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Is German Onshore Wind Power in Crisis?

An analysis of growth trends, barriers and expectations for a renewable energy technology at an advanced stage of diffusion

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Author's declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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ABSTRACT OF THESIS submitted by Jens HONNEN for the degree of Master of Science and entitled: Is German Onshore Wind Power in Crisis? An analysis of growth trends, barriers and expectations for a renewable energy technology at an advanced stage of diffusion

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As renewable energy technologies diffuse, they move through distinct growth stages with qualitatively different underlying challenges. While most existing research has focused on the early stages, the more advanced stages are less well understood. This thesis bridges this gap through an analysis of the recent slowdown in growth of onshore wind power in Germany – a renewable energy technology struggling in its later growth stages. On the basis of growth modelling, interviews, content and data analysis, three research objectives are pursued: (1) determining whether growth of onshore wind power is in persistent decline in Germany, (2) analysing the industry's growth expectations to explain the wide-spread perception of the slowdown as a crisis and (3) identifying the underlying barriers to growth. The results find the technology's long-term growth to be nearly linear, with no evidence of acceleration nor decline. The recent slowdown is mainly understood as a temporary fluctuation following the recent switch from feed-in tariffs to auctions. The crisis narrative is explained by the industry's past growth experiences, its recent struggles, the perceived growth potential and normative scenarios for onshore wind power's role in Germany's energy transition. Future growth is unlikely to exceed the long-term growth rate of 3 GW, being limited by land constraints, political, institutional and social opposition, clashes with conservation and administrative barriers. Immediate action is required for lifting growth to the rates required by Germany's climate targets. Understanding the identified growth challenges will also be essential to facilitate growth of other renewables at advanced stages of growth.

Keywords: onshore wind power, Germany, energy transition, technology diffusion, growth stages, barriers, transition studies, challenges, renewable energy

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> *"I see too many people, including scientists, now accepting climate*[1] *breakdown as a 'sad but done deal.' This is the frog talking from its pot of heating water.*
>
> *Well I say no. My kids say no! Rage, rage against the dying of the light. Do not go gentle into that good night."*
>
> – Peter Kalmus

[1] Feel free to exchange this with 'ecological breakdown' ;-)

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1. Introduction

Onshore wind power has become the backbone of Germany's Energiewende – the country's long-term strategy for a transition to a low-carbon, efficient and nuclear-free energy system. Over the course of a few decades, the technology has moved from niche to mainstream: from 0.3% of gross electricity demand in 1995 to 17.5% as the second largest power source behind lignite in 2019 (AGEB 2020). With Germany's commitments to phase-out nuclear energy by 2022 and coal by 2038 (BMU 2019), onshore wind power will play an even larger role in the future. Recently, however, growth of onshore wind power capacity has slowed down. While the capacity grew by an average of 4.6 GW/year between 2014 and 2017, it grew by only 2.2 GW in 2018 (Quentin 2019a). Capacity growth in 2019, with only 980 MW of net additions[2] of onshore wind farms, was the lowest seen since 1998 (Quentin 2020a). Germany was among the European countries with the least investments in new onshore wind power projects in that year (WindEurope 2019a).

This slowdown has been highlighted and criticised by the German wind power industry, environmental organisations and not least by the mass media – all of which point to mounting job losses and the dangers to the Energiewende (BDEW et al. 2019; von Blazekovic 2019). Their concerns seem valid given that Germany is off track to meet its climate targets. Having reduced its GHG emissions by only 35.7% in 2019 compared to 1990 levels, the country was set to miss its 2020 reduction target of 40% before the Covid-19 pandemic (BMU 2020). Further, an assessment by the Federal Environmental Agency found that, with current policies, Germany is bound to miss its 2030 reduction target of 55% (UBA 2020). To get back on track, Germany will need to continue to expand its renewable energy fleet. Aiming for this, the Federal Government has acknowledged the challenges for onshore wind power and, in autumn 2019, brought forward a set of measures to promote its development (BMWi 2019a). This will not be easy, however, as the required growth is much larger than that observed in 2018 and 2019: Studies estimate that in order to reach the government's 2030 target for a 65% share of renewables in gross electricity demand (CDU et al. 2018), at least 4 GW of yearly gross capacity additions are necessary (Agora Energiewende 2018).

Is German onshore wind power in crisis then? And if yes, what are the underlying factors? While no academic research seems to have addressed these questions directly, a range of themes related to this discussion have been explored in the literature on onshore wind power in Germany.

[2] Every year in Germany, new wind farms are installed and old wind farms are removed. Gross additions refer to the newly added capacity. Net additions refer to the newly added capacity minus the removed capacity.

This includes research on the diminishing social acceptability of wind turbines (Jobert et al. 2007; Zoellner et al. 2008; Sonnberger and Ruddat 2017) and conflicts between nature conservation and onshore wind development (Dorda 2018; Ammermann et al. 2019; Köppel et al. 2019; Voigt et al. 2019). Other studies have investigated the challenges surrounding the transition from the feed-in tariff scheme to wind power auctions (Grashof et al. 2020; Lundberg 2019) and the inability of Germany's electricity grid infrastructure to integrate the increasing onshore wind capacity (Nordensvärd and Urban 2015). What remains missing is a coherent picture of the dynamics of German onshore wind power development, which brings these and other relevant themes together in order to explain the recent slowdown and its consequences for the Germany's energy transition. This thesis aims to fill this gap through a systematic, multi-level analysis of the growth trajectory of German onshore wind power, the industry expectations for and the underlying barriers to deployment.

