structures, the loss of nesting and foraging habitats forms an indirect impact caused by wind parks (Bose et al., 2018). Both factors are relevant for the location of wind parks examined in this paper. The *Nationalpark Wattenmeer* at the coast of Northern Germany is a unique landscape that offers both a place to breed for more than ten million wading and water birds and a place to rest for migratory birds on their way along the east Atlantic migratory route (WWF, 2021). Furthermore, the national park provides recreational purposes for tourists and residents, which are partially lost due to the recent development of wind parks close to or even in protected areas (Arnberger et al., 2018). Consequently, environmentalists, managers and researchers have argued for a restriction of the development of wind parks in protected areas, especially areas with a high density of birds (Arnberger et al., 2018; Bose et al., 2018).

Third, policy-related and public attitudes literature on the one hand investigates how national, federal, and local decision-makers attempt to align the energy industry's prospects and risks with the ambitious target of 100% green energy in 2050. For instance, Nordensvärd and Urban (2015) find that the German Renewable Energy Act and the feed-in tariff have provoked a lock-in effect that focuses heavily on technological advancement and project expansion rather than on establishing long-distance transmission capacity of the current grid system. Studies further draw attention to cumbersome and bureaucratic permission procedures which affect the duration, approval, and may cause legal uncertainties (Guan, 2020). The compulsory tendering process introduced in 2017 has been considered a particular policy hurdle (Fraune et al., 2019). On the other hand, researchers set out to investigate the relationship between wind energy development and public acceptance. A study conducted by Langer et al. (2018) shows that the opportunity of citizen participation in the *Energiewende* plays an overwhelming role. Two contested aspects of wind energy in the public discourse are the concern of infrasound and siting close to residential areas. A study conducted by Krekel and Zerrahn (2017) shows that the construction of wind turbines within 4000 m radius negatively affects life satisfaction of surrounding residents, however discontent is timely limited and does not intensify with proximity.

1.2. Research aims and structure of the paper

In order to link these strands of research and their frequently specific study objects, this paper contributes to the debate on wind energy expansion from a broader topic-transcending perspective. The objective of the paper is to identify and assess the main factors relevant for the diffusion of onshore wind energy in Germany. Based on multi-criteria decision analysis, the relative importance of the identified factors for wind energy development were assessed by an expert sample, representing wind park operators in Lower Saxony's *Wattenmeer* region and energy experts from academia. The present case study does not only deal with areas with high wind generation potential in Germany, but it additionally displays the peculiarities of wind power generation in natural conservation regions. Based on this assessment basic policy strategies for interest groups promoting wind energy diffusion will be

[1] According to German law, wind parks are a minimal concentration of three wind turbines in a way that their impact areas overlap or at least touch (BVerwG, 2004).

derived.

To this end, this article is structured as follows. Section two outlines the research design and the employed methodological approach. In section three, the factors influencing wind energy development are outlined according to their strengths, weaknesses, opportunities, and threats (SWOT). Further, the factors are quantified and prioritised by the means of an Analytical Hierarchy Process (AHP). In section four, basic policy strategies are discussed and recommended based on our findings. A brief conclusion in section five completes the study.

2. Methods

This study was implemented in a four-step study design. As a first step, possible decision factors for the SWOT analysis were identified based on a literature review on wind energy in Scopus. For the sample creation of the literature, 2.035 documents resulted by introducing the keywords 'wind', 'energy' and 'Germany'. To narrow down the list to the most relevant literature, 2014 was taken as the starting date to review literature. In this same year, a comprehensive amendment of the Renewable Energy Sources Act (EEG) was approved by the German parliament *(Deutscher Bundestag,* 2014). Older scientific documents may not correspond to current regulations. In addition, solely articles from peer-reviewed journals were included. The resulting sample size was 583 articles. In a further step, a comprehensive literature review allowed filtering for articles relevant to our research design. Based on the relevant articles a total number of 20 SWOT factors were identified. To determine the most relevant amongst these, a factor validation was carried out subsequently. Thereby, a detailed list of factors was sent to energy sector experts, who were asked to rate them according to their relevance for onshore wind energy development in Germany, specifically in the selected region. The rating scale ranged from 1 - very relevant to 5 - not relevant. The odd scale was chosen because it includes a midpoint, which gave participants the opportunity to rate two factors as equally important.

In a second step, the number of factors per category (strengths, opportunities, weaknesses and threats) was determined, depending on the values the experts attributed to them. Therefore, the mean value for each element was computed. Most of the relevance scores given by the experts ranged between 1 (very relevant) and 2.5 (moderately relevant). Values above 2.5 occurred rather rarely and respective factors were therefore not classified as significant for further analysis. Consequently, out of 20 pre-selected factors 14 were identified as significant for the implementation of the next steps (a list of all 20 factors is included in the supplementary materials).

Furthermore, the results of the expert survey showed a considerably stronger evaluation of the positive factors, which resulted in the division into four strengths and opportunities and three weaknesses and threats respectively. The results are depicted in Appendix A1.

In a third step, personal phone calls were carried out with nine different wind park operators to inquire about their availability to participate in this study. The sample of wind park operators was selected according to their geographical proximity to the North Sea coastal region of Germany and particularly the *Nationalpark Wattenmeer*. Thereupon, individual electronic mails were sent to the nine wind park operators and to the four wind energy experts that previously validated the basic relevant factors. Subsequently, the experts' judgments were gathered with the support of the online tool LimeSurvey. Ten experts completed the questionnaire, of which seven represented onshore wind park operators and three were academic experts. The background of the sample of experts are shown in Table 1. Overall, the sample is considered suitable for the purpose of this study, and in respect to composition and size it is comparable to samples used in related studies (e.g., Brudermann et al., 2015; Posch et al., 2015).

On the basis of 24 pairwise comparisons, the wind energy experts were asked to classify, according to their perceived relevance, the factors' relative importance for the development of onshore wind energy in the North Sea coastal region of Germany. These were divided into six pairwise comparisons each for the four strengths and four opportunities, and three comparisons each for the three opportunities and three risks. The final cross-category analysis again contained six pairwise comparisons, i.e. strength factors opposed to weakness factors. All comparisons were made on the basis of the nine-step scale suggested by Saaty (1999), ranging from 9:1 (factor one is much more important), to 1:9, (factor two is much more important). The even numbers were left out, and the centre of the scale (1:1) indicates that the respective factors were considered to be equally important.

Table 1
Background of the sample of experts.

Background	n
Head of Department	1
Technical operations Manager and Project Planner	1
Consultant for Energy Management	1
Executive Director	1
Project Manager	3
Research & Education	3

In the fourth step, the Analytical Hierarchy Process (AHP) was conducted. This process is useful for making multi-criteria decisions involving strengths, opportunities, weaknesses, and threats (Brudermann et al., 2017). The AHP analysis was used to evaluate the relative importance of the factors as perceived by the respondents. Applying this method also enabled the formulation of possible policy strategies for wind energy development (as discussed in section four). Following the detailed method description by Posch et al. (2015), the judgment matrix for processing with AHP was based on the mean judgments of the respondents. Subsequently, each judgement matrix was multiplied by itself and the principal eigenvectors were determined in order to calculate the relative factor priorities within the individual SWOT categories. The relevant category priorities were determined by a pairwise comparison of SWOT categories and relative overall factor priorities were then derived by multiplying category priorities with the relative factor priorities within the SWOT categories. As the last step of the process, the consistency of the expert judgements was tested through the calculation of the consistency ratio (CR). The level of consistency ought to be below 10% to indicate an adequate degree of consistency (Saaty, 1980).