The analysis is built on three research questions, each exploring a different aspect of the slowing capacity growth of onshore wind power. The **first research question** is whether Germany is really dealing with a 'crisis' – understood as a situation where growth of onshore wind power capacity has started to steadily and persistently decline. This requires looking at the 2018 and 2019 slowdown within the technology's long-term growth trajectory beginning in the 1990s. Are recent developments merely a temporary blip in a long and ongoing success story of German onshore wind deployment or is this story coming to an end? This question is answered through a quantitative analysis that establishes whether growth of onshore wind capacity in Germany is best explained by an exponential (accelerating), linear (steady) or logistic (declining) growth model.

The **second research question** builds on the first one and explores the discourse surrounding the slowdown in an attempt to understand the origins of the wide-spread narrative that German onshore wind power is in crisis. As mentioned above, there seems to be a consensus around this crisis narrative amongst the industry, politicians, experts, civil society and the media. Explaining this narrative requires looking at why there is such a large discrepancy between actual deployment of onshore wind power and the expectations of participants in the public discourse. More specifically, these expectations will need to be examined in terms of their underlying assumptions, targets and points of reference. This is done through a qualitative analysis of information gained through interviews with people employed in the German wind power and energy industry and a content analysis of relevant public documents, interviews and conference proceedings.

Finally, the **third research question** looks at why capacity of onshore wind power does not grow as fast as expected. That is, why did capacity growth slow down exactly in 2018 and

2019? Answering this question is the core objective of this thesis, requiring a comprehensive and detailed investigation into the barriers to the deployment of onshore wind power in Germany and their development over time. This investigation builds on both quantitative data sourced from public databases and non-academic publications (mainly from German energy policy think tanks) and qualitative data collected through interviews and a content analysis. The findings are analysed according to a methodology that takes a project developer's perspective by looking at each individual stage of the process of realising a wind farm. Barriers are matched with the respective stages and analysed for their interactions to allow us to understand when and where in the realisation process they stall deployment.

Together, this research agenda allows for a meaningful interpretation of the recent slowdown in capacity growth within the evolution of onshore wind power in Germany, an explanation of the origins of the public 'crisis discourse' and an identification of key barriers to deployment in the country. As will be shown, such an analysis is highly relevant for the scientific literature on the diffusion of renewable energy technologies. While most research has focused on renewables moving from niche to mainstream, the case of German onshore wind power offers a fitting empirical example of an established technology struggling in its later growth stages. Understanding the underlying growth challenges of these later stages will be essential for safeguarding the continued diffusion of established renewable energy technologies around the world. However, this thesis does not only contribute to the scientific literature but is also highly relevant for decision-makers in Germany. Knowing whether the slowdown is temporary or likely to persist and whether the voices pointing out the crisis are correct, is key to assess the gravity of the situation and the urgency for action. Knowing what is causing the slowdown is essential for making informed decisions on how to reignite deployment. At the same time, the lessons learned from Germany may be transferred to and used in other contexts. Indeed, onshore wind power will have to play a major role in a low-carbon future across the world and in order to safeguard this transition, we need to understand what conditions are conducive to its quick development and which one's give rise to its stagnation and decline.

This thesis is structured as follows: The next chapter introduces the reader to the history of onshore wind power in Germany, explains its significance for the Energiewende and outlines the discussion around the recent slowdown. Further, it introduces a theoretical framework for assessing the slowdown, explains how this study ties into the framework and compiles the scientific knowledge on barriers to the development of onshore wind farms. The third chapter provides more detail on the framework, outlines the study's methodological approach and presents the different quantitative and qualitative research methods used. The fourth chapter presents the results of the analysis, focusing on each research question separately. The fifth section discusses these results – first individually and then in terms of their joint theoretical and practical implications. The final chapter concludes by summarising the findings, explaining their theoretical value, providing policy recommendations, mentioning certain limitations and proposing directions for further research.

2. Background on Onshore Wind Power in Germany's Energiewende

2.1. History and role of onshore wind power in Germany

How has onshore wind power developed from a niche technology to a multi-billion euro industry in Germany? Although experimentation with wind power began in Germany in the 1970s, the technology's country-wide deployment only really started taking off in the 1990s (Ohlhorst and Schön 2010). This first boom followed strong governmental efforts to stimulate the German wind power market and support the emerging wind industry (Bergek and Jacobsson 2003). This included a federal programme to install 250 MW of wind power capacity and the 1990 Electricity Feed-in Act (Stromeinspeisungsgesetz or StrEG), which required utilities to connect renewable energy (RE) producers to the grid and to remunerate them for their electricity (Ohlhorst 2009; Lauber and Mez 2006). In the years that followed, an increasing number of municipalities would adjust the rates of remuneration for renewable electricity so that wind energy producers were adequately compensated for their costs and able to make a profit (Fell 2009). At the same time, wind energy technology was advancing rapidly, becoming much more reliable and cost-efficient (Ibenholt 2002).