3. Results

As described previously, we utilised strict literature review parameters and included empirical validation by experts to identify the most relevant strengths, weaknesses, opportunities and threats with respect to onshore wind energy development in Northern Germany. Strengths and weaknesses represent internal factors which respectively positively or negatively impact wind energy development in Germany. Opportunities and threats on the other hand depict external factors that are advantageous or disadvantageous for the expansion of wind power in Germany. In total, we found 14 relevant factors, four strengths, three weaknesses, four opportunities and three threats. In the following subsections, these factors will be further characterized and quantified, via the AHP method, based on the assessments provided by wind park operators and wind energy experts. The SWOT factors identified are summarized in Table 2.

3.1. Strengths

As a result of the factor validation by wind energy experts, four relevant strengths were identified: low CO2 emissions, the North Sea coast as a suitable location for wind farms, competitiveness of wind energy on the energy market and repowering. Due to low CO2 emissions, wind power is considered a key technology for Germany's

Table 2
SWOT analysis for onshore wind energy development in the German North Sea region.

	Positive	Negative
Internal	Strengths S1: Low CO_2 emissions S2: Location for wind farms (North Sea coast) S3: Repowering S4: Competitiveness of wind energy on the energy market	Weaknesses W1: Impacts on humans W2: Impacts on wildlife W3: Limited spatial opportunities for wind energy expansion
External	Opportunities O1: Political will and incentives O2: Technological developments in the storage sector O3: Coal and nuclear phase-out O4: Climate Change	Threats T1: Local protest and resistance against projects T2: Complicated and lengthy bureaucratic procedures T3: Strict ecological protection regulations

transformation towards a low-carbon economy (Destek and Aslan, 2020). The majority of human-induced greenhouse gases originate in the energy sector (IPCC, 2014); thus, it is necessary to increasingly replace fossil-fuelled power plants by alternative renewable energy sources. Of all technologies available, generation of energy through wind provides the strongest potential in terms of installed capacity after hydro power (Jenniches et al., 2019).

The second identified strength refers to the selected geographical location for wind energy development. The North Sea coast represents an opportune area for siting wind parks due to the favourable wind conditions (Croonenbroeck and Hennecke, 2020). From a Germany-wide perspective, Lower Saxony by far operates most wind parks and has an overall wind power capacity of 11,430 MW (STROM-REPORT, 2021). In the future, however, one of the surveyed experts expects that local wind conditions will play a subordinate role compared to power generation close to consumption.

The third strength of the current wind energy development in Northern Germany concerns the competitiveness of wind technology. Since the introduction of the Renewable Energy Act in 2000, considerable progress has been achieved in optimising technology and costs of wind energy. This is clearly indicated by the regulatory transition from monetary subsidies through feed-in tariffs to open market tendering processes in 2017 (Guan, 2020). Regarding costs, onshore wind energy technology is already able to compete with conventional energy power plants. Wind power generation is considered the most cost-competitive alternative compared to other renewable electricity sources (Chang et al., 2021; International Renewable Energy Agency, 2020; Smith Stegen and Seel, 2013). From an economic perspective, wind energy is technically mature and is progressing as a cost-effective electricity source (Nordensvärd and Urban, 2015).

The fourth relevant strength is summarized under the term repowering. It refers to the modernization, replacement, and renewal of older wind turbines with the aim of increasing energy production and efficiency (Jung et al., 2018). With many wind turbines reaching the end of their service lifetime in 2020, repowering is a viable option to maintain wind power efficiency even without the benefits provided by the German Renewable Energy Act (Grau et al., 2021). According to one of the surveyed academic experts, repowering is especially significant vis-à-vis policymakers only reluctantly releasing new siting opportunities for wind turbines.

3.2. Weaknesses

The factor validation by wind energy experts revealed a total of three relevant weaknesses of wind energy development in Germany's Northern region. First, wind turbines generate negative external effects for humans. Residents are impaired by noise emissions emanating from wind turbines (Krekel and Zerrahn, 2017). Moreover, wind parks are perceived as a severe disturbance of the surrounding landscape (Arnberger et al., 2018) which additionally and negatively affects local tourism demand (Broeke and Alfken, 2015).

Second, impacts on wildlife negatively affect wind energy development. Thereby, concerns relate to the increased mortality of migratory birds, the cease of endangered species' habitats and the degradation of local flora (Welcker et al., 2017). On the other hand, the occurrence of certain species and citizen nature conservation initiatives might considerably delay or even hinder the construction of new sites (Weber et al., 2017).

The third weakness identified refers to the limited spatial opportunities for wind energy expansion. Although repowering endeavours increase efficiency and production of wind energy, studies conclude that improvements alone are not sufficient for a successful energy transformation in Germany (Grau et al., 2021) and sustainable wind power locations ought to be identified (Eichhorn et al., 2017). However, several favourable sites for wind turbines are already in use, under strong competition or may not be built on due to legal regulations and political manoeuvring, for instance the controversial minimum distance regulations (Eichhorn et al., 2017; Masurowski et al., 2016; Naturschutzbund Deutschland, 2018).

3.3. Opportunities

Regarding opportunities related to wind energy development in Germany's North Sea region, four factors have been identified and validated by the consulted wind energy experts. First, political will and incentives for wind energy operators are crucial for wind energy development in Germany. In recent times, political agreements and climate-related goals on regional, national, and sub-national levels have been adopted and publicly communicated. One major milestone is the European Green Deal and the ambition to reduce Europe's CO2 emissions by 55% until 2030 (European Commission, 2020). With this, a European Climate Law which emphasizes the significance of a sustainable, affordable and secure energy system has recently achieved provisional agreement between the European Parliament and Council (European Council, 2021). In Germany, a decision issued by the Supreme Court in favour of more ambitious and strict climate laws is considered a historical achievement in the fight against global warming (BVerfG, 2021). A novel scenario-based study commissioned by Agora *Energiewende* (Prognos, 2021) takes account of these more ambitious goals. Although the significance of hydrogen production is expected to grow substantially, the study builds on PV and wind to achieve a sustainable energy transition by 2045. However, one of the experts indicates that the lacking political will of national and sub-national governments in recent years have clearly outlined how heavily this factor influences wind energy development in Germany.

Second, the coal and nuclear phase-out as enacted by the German Government is an important trigger for renewable energy development. In 2011, Germany decided to phase-out eight nuclear power plants and nuclear power by 2022 (de Menezes and Houllier, 2015; Cherp et al., 2017). Currently, there are six active nuclear power plants to be shut down (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 2020). Furthermore, in 2020 the government put forward an action plan and laws governing the phase-out of coal-fired power generation (*Bundesministerium für Wirtschaft und Energie, 2020*). As to ensure that the structural transition occurs in a socially bearable and economically feasible manner, it is set to be realized by 2038.

The third factor identified aims at the opportunities for wind energy development which are derived from Climate Change. Wind energy generates power from never-ending resources and produces low greenhouse gas emissions and waste. Moreover, it was found that wind energy is not strongly affected by a changing climate (Koch and Büchner, 2016). The ever-growing presence and latency of Climate Change has triggered the necessity for low-carbon innovations and investments with the potential to mitigate the negative impacts caused by global warming (Chang et al., 2021). Halting the Earth's rising global average temperature is an increasingly prioritised and publicly debated topic on the transnational scene (ProCon.org, 2021).

The fourth opportunity related to wind energy development involves technological developments in the storage sector. With increasing amounts of renewable energy sources being fed into the German grid, the variability of electricity supply increases (Sinn, 2017). Similarly, electricity demand is temporally variable. To ensure long-term grid stability, energy storage options are considered key technologies for the energy transformation in Germany (Weitemeyer et al., 2015). Energy storage technologies have developed considerably in the last decade (Siddique and Thakur, 2020). According to a study conducted by the European Patent Office and the International Energy Agency (2020), patent registrations in the energy storage sector grew by 14% per year from 2005 to 2018. The patent currently dominating the energy storage market is battery storage with lithium-ion batteries.