As a result, onshore wind power capacity grew rapidly in the 1990s – by an average of around 480 MW a year from a mere 19 MW in 1989 to 4.4 GW in 1999 (see Figure 1). At the end of the decade, wind energy represented 1% of Germany's power production (Cherp et al. 2017). Benefitting from this growing domestic market, the German wind power industry had become the second largest in the world by the early 2000s (Cherp et al. 2017). In 2000, then, the StrEG was replaced by the Renewable Energy Sources Act (EEG), increasing support for wind energy by guaranteeing technology- and resource-specific feed-in tariffs with 20-year periods for renewable electricity and forcing utilities to prioritise renewable over conventional electricity (Cherp et al. 2017; Lauber and Mez 2006). As a result, the 2000s saw a large capacity growth of 2.1 GW/year on average, with growth peaking at 3.3 GW/year in 2002 and then gradually declining to 1.4 GW/year in 2010 (see Figure 1). At the end of 2009, the installed capacity was at 25.8 GW.

It is worth noting that, from the beginning, the policy environment allowed for much of the investment into wind energy to come from ordinary citizens, who would often organise to realise community wind energy projects (Bauwens et al. 2016). This empowerment of citizens to actively participate in the Energiewende as small decentralised power producers, while at the same time creating jobs and tax income, helped fostering a strong public support for renewables within German society (Leiren and Reimer 2018). These benefits for small investors such as farmers, energy cooperatives, churches and local companies continued with the introduction of the EEG, further spreading community wind energy across the country (Nolden 2013). By 2012, 20% of German onshore capacity was made up by community wind farms (Gotchev 2015).

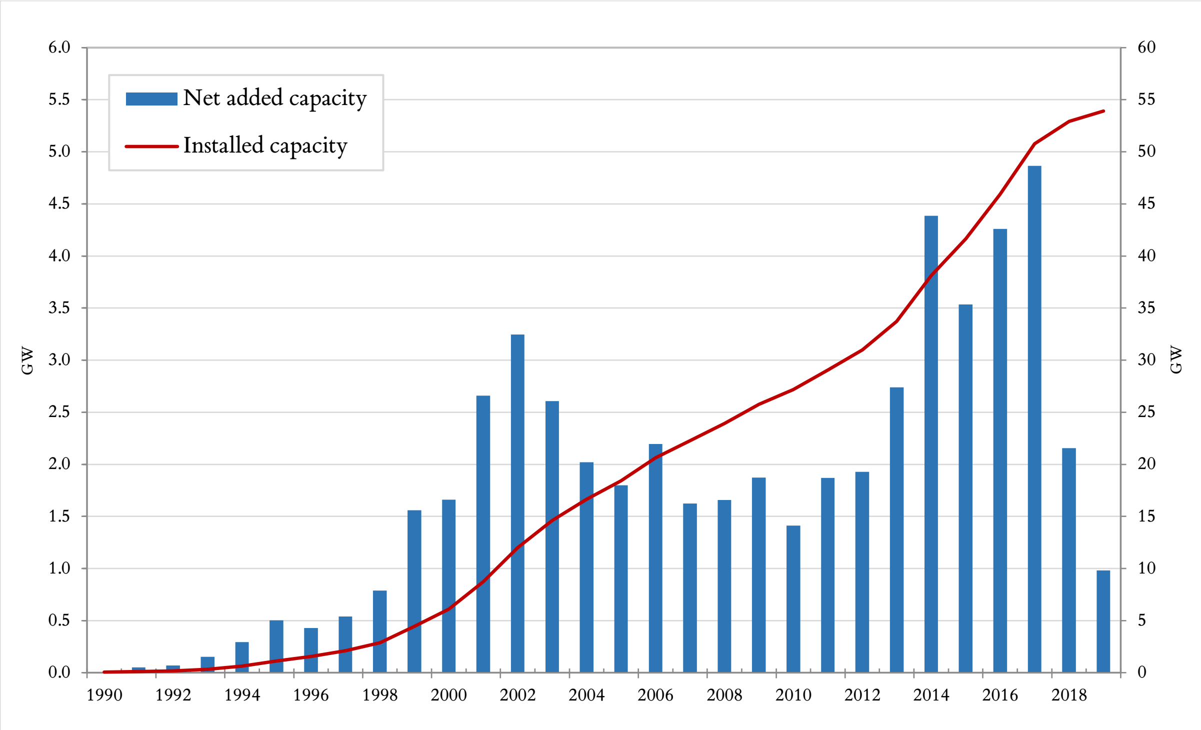


Figure 1 – Development of onshore wind power capacity in Germany.
Left y axis for net added capacity per annum (in GW). Right y axis for installed capacity (in GW). Source: own representation. All data is from: (BWE 2020a). For further information, see Table 8 in the Appendix.

During the 2010s, the political framework conditions became more unstable for wind energy development. On the one hand, the case for wind power as a foundation of Germany's future energy system continued to get stronger: In 2010, ambitious targets for the expansion of renewable energy were set in Germany's 'Energiekonzept' (Cherp et al. 2017) and in 2011, the accelerated phase-out of nuclear energy by 2022 was announced, providing more space for the expansion of renewables (Glaser 2012). One the other hand, the EEG would be amended several times after its adoption – and not always to the advantage of wind energy producers: From 2014, renewable energy producers had to directly market their electricity themselves instead of leaving this to the transmission system operator (Bauwens et al. 2016). Eventually, the feed-in tariff scheme also would be abolished. The 2014 and 2016 EEG amendments stipulated the transition to a tender system, which constrains renewable energy development through annual quotas or growth corridors (see Table 1) and determines remuneration through technology-specific auctions from 2017 onwards (Berkhout et al. 2019). This change was meant to prepare renewable energy for competition on the market and make them more cost-efficient (Lieblang 2018).