3.4. Threats

Wind energy development in Germany is exposed to different threats, of which three are especially relevant to the consulted experts. First, local protest and resistance against projects influence the expansion of wind power. Local resistance against the construction of new wind parks is a complex and multi-layered social phenomenon (Weber et al., 2017). Whereas the so-called *Not in My Backyard* Phenomenon (NIMBY) represents oppositional attitudes towards the construction of wind parks nearby residential areas, Reusswig et al. (2016) found that public health, local identity, aesthetics and economic feasibility considerations play a role, too. As a consequence, such protests have caused substantial added costs and delays to projects due to pending lawsuits and deliberate blockades (Reusswig et al., 2016). One of the experts points at regional plans in Lower Saxony which are essential for the expansion of wind energy siting and against which lawsuits were introduced.

The second factor threatening the development of wind energy in Germany refers to complicated and lengthy bureaucratic procedures. National and sub-national regulations as well as bureaucratic obstacles lead to uncertainty for wind energy companies (Smith Stegen and Seel, 2013). This is reflected in the lagging development of new wind plants since 2017, the same year of the introduction of tendering processes for wind energy expansion. Potential causes for this underdevelopment and the systematically underbid tenders are yet unexplored, however explanations are associated with lagging construction approvals, complicated submission requirements, lawsuits and minimum distance requirements (Grashof et al., 2020). One expert justifies these complex procedures by pointing at different regional concerns which require careful weighting to prevent spatial conflicts.

Third, strict ecological protection regulations pose a threat to wind energy expansion in Germany. European as well as German species protection laws require that impacts on nature and endangered species are taken account of when planning for wind energy sites. Hence, on European as well as national level the legal regime for species protection has the potential to become a substantial obstacle for enlarging the capacity of wind energy (Akerboom et al., 2021). An example for these conflicts is the direct interference of the rotor blades of a wind turbine with the airspace of birds and bats causing collisions and deaths (Bose et al., 2018), as well as the habitat loss of local, wind energy sensitive bird populations in proximity to wind turbines (Eichhorn et al., 2017; Masurowski et al., 2016; Naturschutzbund Deutschland, 2018).

3.5. AHP analysis

The SWOT analysis is a qualitative tool that allows one person or company to visualize factors important for strategic decision-making. However, the SWOT matrix does not provide insights on the relative relevance among factors and thus complicates the task of decision-makers to prioritise among the available options (Brudermann et al., 2017). The Analytic Hierarchy Process (AHP) method aims to overcome this obstacle and provides a tool for assessing and organising complex decisions. Hence, a rational framework is created for the factors and the criteria and alternative decisions are quantified in order to derive an overall ranking for the importance of all SWOT factors.

During the information gathering and evaluation, 80% of the respondents' judgments were accepted in this research paper. Thus, two out of the ten participants' responses were considered as invalid due to very high inconsistencies in their pairwise comparisons. As for the analysis phase, there is a clear tendency that both positive categories, namely opportunities (p = .57) and strengths (p = .25) show significantly higher group priority values than their negative peers, threats (p = .12) and weaknesses (p = .06). As a consequence, the AHP method assigns more importance to the positive category factors.

In the highest-rated category, opportunities, the factor [O3] *Coal and nuclear phase-out* was given the highest relative priority (p = .53), followed by [O4] *Climate Change* (p = .26) and [O2] *Technological developments in the storage sector* (p = .15]. [O1] *Political will and incentives* achieved a relative priority way below its equivalents (p = .06). Second, the group of strengths is led by the factor [S1] *Low CO2 emissions* (p = .52). [S4] *Competitiveness of wind energy on the energy market* (p = .27) and [S3] *Repowering* (p = .14) are perceived as less important by the sample participants. In fourth place with the lowest relative priority (p = .07) is [S2] *Location for wind farms (North Sea coast)*.

As for the negative categories, threats are given more importance than the group of weaknesses. The two factors, [T3] *Strict ecological protection regulations* (p = .58) and [T2] *Complicated and lengthy bureaucratic procedures* (p = .32), have scored a high relative relevance. [T1] *Local protest and resistance against projects* (p = .10) is considered, by far, the least important factor as a potential threat for the wind energy development. Finally, as mentioned before, the weaknesses category was considered the weakest group in our sample. [W3] *Limited spatial opportunities for wind energy expansion* (p = .59) and [W1] *Impacts on humans* (p = .30) are regarded as the strongest decision factors opposed to [W2] *Impacts on wildlife* (p = .11).

To explain the spikes of relative local priorities (p ratings above .55) within the two negative categories weaknesses and threats, it is important to remember that these SWOT groups each include three decision factors unlike the positiveSWOT categories that comprise four factors. Naturally, this implies that the relative scores for the positively connoted factors will be lower, as the relative priorities are distributed among a higher number of factors. This is shown by the factors [T3] *Strict ecological protection regulations* (p =.58) and [W3] *Limited spatial opportunities for wind energy expansion* (p = .59) compared to the highest-ranking factors [O3] *Coal and nuclear phase-out* (p = .53) and [S1] *Low CO2 emissions* (p = .52). However, the influence is diminished in the AHP as the group priorities of the positive SWOT categories prevail over the groups of weaknesses and threats.

In order to analyse the decision factors throughout the SWOT groups, the relative priorities of each factor were multiplied with the group priority of their respective SWOT category. In the AHP method, these computations are named overall priorities as all factors are placed on the same level. It is worth mentioning that the overall priorities ranking will

Table 3
Relative priorities of wind energy development SWOT factors.

			factor priority*	overall priority
Strengths (p = .25)	S1	Low CO_2 emissions	.52	.13
	S2	Location for wind farms (North Sea coast)	.07	.02
	S3	Repowering	.14	.03
	S4	Competitiveness of wind energy on the energy market	.27	.07
Weaknesses (p = .06)	W1	Impacts on humans	.30	.02
	W2	Impacts on wildlife	.11	.01
	W3	Limited spatial opportunities for wind energy expansion	.59	.04
Opportunities (p = .57)	O1	Political will and incentives	.06	.03
	O2	Technological developments in the storage sector	.15	.08
	O3	Coal and nuclear phase-out	.53	.30
	O4	Climate Change	.26	.15
Threats (p = .12)	T1	Local protests and resistance against projects	.10	.01
	T2	Complicated and lengthy bureaucratic procedures	0.32	0.04
	T3	Strict ecological protection regulations	0.58	0.07

* The sums of all factor priorities within a SWOT equals to 1. The sum of all overall factor priorities also equals 1 (not considering rounding errors).

be dominated by decision factors of opportunities and strengths because the positive SWOT categories outweigh their negative coequals. Thus, it is not surprising that the three highest rankings belong to the factors from the group of opportunities. [O3] *Coal and nuclear phase-out* (p = .30) and [O4] *Climate Change* (p = .15) dominate the overall priorities. [S1] *Low CO2 emissions* (p = .13) is considered the third highest-ranking factor, while for the factors of the negative categories, the superior overall priority value is attributed to [T3] *Strict ecological protection regulations* (p = .07). It grades as the fifth highest overall factor.

The results of the AHP method of the sample are shown in Table 3 and illustrated in Fig. 1. Moreover, Consistency Ratios (CR) of every comparison are documented in Table 4 and stay below the 10% threshold that Saaty fixed in his literature (Saaty, 1980). By analysing the AHP method of two distinct groups, company representatives, with five participants and academic experts, with three participants, a minimal difference in judgments is perceivable. Both groups of respondents provided the same ranking for the SWOT groups. In fact, it is noticeable that the distance between the highest-ranking group of strengths and the lowest scoring category of weaknesses are in the same range for the group of wind park company representatives (group priority ranking from .58 to .06) and for the academic experts' group (with p ranking from .54 for opportunities to .07 for weaknesses).

Even though the judgments of both expert groups are almost identical, there are some changes regarding the importance of the individual factors within each SWOT category, namely the local priority rankings. Note that the local priorities of the wind park operators' personnel are highly similar to the rankings of the total sample, as it is depicted in Appendix A2. This is the case as this group consists of more participants than the academic experts group. In the category of strengths, the judgments of both groups ranked the decision factors completely differently. In fact, while company representatives ranked the four factors in the same way as in the overall average sample (c.f. previous example), the academic experts assigned more significance to [S4] *Competitiveness of wind energy on the energy market* followed closely by [S1] *Low CO2 emissions* and classified [S3] *Repowering* as the least important factor of decision.

With regards to weaknesses, the respondents of the scientific community ranked [W1] *Impacts on humans* as the highest priority, while the other group perceives [W3] *Limited spatial opportunities for wind energy expansion* as the most pressing fragility for the wind energy development in Germany. Both groups agree that [W2] *Impacts on animals* are the least significant factor in this category. Contrary to the previously mentioned categories, this time the group of academic experts influences the strongest the average of the opportunities group. [O3] *Coal and nuclear phase-out* and [O4] *Climate Change* rate the strongest for the group of academics. The respondents of company representatives also acknowledge [O3] *Coal and nuclear phase-out* as the most important factor, however to a lesser degree. The next decision factor is [O2] *Technological developments in the storage sector* and then, do the group of wind park personnel judge the German coal and nuclear phase-out as a significant opportunity factor.

In the category of threats, academic experts judged that [T3] *Strict ecological protection regulations* are the main reason of concern for the wind electricity sector. The subsequent factors [T1] *Local protest and resistance against projects* and [T2] *Complicated and lengthy bureaucratic procedures* rank very close to each other. The company delegates' responses are closely matched to the overall sample's judgements. As a reminder, [T3] *Strict ecological protection regulations* lead the priority ranking, followed by [T2] *Complicated and lengthy bureaucratic procedures*, while [T1] *Local protest and resistance against projects* is rated as the least significant decision factor.

4. Discussion

This study enabled us to achieve the primary objective: to identify and assess the main factors relevant for the diffusion of onshore wind energy in Germany. We assessed the relative importance of these identified factors for wind energy development with a multi-criteria decision analysis. A sample was taken of wind park operators in Lower Saxony's *Wattenmeer* region. This study allowed the identification of unique aspects of wind power generation in natural conservation regions.

Several limitations apply to the methodology utilised in this study. First, the literature review approach may be prone to subjective biases. The authors followed strict criteria for the choice of suitable articles by using keywords, date limitations and relevance filtering. That way, the approach may accurately be reproduced. However, the choice of abstracts and scientific papers was a decision finally made by the authors. Hence, future researchers may judge the relevance of the articles within the final sample differently. Second, the representatives of wind energy experts and wind park operators were limited. The total number of participants resulted from a small number of delegates per professional group, which does not represent the majority of all expert opinions in Germany. Third, a selection of save off factors needed to be conducted, since the AHP is not feasible with many factors. This led to the exclusion of relevant factors for the expansion of wind energy in Germany. Fourth, albeit the advantage an odd scaling offers to participants, namely the equal weighting of factors, it also entails a significant disadvantage. Midpoints have proven to be used as an 'escape category' for indecisive participants. Fifth, the results of the AHP calculations revealed that the answers were often inconsistent on an individual level (exceedance of the 10% inconsistency threshold recommended by relevant literature). This constraint resulted from the limited cognitive capacities and biases of the respondents. Nevertheless, there is no scientific justification for this threshold and the aggregated consistency ratios equalised the individual cognitive biases.

The relevance and contribution of this paper to current research lies in the perspective applied. Previous studies on wind energy so far were strongly oriented towards the in-depth consideration of single aspects of wind energy, such as specific technical, economic, or environmental risks and benefits. In this respect, individual factors, but not a comprehensive comparison of factors influencing the wind energy development of a specific region were addressed. Some studies have investigated the risks posed by wind turbines to certain bat and bird species (Welcker

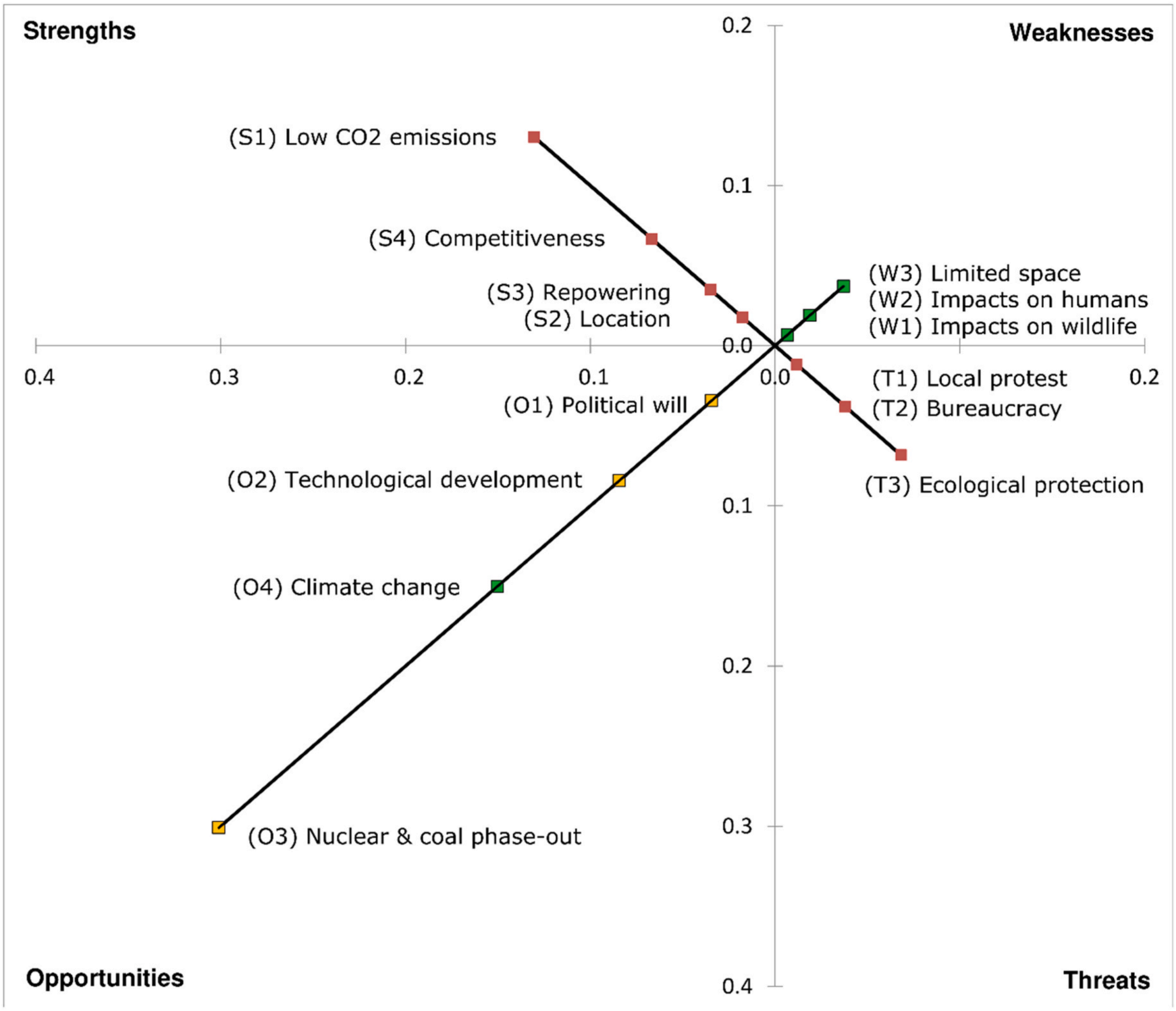

Fig. 1. Illustration of SWOT-AHP results. Higher distance to the centre of the matrix indicates higher factor priority. Positive SWOT factors (Strengths and Opportunities) dominate over the negative factors (Weaknesses and Threats), leading to an asymmetrical presentation.