Table 1 – The government's growth corridors for onshore wind power

The table shows the yearly growth corridors (in GW) for onshore wind power as set by the EEG. These growth corridors are equivalent to the annually tendered capacity at onshore wind power auctions. The table also shows the government target for the total installed capacity of onshore wind power by 2030. Source: (Bundesministerium der Justiz und für Verbraucherschutz 2017; Baumann and Jarass 2020);(Quentin 2017a,b; Quentin 2018b-f; Quentin 2019c-g; Quentin 2020b,d)

2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Mean	2030 target
2.8	2.7	3.7	4.3	4.5	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	3.2	67-71

Throughout the 2010s, yearly capacity growth would average at 3.1 GW before deployment rates slowed down in 2018 and 2019. In the years of 2014 to 2017, onshore wind power was growing exceptionally fast, with rates up to 4.9 GW in 2017. During these peak years, the German wind industry employed around 130,000 people (BMWi 2019b). Despite the recent slowdown, then, Germany's onshore wind fleet had grown enormously in three decades. By the end of 2019, around 29,500 turbines with a capacity of 53.9 GW were feeding into the German grid. In the same year, onshore wind farms produced 101.3 TWh of power or 17.5% of gross electricity demand (AGEB 2020). In the future, this share will have to substantially increase: In 2018, the government coalition increased its 2030 target for the share of renewables in the power mix from 50% to 65% (CDU et al. 2018) and in January 2020, the German cabinet adopted a coal exit law, which foresees a gradual phase-out of both lignite and hard coal by 2038. (BMWi 2020). At the same time, however, the Federal Government decreased the 2030 target for the capacity of onshore wind power from 81.5 GW to 67-71 GW in October 2019. (Baumann and Jarass 2020).

Globally, Germany has represented one of the largest markets for onshore wind power. Its installed capacity is the third largest in the world, falling only behind China (204.5 GW) and the USA (103.6 GW) (IRENA 2020). In Europe, Germany's onshore wind power capacity is followed by that of Spain (25.8 GW), France (16.6 GW), the UK (13.6 GW) and Italy (10.5 GW) (WindEurope 2020). However, with Ireland (33%), Denmark (31%) and Portugal (27%), three European countries still obtain a larger share of their net electricity demand from onshore wind than Germany (21%) (WindEurope 2020). Furthermore, while new installations recently decreased in Germany, the European onshore wind market keeps growing steadily – with Spain (2.3 GW), Sweden (1.6 GW) and France (1.3 GW) having commissioned more wind farms than Germany in 2019 (WindEurope 2020). Meanwhile, onshore wind power is also booming globally: While established markets in North America and Asia are still growing steadily, emerging markets in Latin America, South-East Asia, Africa and the Middle East are expanding fast (GWEC 2020). We may ask, then, if development of onshore wind power is thriving both on a European and global scale, why does it seem to be in trouble in Germany?

2.2. Realising a wind farm in Germany: The process and the actors involved

In order to understand the underlying factors of the slowdown in growth of onshore wind power in Germany, we need to know when and where issues arise. Therefore, it is essential to understand the typical process of realisation for a German wind farm as well as the different actors involved in this process.

First of all, who develops and owns wind farms in Germany? While in the beginning, it was mainly private citizens and citizens' energy cooperatives that would develop and own wind farms, over time professional project developers would enter the field (BWE and Deutsche WindGuard 2015). Especially since the 2000s, the technological advancement of turbine technology and the increasingly complex planning procedures have meant that technical expertise and investment capability have been required to realise a wind farm in Germany. As a consequence, next to large citizens' coalitions, also banks, funds and other large investors would start getting into onshore wind power development, usually tasking project developer companies with realisation (BWE and Deutsche WindGuard 2015). At the same time, it is also common for project developers to own wind farms themselves. A study from 2017 found that 39% of wind farms were owned by private citizens, 23% by project developers, 15% by banks and funds, 11% by energy supply companies, 6% by industry actors and only 4% by Germany's Big Four utilities RWE, E.ON, Vattenfall and EnBW (trend:research GmbH 2017).

Table 2 summarises the four stages of realisation for an onshore wind farm in Germany: (1) planning; (2) licensing; (3) auctioning and (4) implementation (Pietrowicz and Quentin 2015). The first stage, planning, takes an average of 36 months and involves pre-assessment and preparations for the permit application. During pre-assessment, the legal and technical aspects and the site-specific conditions of the potential project are clarified. That mainly means assessing the suitability of the site including the exact area requirements based on the project layout and resource evaluation, the area availability and the admissibility according to planning law. Legal admissibility can be assessed on the basis of the existing municipal or regional development plan, which designates certain areas of onshore wind power development. Different Länder have different rules on whether these plans are created on the municipal or regional level, with regional planning (which involves one or several administrative districts) being more common by covering 86% of German land area (UBA 2019a; Bons et al. 2019). This assessment of legal admissibility is key for any new project, since the permit necessary for realisation tends to only be granted if the potential project falls within a designated area for onshore wind power development as set by the development plan.

Table 2 – Realising an onshore wind farm in Germany
Sources: (Pietrowicz and Quentin 2015; Endell and Quentin 2017; Quentin 2020b; BMJV 2013; WindEurope 2019b)

Realisation (*6 ⅓ years or 76 months*)	Planning
	36 months
		• Pre-assessment
		  o Site suitability assessment
		    · Planning law situation
		    · Area requirements and availability
		    · Resource evaluation
		    · Infrastructural layout
		  o Securing the area
		    · Coordination with municipality and property owner
		    · Finalisation of lease/purchase contract
		• Preparing permit application
		  o Preparation of scientific assessments
		    · Stability report
		    · Immission protection report
		    · Species protection report
		    · Detailed plan of wind farm
		  o Integration of wind farm within development plans

	Licensing
	18 months
		• Licensing procedure according to the *Federal Immission Protection Law*
		  o Submission of permit application
		  o Assessment of the need for an EIA by the immission protection authority and conduct of EIA (if necessary)
		  o Participation of specialised authorities
		  o Participation of stakeholders and the public
		  o Assessment of all statements by the immission protection authority and decision on whether to grant permit

	Auctioning
	6 ½ months
		• Required for all onshore wind power projects above 750 kW
		• Auctions are technology-specific, held several times a year and subject to a ceiling price (currently at €6.2 ct/kWh)
		• Requirements for participation (as of 2018)
		  o Valid permit for participating project
		  o Deposit of 30,000€ per MW (expires in case a contracted projects is not implemented within two years)
		• Contract is granted to project with lowest bid price (ct/kWh)
		• Contract guarantees premium payment (equivalent to winning price) for a period of 20 years

	Implementation *15 months*	• Order of turbines and parts • Finalisation of plans for construction site • Opening of site and preparation for installation • Securing road access for turbine delivery • Installation of turbine, grid connection and commissioning

After the site suitability assessment is performed, the final part of pre-assessment regards securing the area (Pietrowicz and Quentin 2015). This involves coordinating with the respective municipality and negotiating a lease or purchase contract with the property owner. The next step of the planning phase regards the preparations for the permit application. This requires preparing scientific assessments related to stability (e.g. turbulence), immission protection (e.g. noise emission and shadow casting) and species protection. Here, the preparation of the species protection report alone will usually take an average of 18 months. Further, a detailed plan of the wind farm is to be drafted during this step, covering information on the number and types of turbines and the plans for grid connection. Lastly, the project is to be integrated within the existing regional or municipal development plan, which may require changing it.

The second stage of realisation is licensing, which typically takes around 18 months and comprises the licensing procedure as regulated by the *Federal Immission Protection Law* (BImSchG) (Pietrowicz and Quentin 2015; BMJV 2013). It begins with the submission of the permit application by the developer to the respective immission control authority. The authority will then assess the need for an environmental impact assessment and, if necessary, direct the preparation of such an assessment. Also, it will coordinate the participation of several specialised authorities, including the building, species protection, disaster control, soil protection, road traffic and forestry authority, each of which will assess the project and prepare a statement on it. Participation is also open to stakeholders and the public, which can file a complaint with the immission protection authority. After assessing all statements, the immission protection authority will decide on whether to grant the permit. This permit typically lasts for 10 to 15 years.

The third stage is auctioning, which takes an average of 6 ½ months. Auctions are required for all onshore wind power projects above 750 kW, held several times a year, technology-specific and regulated through a ceiling price, which is currently at €6.2 ct/kWh (Quentin 2020b). The two requirements for auction participation are a valid permit for the respective project and a refundable deposit payment of 30,000€ per MW. Importantly, in 2017, citizens' energy cooperatives were eligible to participate with unpermitted projects and only required to provide a deposit of 15,000€ per MW (Endell and Quentin 2017). At the auction, project developers then submit a bid for their project with the price per kWh at which they would realise it. The project with the lowest bid price receives a contract, which guarantees a premium payment for 20-years (WindEurope 2019b). This premium is equivalent to the bid price, with which the developer won the contract. Once the project has been contracted, it must be implemented within 24 months (with the exception of 54 months for energy cooperatives in 2017), after which the deposit will forfeit (Endell and Quentin 2017). What remains worth mentioning is that the so-called grid expansion area in Northern Germany, which includes the Länder of Schleswig-Holstein, Mecklenburg-Western Pomerania, Bremen, Hamburg and parts of Lower Saxony, is subject to an upper limit for available contracts at each auction. This is a temporary instrument in effect until improvements to the electricity grid will have reduced the bottlenecks associated with the oversupply of onshore wind-generated electricity in Northern Germany (Endell and Quentin 2017).

Finally, the fourth stage of the realisation process is implementation. It takes an average of 15 months and begins with ordering the turbine(s) and other necessary parts (Quentin 2020b; Pietrowicz and Quentin 2015). While the delivery by the manufacturer is awaited, the final plans for the construction site need to be finalised, the site needs to be opened and prepared for installation and the road access for the turbine delivery needs to be secured. Once the turbine is delivered, it needs to be installed, connected to the grid and commissioned. This concludes the realisation process, which takes an average of 6 ⅓ years or 76 months from the start of planning until the wind farm is in operation (Pietrowicz and Quentin 2015).