Table 4
Consistency ratios for AHP assessments.

Comparisons	Consistency Ratio
Strengths	9.54%
Weaknesses	3.05%
Opportunities	8.37%
Threats	8.59%
SWOT Factors	8.72%

et al., 2017; Bose et al., 2018; Jenniches et al., 2019), as well as possible negative impacts on humans (Krekel and Zerrahn, 2017). Others have focused on aspects such as technological development of batteries (Siddique and Thakur, 2020), grid integration and (Weitemeyer et al., 2015; Sinn, 2017), monetary incentives (Nordensvärd and Urban, 2015), the political (Grashof et al., 2020) and societal discourse (Reusswig et al., 2016; Langer et al., 2018; Fraune et al., 2019). Additionally, some researchers have questioned the impact of wind energy development on Climate Change and the potentials and threats the climate crisis might pose for the further development of wind energy (Koch and Büchner, 2016). All in all, these studies were rather oriented towards discovering novel and discipline-specific insights and have contributed to basic research.

In contrast, an applied research approach was deployed to connect individual aspects and establish a broad and cross-disciplinary view of the overall furtherance of wind energy in Germany. In this article, a policy-oriented approach was selected to investigate the relative importance of internal and external facilitators and barriers from the viewpoint of wind park operators and wind energy experts. The combination of these distinctive perspectives made it possible to obtain a holistic view of favourable and hindering factors for wind energy expansion in Germany and consequently to develop particularly relevant policy strategies. All experts involved had a solid knowledge background in different wind energy related fields. Nevertheless, a deliberate interpretation of the results is necessary because every wind park location is different. The specific, location-dependent factors and the context, in which the wind parks operate, require consideration. This holds especially for external factors, such as threats and opportunities.

As far as the selected case is concerned, this is the first paper to apply SWOT-AHP analysis in order to evaluate decision factors governing wind energy development. Thereby, the organisation of SWOT factors and quantification of their relevance supports the formulation of basic strategies for large-scale implementation of wind energy development policies in Germany. The comparison of strengths and opportunities (S-O) allows the derivation of basic strategies for the future. The guiding question may be formulated as follows: How can strengths be built upon to realize opportunities? Wind energy technology produces very low emissions and has been rapidly evolving in the last decades. Over time, an entirely new market that is capable of competing with incumbent fossil-based energy technologies emerged. In addition, wind turbine technology continuously offers considerable improvement opportunities through repowering. Thus, the environmental friendliness and advanced wind technology ought to be emphasized and strategically coupled with external opportunities. With two unsustainable and fossil-intensive electricity industries being phased out and the climate crisis drastically worsening, there is an urgent need for rapid and large-scale action. While alternative technologies such as hydrogen are still niche developments, wind energy has the capacity to provide much of the electricity needed at reasonable prices while adhering to the CO2 balance. Due to the high relevance of the strengths and opportunities, policy-oriented strategies should emphasize the environmental and commercial benefits of wind energy. It may be fortuitous for local policymaking to publicly communicate the ecological and monetary advantages of renewable energy sources by illustrating them in direct juxtaposition to the downsides of coal and nuclear electricity generation.

Additional strategic leads can be derived by analysing the external opportunities of wind energy development and the internal weaknesses of the technology. The primary question for basic strategies in this field is how the weaknesses of wind energy can be retained to realize the opportunities provided by wind energy. In general, weaknesses were rated the least relevant factor category. Thus, these results indicate that wind energy experts and operators are rather unpreoccupied with weaknesses of wind energy. With rapidly evolving technological breakthroughs, electricity generation by wind is becoming less dependent on weather conditions and storable. Thus, expanding wind energy to regions that are technically less favourable is possible and provides an opportunity to attribute more priority to the impacts that wind turbines cause on humans and wildlife. With wind energy expanding at much higher pace, a smoother phase-out of coal and nuclear power can be ensured.

Further, basic strategies can be inferred from comparing strengths and threats (S-T). How may the strengths be applied to reduce the technology's vulnerability to threats? An action plan is required to counter scepticism towards wind energy and at the same time strengthen the advantages offered by low CO2 emissions and the competitiveness of wind energy on the energy market. In addition to the diffusion of education and knowledge-sharing to greater audiences, policymakers should reinforce the inherent transformative capacity of wind power in promoting active stakeholder engagement. This is supported by Rand and Hoen (2017) and Petrova (2013), who found community ownership to be correlated to higher support and more positive attitudes towards wind energy. In fact, a sense of participation, trust and fairness by stakeholders may prevent strong opposition and make it possible for an in-depth comprehension of projects. Multiple stakeholders of different backgrounds, i.e. residents, wind park developers, environmental conservation experts, fossil-fuel plant managers, shareholders, etc. should be brought together. The goal would be to define policies that take the interests of most stakeholders into consideration. Such projects can support public participation, while they remove social barriers (D'Souza and Yiridoe, 2014).

As a final strategic direction, internal weaknesses are considered with respect to external threats. Hence, the guiding question may be how to come up with containment strategies that limit the influence of current deficiencies on the wind power sector. The risks and uncertainties associated with strict ecological protection laws and citizen resistance in form of e.g. lawsuits may deter wind park companies and impede future project development. The wind park representatives perceived the required complicated bureaucracy and lengthy procedures as a relevant barrier. Hence, reliable implementation of corresponding policy strategies is necessary to prevent the mutual contribution of weaknesses and threats to negatively influencing the further development of wind energy. For instance, the simplification and unification of federal and national legislations might ensure higher legal certainty, transparency of information flows and more swift availability of wind park construction permits. To absorb some of the aforementioned risks and uncertainties in the early project development phase, especially for smaller and citizen initiatives, the state could instate risk assumption mechanisms. In cases where wind project development encountered implementation barriers, governmental authorities could step in and guarantee both financial and consultative support. Lastly, the amount of new construction locations could be increased by improved coordination and unity of the German states about ecological protection regulations.

The AHP process revealed a strong positive attitude of wind energy experts and operators towards the advancement of wind power in Germany. In contrast, low priorities were assigned to weaknesses and threats, thus rendering the defence strategy rather negligible. Private sector representatives are involved in daily activities and especially aware of the internal operational and strategic challenges that their organisation or sector faces and yet assign the same relative importance to the positive categories as the academic expert respondents. These in turn demonstrate more awareness with respect to external technological, political and ecological related challenges to the wind energy generation sector. The empirical evidence clearly emphasizes environmental and ecological benefits from the experts' perspective. The replacement of fossil-intensive energy sectors by low CO2-emission technologies and the growing global awareness of Climate Change may play in favour of the wind park industry, however its success is still dependent on how political and social barriers may be surpassed to proceed with the transformation of the current fossil-based economy.

In future work, more research and scientifically independent investigation should be dedicated to this question. Since feed-in tariffs have been replaced by mandatory obligatory tendering processes as a next logical step for building a competitive wind energy market in 2017, the development of wind power has been stagnating. The cause for these developments and its effects on future wind energy expansion are still underrepresented in academic research. According to a study commissioned in 2020 by the think tank Energy Watch group and the foundations World Future Council and the Haleakala Foundation, the introduction of tendering has been leading to 'higher market concentrations of a few incumbent firms and international developers, to the detriment of small or new actors (Jacobs et al., 2020). Small and medium-sized business initiatives such as citizen energy projects are deterred by the risks of bearing the transaction and potential sunk costs of bidding. In contrast, larger-scale actors benefit from economies of scale and easier access to project capital. The study conducted in 2020 is based on empirical observations in 20 countries and concludes that a more innovative and target group-oriented policy mix is necessary to meet climate targets in an inclusive and participatory way. All in all, this study supports the literature in that much of the scientific research firmly assesses wind energy as an indispensable power source in the future electricity mix. Moreover, the results highlight that weaknesses and threats of wind energy development cannot be ignored but are considered manageable from the respondents' perspectives.

5. Conclusions and policy implications

The overall opinion of the experts is rather optimistic for the future development of wind energy in the North German coastal region. In the SWOT-and-AHP analysis, the perception of positive decision factors exceeds the adversely perceived factors. In fact, the wind power sector has benefitted from various external opportunities such as Climate Change or the nuclear and coal phase-out. Furthermore, the low greenhouse gas emissions and the competitive characteristics of the wind technology in the energy market have contributed to wind electricity being the largest green energy source with a market share of more than a quarter of Germany's total electricity in 2020 (STROM-REPORT, 2021).

However, wind park operators are confronted with barriers and uncertainties that influence the further development of the sector. Wind power businesses face difficulties with strict ecological protection laws and standards and cumbersome bureaucratic procedures. Furthermore, various suitable locations for new wind parks are unavailable and thereby slowing down the overall pace of wind energy expansion. To a smaller extent, impacts on humans and wildlife are hindering factors in the implementation of wind parks in the Northern coastal region. Nevertheless, the participants of the study judged that these two factors are not a substantial matter for future wind energy expansion.

Basic policy-oriented strategies were derived from the quantitative and qualitative findings. Due to the high significance of strengths and opportunities, it was recommended that policymakers should take timely and direct actions in this regard. In particular, local policy-making might emphasize the environmental and monetary benefits of wind energy projects through communication strategies and awareness-raising campaigns. Second, we investigated in what way the impacts of weaknesses could be dampened as to allow the realization of opportunities. Rather incremental policy strategies should be pursued, especially in view of the inferior significance of weaknesses. As wind energy generation is gradually becoming less dependent on the weather conditions, regional and national planners might place stronger priority on environmental and human well-being when scouting new wind turbine sites. The third set of policy measures classify as incremental and indirect. Threats stemming from various stakeholders can become serious obstacles and risks for wind park operators. Hence, policymakers and public institutions of the energy sector could foster multi-actor participation and advocate for policy-oriented stakeholder dialogues. Fourth, this study's results pointed out the complicated bureaucratic procedures as well as strict ecological protection regulations that wind park operators must abide by. Policy strategies to tackle these issues classify as direct and swift in their implementation. Basic strategies should ensure higher transparency of information flows, contain early-stage risks of project development, and accelerate construction procedures of new sites. Whilst these are restrained by eco-regulations, bureaucratic processes can still be simplified.

The diversification of policy strategies is decisive for the achievement of the different goals that are implied within the individual factors. Particularly, the strategies aim to strengthen the environmental benefits and maintain the competitiveness of wind power on the energy market. Also of high significance is the integration of citizen-based small and medium projects that foster public participation and community resilience. A promising opportunity for the practical application of such a multi-layered policy strategy is the COMPILE project put forward by the EU commission. The projects' main goals involve the empowerment of local energy systems together with the decentralization of energy networks, the optimal integration and control of all energy vectors and storage opportunities and the creation of new ways to stimulate the adaptation of technological solutions that foster a large-scale replication. The active strengthening of community resilience might create new traction in the currently stagnating wind energy development in Germany. By creating individual energy islands for decarbonisation (Compile Project, 2021), the development of an entire landscape based on renewable energies is promoted.

Overall, our study offered an amplified overview over experts' current opinions on factors that influence the wind energy development in Germany in both positive and negative terms. To obtain finer nuances of the factors to be considered and their respective relevance in the future, we recommend researchers to conduct the survey on a larger scale and include qualitative interviews during the factor validation. Lastly, it would be of particular interest to create target group-independent samples that evaluate the perspectives of wind energy experts, wind park operators, environmental interest groups and experts as well as residents.

CRediT authorship contribution statement

Theresa Kiunke: Writing – original draft, Formal analysis, Investigation, Conceptualization. **Natalia Gemignani:** Writing – original draft, Formal analysis, Investigation, Conceptualization. **Pedro Malheiro:** Writing – original draft, Formal analysis, Investigation, Conceptualization. **Thomas Brudermann:** Conceptualization, Methodology, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2022.112962.

References

Akerboom, S., Tegner Anker, H., Backes, C., Bovet, J., Cavallin, E., Cliquet, A., Kock, W., Mathews, F., McFillivray, D., Schoukens, H., 2021. Wind energy projects and species protection law: a comparative analysis of the application of EU law in five member states. Eur. Environ. Law Rev. 28 (4), 144–158. URL: https://kluwerlawonline.com/journalarticle/European+Energy+and+Environmental+Law+Review/28.4/EELR2019111. (Accessed 11 May 2021).

Arnberger, A., Eder, R., Allex, B., Preisel, H., Ebenberger, M., Husslein, M., 2018. Trade-offs between wind energy, recreational, and bark-beetle impacts on visual preferences of national park visitors. Land Use Pol. 76, 166–177. https://doi.org/10.1016/j.landusepol.2018.05.007.

Bose, A., Dürr, T., Klenke, R., Henle, K., 2018. Collision sensitive niche profile of the worst affected bird-groups at wind turbine structures in the Federal State of Brandenburg, Germany. Sci. Rep. 8 (1), 3777. https://doi.org/10.1038/s41598-018-22178-z.

Broekel, T., Alfken, C., 2015. Gone with the wind? The impact of wind turbines on tourism demand. Energy Pol. 86, 506–519. https://doi.org/10.1016/j.enpol.2015.08.005.

Brudermann, T., Sangkakool, T., 2017. Green roofs in temperate climate cities in Europe – an analysis of key decision factors. Urban For. Urban Green. 21, 224–234. https://doi.org/10.1016/j.ufug.2016.12.008.

Brudermann, T., Reinsberger, K., Orthofer, A., Kislinger, M., Posch, A., 2013. Photovoltaics in agriculture: a case study on decision making of farmers. Energy Pol. 61, 96–103. https://doi.org/10.1016/j.enpol.2013.06.081.

Brudermann, T., Mitterhuber, C., Posch, A., 2015. Agricultural biogas plants – a systematic analysis of strengths, weaknesses, opportunities and threats. Energy Pol. 76, 107–111. https://doi.org/10.1016/j.enpol.2014.11.022.

Bundesministerium für Umwelt, 2020. Naturschutz und nukleare Sicherheit. Kernkraftwerke in Deutschland. URL: https://www.bmu.de/themen/atomenergie-strahlenschutz/nukleare-sicherheit/aufsicht- ueber-kernkraftwerke/kernkraftwerke-in-deutschland/. (Accessed 6 June 2021).

Bundesministerium für Wirtschaft und Energie, 2020. Kohleausstieg und Strukturwandel. URL: https://www.bmwi.de/Redaktion/DE/Artikel/Wirtschaft/kohleausstieg-und-strukturwandel.ht. (Accessed 6 June 2021).

Bundesnetzagentur, 2021. Ausschreibungsverfahren für Windenergieanlagen an Land. URL: https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/Ausschreibungen/Wind_Onshore/Wind_Onshore_node.html. (Accessed 23 June 2021).