2.3. Onshore wind power in trouble: Barriers to realisation

2.3.1. Germany's slowdown in onshore wind power growth: What it means and how it is perceived

Let us focus now on the 2018/2019 slowdown and its consequences in more detail. With 2.2 GW of net added onshore wind farms, the year of 2018 saw the lowest rate of growth since 2012. Marking the lowest capacity growth since 1998 – before the introduction of the EEG – 2019 was even worse with only 980 MW. The German wind power industry has already suffered from these developments. While the German manufacturer Senvion has gone bankrupt, the sales of other manufacturers such as Nordex, Enercon and Siemens Gamesa are dwindling in Germany (IG Metall 2019). At the same time, the German wind power industry is downsizing at a worrying rate: While almost 40,000 thousand jobs have been cut since the beginning of 2017, more are likely to follow in the future (BMWi 2019b; Zeit Online 2019).

While jobs are lost, the future of the Energiewende also seems at risk. This is because, on the one hand, the future of Germany's electricity supply is bound to be nuclear- and coal-free. One the other, electricity demand is likely to rise due to the country's ambitions for sector coupling, that is, electrifying the heating and transport sector with renewable electricity (Agora Energiewende 2020; BMU 2019). In the short term, this will require strong and stable rates of renewable energy expansion – first and foremost of onshore wind power, which, with 41.5%, accounted for the lion share of generated renewable electricity in Germany in 2019 (AGEB 2020). Several studies have modelled the required annual gross additions of onshore wind power for achieving Germany's 2030 renewable electricity target of 65% renewables in the power mix. Their estimates for the required total capacity of onshore wind farms in 2030 average at 82.4 GW (Agora Energiewende 2018; Oei et al. 2019; BEE 2019; BDEW 2019). Their estimates for the yearly gross additions of onshore wind farms until 2030 average at 4.2 GW. The individual estimates of these studies can be found in Table 3.

Table 3 – Scenarios for the required growth to meet the 65% target
The table shows (1) the estimates (GW) of different studies for the required annual gross onshore wind power additions and (2) the required onshore wind power capacity at 2030 target in order to reach the 65% target.

	Estimates for the required yearly gross additions	**Target capacity for 2030**
Agora Energiewende (Agora Energiewende 2018)	4.2	81.9
German Association of Energy and Water Industries (BDEW 2019)	3.8	77
The German Renewable Energy Association (BEE 2019)	4.7	-
German Institute for Economic Research (Oei et al. 2019)	4.3	84.6
Mean	4.2	82.4

Other studies have estimated the yearly required onshore wind additions until 2030 for Germany to be on track to meet its 2050 target of becoming carbon neutral (Öko-Institut e.V. and Fraunhofer ISI 2015; Boston Consulting Group and Prognos AG 2019; dena 2018; UBA 2019b). Their estimates average at 4.8 GW a year, with a range from 3.9 to 5.9 GW – an even starker contrast to the additions of 2018 and 2019. Quite clearly then, the deployment of onshore wind power seems to be failing at a time when it is most central to getting Germany back on track to speed up its energy transition and reach its climate targets.

These challenges have been the subject of intense discussion in politics and public discourse. And, interestingly, while the discourse is marked by different opinions on what is at fault and who is to blame, almost everyone does seem to agree that German onshore wind power is in crisis. All major national newspapers and media outlets have run stories on the slowdown, literally calling it a "crisis" and pointing to its negative consequences for the Energiewende and the German wind power industry (Balser and Bauchmüller 2019; Witsch 2019; Uken 2019; von Blazekovic 2019; Schultz 2019). The German wind energy industry has of course been one of the loudest and most critical voices, lamenting the failing domestic market and the associated job losses as well as stressing the need for continued wind energy expansion to secure the country's future electricity supply (BWE 2020b; BWE 2019a; zdf 2020). But also, the energy industry as well as many different environmental and climate NGOs have stressed the need for action. Specifically, a coalition of key energy industry associations and NGOs has issued a document criticising the "paralysis" of German onshore wind power and proposing ten measures aimed at promoting deployment (BDEW et al. 2019). Finally, the crisis is also acknowledged by most parties across the political spectrum – not only by the Greens (Bündnis 90/Die Grünen 2018) but also by the ruling coalition of Christian Democrats (CDU) and Social Democrats (SDP), with the Federal Ministry of Economy and Energy having published a concrete plan to remove the obstacles to deployment (BMWi 2019a).