Bundesregierung, 2021. Erneuerbare Energien. URL: https://www.bundesregierung.de/breg-de/themen/energiewende/energie-erzeugen/erneuerbare-energien-317608. (Accessed 10 April 2021).

BVerfG, Beschluss des Ersten Senats, 2021. 1 BvR 2656/18, 1 BvR 96/20, 1 BvR 78/20, 1 BvR 288/20,1 BvR 96/20, 1 BvR 78/20 - Rn. (1 - 270). Bundesverfassungsgericht. URL: http://www.bverfg.de/e/rs20210324_1bvr265618.html. (Accessed 23 June 2021).

BVerwG, Urteil vom 30.06.2004 - 4 C 9.03, 2004. Bundesverwaltungsgericht. URL: https://www.bverwg.de/300604U4C9.03.0https://www.bverwg.de/300604U4C9.03.0. (Accessed 22 June 2021).

Chang, V., Chen, Y., Justin, Zhang, Z., Xu, Q., Baudier, P., Liu, B., 2021. The market challenge of wind turbine industry-renewable energy in PR China and Germany. Technol. Forecast. Soc. Change 166, 120631. https://doi.org/10.1016/j.techfore.2021.120631.

Cherp, A., Vinichenko, V., Jewell, J., Suzuki, M., Antal, M., 2017. Comparing electricity transitions: A historical analysis of nuclear, wind and solar power in Germany and Japan. Energy Policy, 101(May 2016, 612–628. https://doi.org/10.1016/j.enpol.2016.10.044.

Compile Project, 2021. URL: https://www.compile-project.eu. (Accessed 20 June 2021).

Croonenbroeck, C., Hennecke, D., 2020. Does the German renewable energy act provide a fair incentive system for onshore wind power? — a simulation analysis. Energy Pol. 144, 111663 https://doi.org/10.1016/j.enpol.2020.111663.

de, W.W.F., 2021. Wattenmeer. URL: https://www.wwf.de/themen-projekte/projektregionen/wattenmeer. (Accessed 11 April 2021).

de Menezes, Houllier, M.A., 2015. Germany's nuclear power plant closures and the integration of electricity markets in Europe. Energy Policy 85, 357–368. https://doi.org/10.1016/J.ENPOL.2015.05.023.

Destek, M., Aslan, A., 2020. Disaggregated renewable energy consumption and environmental pollution nexus in G-7 countries. Renew. Energy 151, 1298–1306. https://doi.org/10.1016/j.renene.2019.11.138.

Deutsche WindGuard, 2020. Wind Energy Statistics. Status des Windenergieausbaus an Land – Jahr 2020. URL: https://www.windguard.com/publications-wind-energy-statistics.html. (Accessed 11 April 2021).

Deutscher Bundestag, 2014. Entwurf eines Gesetzes zur grundlegenden Reform des Erneuerbare-Energien-Gesetzes und zur Änderung weiterer Bestimmungen des Energiewirtschaftsrechts. URL: https://dserver.bundestag.de/btd/18/013/1801304.pdf. (Accessed 23 June 2021).

Dóci, G., Vasileiadou, E., Petersen, A., 2015. Exploring the transition potential of renewable energy communities. Futures 66, 85–95. https://doi.org/10.1016/j.futures.2015.01.002.

D'Souza, C., Yiridoe, E., 2014. Social acceptance of wind energy development and planning in rural communities of Australia: a consumer analysis. Energy Pol. 74, 262–270. https://doi.org/10.1016/j.enpol.2014.08.035.

EEG, Einzelnorm, 2021. Gesetze Im Internet - Bundesamt Für Justiz. https://www.gesetze-im-internet.de/eeg_2014/__1.html. (Accessed 10 April 2021).

Eichhorn, M., Tafarte, P., Thrän, D., 2017. Towards energy landscapes – "Pathfinder for sustainable wind power locations". Energy 134, 611–621. https://doi.org/10.1016/j.energy.2017.05.053.

Energy Charts, 2021. Net Public Electricity Generation in Germany in 2020. URL: https://energy-charts.info/charts/energy_pie/chart.htm?l=en&c=DE&year=2020&source=public. (Accessed 10 April 2021).

European Commission, 2020. European Climate Law. URL: https://ec.europa.eu/clima/policies/eu-climate-action/law_en. (Accessed 6 June 2021).

European Council, 2021. European Climate Law: Council and Parliament Reach Provisional Agreement. URL: https://www.consilium.europa.eu/en/press/press-releases/2021/05/05/european-climate-law-council-and-parliament-reach-provisional-agreement/. (Accessed 6 June 2021).

European Patent Office and the International Energy Agency, 2020. Innovation in Batteries and Electricity Storage – A Global Analysis Based on Patent Data. URL: http://documents.epo.org/projects/babylon/eponet.nsf/0/969395F58EB07213C12585E7002C7046/$FILE/battery_study_executive_summary_en.pdf. (Accessed 24 May 2021).

Fraune, C., Knodt, M., Gölz, S., Langer, K., 2019. Akzeptanz und politische Partizipation in der Energietransformation. Springer, Berlin. https://doi.org/10.1007/978-3-658-24760-7.

Geels, F., Sovacool, B., Schwanen, T., Sorrell, S., 2017a. The socio-technical dynamics of low-carbon transitions. Joule 1 (3), 463–479. https://doi.org/10.1016/j.joule.2017.09.018.

Geels, F.W., Sovacool, B.K., Schwanen, T., Sorrell, S., 2017b. Sociotechnical transitions for deep decarbonization. Science 357 (6357), 1242–1244. https://doi.org/10.1126/science.aao3760.

Grashof, K., Berkhout, V., Cernusko, R., Pfennig, M., 2020. Long on promises, short on delivery? Insights from the first two years of onshore wind auctions in Germany. Energy Pol. 140, 111240 https://doi.org/10.1016/j.enpol.2020.111240.

Grau, L., Jung, C., Schindler, D., 2021. Sounding out the repowering potential of wind energy – a scenario-based assessment from Germany. J. Clean. Prod. 293, 126094 https://doi.org/10.1016/j.jclepro.2021.126094.

Guan, J., 2020. Westerly breezes and easterly gales: a comparison of legal, policy and planning regimes governing onshore wind in Germany and China. Energy Res. Social Sci. 67, 101506 https://doi.org/10.1016/j.erss.2020.101506.

Gürtler, K., Postpischil, R., Quitzow, R., 2019. The dismantling of renewable energy policies: the cases of Spain and the Czech Republic. Energy Pol. 133, 110881 https://doi.org/10.1016/j.enpol.2019.110881.

Hodbod, J., Adger, W., 2014. Integrating social-ecological dynamics and resilience into energy systems research. Energy Res. Social Sci. 1, 226–231. https://doi.org/10.1016/j.erss.2014.03.001.

International Energy Agency, 2021. World energy Outlook 2021. URL: https://www.iea.org/reports/world-energy-outlook-2021. (Accessed 14 February 2022).

International Renewable Energy Agency, 2020. Renewable Power Generation Costs in 2019. URL: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Power_Generation_Costs_2019.pdf. (Accessed 13 June 2021).

IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team. IPCC, Geneva, Switzerland, pp. 151–pp.

Jacobs, D., Grashof, K., Del Ró, P., Fouquet, D., 2020. The case for a wider energy policy mix in line with the objectives of the Paris agreement: shortcomings of renewable energy auctions based on World-wide empirical observations. In: IET – International Energy Transition, IZES, Spanish National Research Council (CSIC), Becker Büttner Held. A Study Commissioned by Energy Watch Group (EWG), World Future Council/Global Renewables Congress (WFC/GRC), and Haleakala Stiftung. URL: https://renewablescongress.org/2020/12/study-on-re-auctions-the-case-for-a-wider-energy-policy-mix-in-line-with-the-objectives-of-the-paris-agreement/. (Accessed 12 June 2021).