While the acknowledgement of the crisis seems almost universal, the opinions on the underlying reasons and responsible actors for the slowdown vary. Generally, politicians from CDU, SPD and the Liberal Democrats (FDP) have been framing the crisis as a result of a lack of social acceptability of and legal certainty for onshore wind power projects, both of which need to be restored to guarantee higher deployment rates (BMWi 2019a; FDP 2019). A popular proposal among this camp for enhancing acceptability sees for Germany-wide minimum distances between turbines and settlements. Indeed, a draft law by the Federal Ministry of Economy and Energy from November 2019 included minimum distances of 1000m – sparking fierce public debates ever since. In discussing the reasons for the slowdown, the Greens point to missing permits and a lack of available areas for new projects and blame both the governing parties for contributing to these barriers (Bündnis 90/Die Grünen 2019). Although the German wind energy industry sees issues with area availability and permitting too, it also highlights problems with the transition to the auction scheme as well as an increasing number of lawsuits against projects (BWE 2019a; BWE 2020b). Finally, environmental NGOs blame the lack of regional development plans, conflicts between species protection and wind power, bureaucratic hurdles and a deficient auction scheme for the slowdown (Deutscher Naturschutzring et al. 2019).

2.3.2. In search of scientific explanations for the 2018/2019 slowdown

This short review of the discourse around Germany's 2018/2019 slowdown in onshore wind power growth has shown that, firstly, there seems to be almost universal acknowledgement of the crisis and that, secondly, the discussion about the underlying causes remains unsettled. Now, let us review the scientific literature for theories and observations that can help us evaluate the 'crisis character' of the slowdown and shed some light on the country's challenges to deployment. As discussed, judging the gravity of the slowdown, and thus evaluating whether it represents a crisis, requires us to interpret it within the long-term growth trajectory of onshore wind power in Germany. For this, we need to look at how German onshore wind power capacity has grown in the past and is expected to grow according to scientific theory.

The growth dynamics of energy technologies such as onshore wind power have been extensively studied. Technology studies show us that the diffusion of new technologies generally follows an S-shaped curve, with three distinctive phases that are characterised by different growth patterns (see Figure 2) (Rogers 2010; Grübler 1996; Nieto et al. 1998; Andersen 1999).

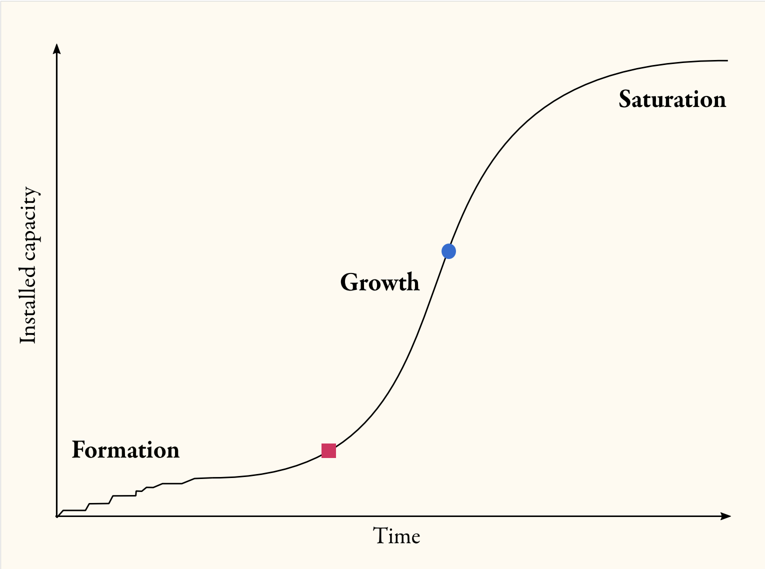


Figure 2 – Diffusion of energy technologies
The three phases of technological diffusion for energy technologies. In the formative phase, growth is volatile and erratic. After hitting the take-off point (red square), the technology enters the growth phase – characterised by accelerated growth up to the inflection point (blue circle). Here, growth peaks and starts declining until the technology reaches the saturation phase, where growth plateaus. Source: own representation.

Several studies have found these diffusion dynamics to also apply to energy technologies in general (Barreto and Kemp 2008; Kramer and Haigh 2009; Grübler et al. 1999; van Sluisveld et al. 2015; Wilson et al. 2013; Wilson 2012) and renewable energy in specific (Iyer et al. 2015; Schilling and Esmundo 2009; Jacobsson and Bergek 2004). For renewables such as wind power, each phase of the diffusion curve is shaped by underlying socio-technical, techno-economic and political drivers and barriers, which either promote or hinder diffusion (Cherp et al. 2018; Markard 2018). According to theory, diffusion starts with the formative phase, which is characterised by niche protection, experimentation with small scale units, uncertainty and slow and volatile growth (Bento and Wilson 2016; Wilson 2012). Once the technology hits a 'take-off' point, it leaves its niche to enter the growth phase, distinguished by accelerated and rapid diffusion (Jacobsson and Bergek 2004). At some point, the technology will pass a so-called inflection point of peak growth, after which growth starts to persistently decline as it encounters a range of constraints (Markard 2018; Kramer and Haigh 2009). Eventually, the technology reaches the saturation phase, where growth plateaus (Rotmans et al. 2001).