Jenniches, S., Worrell, E., Fumagalli, E., 2019. Regional economic and environmental impacts of wind power developments: a case study of a German region. Energy Pol. 132, 499–514. https://doi.org/10.1016/j.enpol.2019.05.046.

Jung, C., Schindler, D., Grau, L., 2018. Achieving Germany's wind energy expansion target with an improved wind turbine siting approach. Energy Convers. Manag. 173, 383–398. https://doi.org/10.1016/j.enconman.2018.07.090.

Koch, H., Büchner, M., 2016. Is climate change a threat to the growing importance of wind power resources in the energy sector in Germany? Energy Sources B Energy Econ. Plann. 11 (12), 1128–1136. https://doi.org/10.1080/15567249.2013.846442.

Krekel, C., Zerrahn, A., 2017. Does the presence of wind turbines have negative externalities for people in their surroundings? Evidence From Well-being data. J. Environ. Econ. Manag. 82, 221–238. https://doi.org/10.1016/j.jeem.2016.11.009.

Langer, K., Decker, T., Roosen, J., Menrad, K., 2018. Factors influencing citizens' acceptance and non-acceptance of wind energy in Germany. J. Clean. Prod. 175, 133–144. https://doi.org/10.1016/j.jclepro.2017.11.221.

Leipprand, A., Flachsland, C., 2018. Regime destabilization in energy transitions: the German debate on the future of coal. Energy Res. Social Sci. 40, 190–204. https://doi.org/10.1016/j.erss.2018.02.004.

Lin, M.X., Liou, H.M., Chou, K.T., 2020. National energy transition framework toward SDG7 with legal reforms and policy bundles: the case of Taiwan and its comparison with Japan. Energies 16 (3), 1387. https://doi.org/10.3390/en13061387.

Mah, D. N. yin, Wu, Y.Y., Ip, J. C. man, Hills, P.R., 2013. The role of the state in sustainable energy transitions: a case study of large smart grid demonstration projects in Japan. Energy Pol. 63, 726–737. https://doi.org/10.1016/J.ENPOL.2013.07.106.

Masurowski, F., Drechsler, M., Frank, K., 2016. A spatially explicit assessment of the wind energy potential in response to an increased distance between wind turbines and settlements in Germany. Energy Pol. 97, 343–350. https://doi.org/10.1016/j.enpol.2016.07.021.

Mori, A., 2018. Socio-technical and political economy perspectives in the Chinese energy transition. Energy Res. Social Sci. 35, 28–36. https://doi.org/10.1016/j.erss.2017.10.043.

Naturschutzbund Deutschland, e.V., 2018. Naturverträgliche Nutzung der Windenergie an Land und auf See. URL: https://www.nabu.de/imperia/md/content/nabude/klimaschutz/190219_nabu-hintergrundpapier_naturvertr_gliche_nutzung_der_windenergie.pdf. (Accessed 7 June 2021).

Nordensvärd, J., Urban, F., 2015. The stuttering energy transition in Germany: wind energy policy and feed-in tariff lock-in. Energy Pol. 82, 156–165. https://doi.org/10.1016/j.enpol.2015.03.009.

Petrova, M., 2013. NIMBYism revisited: public acceptance of wind energy in the United States. Wires Clim. Chang. 4 (6), 575–601. https://doi.org/10.1002/wcc.250.

Posch, A., Brudermann, T., Braschel, N., Gabriel, M., 2015. Strategic energy management in energy-intensive enterprises – a quantitative analysis of relevant factors in the Austrian paper and pulp industry. J. Clean. Prod. 90, 291–299. https://doi.org/10.1016/j.jclepro.2014.11.044.

ProCon.org, 2021. History of Climate Change Debate. URL: https://climatechange.procon.org/history-of-climate-change-debate/. (Accessed 6 June 2021).

Prognos, Öko-Institut, Wuppertal-Institut, 2021. Klimaneutrales Deutschland 2045. Wie Deutschland seine Klimaziele schon vor 2050 erreichen kann. Report on behalf of Stiftung Klimaneutralität, Agora Energiewende und Agora Verkehrswende. URL: https://www.agora-energiewende.de/veroeffentlichungen/klimaneutrales-deutschland-2045/. (Accessed 6 June 2021).

Rand, J., Hoen, B., 2017. Thirty years of North American wind energy acceptance research: what have we learned? Energy Res. Social Sci. 29, 135–148. https://doi.org/10.1016/j.erss.2017.05.019.

Reusswig, F., Braun, F., Heger, I., Ludewig, T., Eichenauer, E., Lass, W., 2016. Against the wind: local opposition to the German Energiewende. Util. Pol. 41, 214–227. https://doi.org/10.1016/j.jup.2016.02.006.

Saaty, T.L., 1980. The Analytic Hierarchy Process. McGraw-Hill, New York.

Saaty, T.L., 1999. Decision Making for Leaders. The Analytic Hierarchy Process for Decisions in a Complex World. RWS Publications, Pittsburgh, US.

Siddique, M.B., Thakur, J., 2020. Assessment of curtailed wind energy potential for off-grid applications through mobile battery storage. Energy 201, 117601. https://doi.org/10.1016/j.energy.2020.117601.

Sinn, H.W., 2017. Buffering volatility: a study on the limits of Germany's energy revolution. Eur. Econ. Rev. 99, 130–150. https://doi.org/10.1016/j.euroecorev.2017.05.007.

Smith Stegen, K., Seel, M., 2013. The winds of change: how wind firms assess Germany's energy transition. Energy Pol. 61, 1481–1489. https://doi.org/10.1016/j.enpol.2013.06.130.

Statista, 2021. Onshore-Windenergieanlagen – Anzahl nach Bundesland 2020. URL: https://de.statista.com/statistik/daten/studie/28154/umfrage/anzahl-von-windenergieanlagen-nach-bundesland/. (Accessed 26 March 2021).

Stokes, L.C., Breetz, H.L., 2018. Politics in the U.S. energy transition: case studies of solar, wind, biofuels and electric vehicles policy. Energy Pol. 113, 76–86. https://doi.org/10.1016/J.ENPOL.2017.10.057.

STROM-REPORT. Strommix Deutschland: Stromerzeugung nach Energieträger. URL: https://strom-report.de/strom. (Accessed 10 April 2021).

Unnerstall, T., 2017. How expensive is an energy transition? A lesson from the German Energiewende. Energy, Sustain. Soc. 7 (1), 38. https://doi.org/10.1186/s13705-017-0141-0.

von Lüpke, H., Well, M., 2020. Analyzing climate and energy policy integration: the case of the Mexican energy transition. Clim. Pol. 20 (7), 832–845.

Weber, F., Jenal, C., Rossmeier, A., Kühne, O., 2017. Conflicts around Germany's Energiewende: discourse patterns of citizens' initiatives. Quaest. Geogr. 36 (4), 117–130. https://doi.org/10.1515/quageo-2017-0040.

Weitemeyer, S., Kleinhans, D., Vogt, T., Agert, C., 2015. Integration of Renewable Energy Sources in future power systems: the role of storage. Renew. Energy 75, 14–20. https://doi.org/10.1016/j.renene.2014.09.028.

Welcker, J., Liesenjohann, M., Blew, J., Nehls, G., Grünkorn, T., 2017. Nocturnal migrants do not incur higher collision risk at wind turbines than diurnally active species. Ibis 159 (2), 366–373. https://doi.org/10.1111/ibi.12456.

Zaman, R., Brudermann, T., 2018. Energy governance in the context of energy service security: a qualitative assessment of the electricity system in Bangladesh. Appl. Energy 223, 443–456.