As renewable energy technologies move along their paths of diffusion, they are subjected to a range of varying challenges (Markard 2018; Kramer and Haigh 2009). The period up until 'take-off' is shaped by the purpose to guarantee the technological and economic feasibility of the technology beyond its niche (Markard 2018). This is achieved by experimenting with pilot projects, developing innovative business models, building stable socio-technical networks and tailoring supportive policy schemes (Markard 2018; Geels et al. 2017; Jolly et al. 2012; Bauknecht et al. 2013). In the later stages of growth, however, the nature of challenges seems to change for renewables. This is because, over time, the focus of an energy transition based on renewables shifts from the generation of energy to its distribution, transformation and storage (Markard 2018). This has to do with the increasing supply of intermittent renewables causing fluctuations and grid integration issues (Schroeder et al. 2013; Schmid et al. 2016). As a result, 'complementary and enabling technologies' such as smart grids, ultra-high voltage transmission, Power-to-X and modern energy storage become foundational for the continued growth of renewables (Markard 2018; Nordensvärd and Urban 2015). At the same time, renewables face the challenge of further reductions in unit costs as protective support schemes such as feed-in tariffs are abolished to allow for market integration and prevent cost escalation (Kramer and Haigh 2009; Lundberg 2019; Frondel et al. 2015). Further, competition with the incumbent energy industry tends to become more fierce as renewable energy poses more of an essential threat to their business models (Kungl 2015; Lauber and Jacobsson 2016). Finally, the decentralised nature of renewables means that their land-use requirements can start to exceed what is geographically available or socially acceptable (Kramer and Haigh 2009; Wüstenhagen et al. 2007).

How does this relate to German onshore wind power? Looking at the technology in Germany, we find that it has very much established itself on the market. Indeed, as was noted, the country has the third-largest onshore wind fleet in the world. This means that German onshore wind power is not any longer struggling to move out of its niche as technologies do in their formative phase. At the same time, the technology is still growing and has therefore not reached market saturation. This means that German onshore wind power will be located somewhere along the growth phase. Given the recent slowdown in the technology's growth, the pressing question is now whether it is already on its way towards market saturation or not. That is, whether, from now on, its growth will steadily decline or rise again. Such an analysis is not only relevant for explaining Germany's case but also for advancing the scientific knowledge on the later stages of technological diffusion. This is necessary because the majority of research on diffusion of renewable energy technologies has focused on the early stages of diffusion, mainly the transition from a niche position to the mainstream market (Popp et al. 2011; Bento and Wilson 2016; Jolly et al. 2012). This imbalance in focus on the whole spectrum of diffusion has meant that not enough attention has been paid to the constraints that renewable energy technologies run into during the later stages of growth (Markard 2018). And as we have seen, this is especially concerning given that these later challenges seem to be qualitatively different from the ones during early diffusion (Markard 2018; Kramer and Haigh 2009). What the literature is especially lacking, are empirical observations of renewable energy technologies in the later stages of commercialisation, which can corroborate, reify and expand the existing theoretical knowledge. An investigation of the specific challenges for the established onshore wind power technology in Germany offers this possibility. By locating Germany in its particular phase of diffusion and describing the underlying growth challenges, the technology diffusion model can be empirically substantiated and theoretically expanded.

2.3.3. Existing research on challenges for onshore wind power

In order to explain the reasons for the 2018/2019 slowdown in Germany, we need to complement the knowledge on general constraints for growing renewable energy technologies with research on specific challenges for onshore wind power development, both in general and for Germany in particular. To begin here, it should be emphasised that synthesising the state of scientific knowledge on these issues requires taking an interdisciplinary perspective. This is because Germany's energy transition cannot be understood merely as a progression of technological innovation but also as one of social processes and institutional changes (Schmid et al. 2016). Indeed, some authors even claim that the Energiewende is to be understood as an 'institutional battle' between green energy proponents and climate advocates, on the one hand, and opponents from conservative political camps and the traditional energy industry, on the other (Jacobsson and Lauber 2006). For the study of challenges for wind power deployment, this means extending one's view beyond issues such as resource quality, electricity costs and grid integration to incorporate the entire spectrum of institutional and market, socio-cultural and environmental challenges (Breukers and Wolsink 2007; Timilsina et al. 2013; Firestone 2019; Katzner et al. 2019).

Let us begin with the institutional and market challenges. Studies show that onshore wind energy only tends to thrive within effective support schemes – often through feed-in tariffs but also through auction schemes, as long as they represent part of an integrated government strategy to promote renewable energy deployment and guarantee profitable rates of remuneration for wind-generated electricity (González and Lacal-Arántegui 2016). In countries, where these support schemes are lacking or unstable, wind energy has not fared as well (Lüthi and Prässler 2011). Other challenges of this category lie in legal uncertainties, administrative hurdles and grid access problems, which may discourage developers from investing in onshore wind farms (Lüthi and Prässler 2011). Furthermore, onshore wind energy tends to do less well in countries where it has to engage in competitive struggles with conventional power sources such as coal, nuclear energy and natural gas (Timilsina et al. 2013).

Scanning the scientific literature for current institutional and market challenges for wind power in Germany reveals two different themes: the recent transition from feed-in tariffs to auctions and the inadequate grid infrastructure. Let us first discuss the former. After the EEG was amended, technology-specific auctions were introduced for onshore wind energy from 2017 (Thomas 2019). During 2017, there were exemption clauses for citizens' energy cooperatives in order to guarantee the continued deployment of community wind energy (Lundberg 2019). The main three exemptions for these cooperatives were: (1) the right to participate at auctions with unpermitted projects; (2) longer implementation deadlines (54 as opposed to 24 months); (3) the remuneration rate for contracted projects was based on the highest winning bid instead of one's own bid. As a result, the vast majority of contracts went to energy cooperatives in 2017 (Lundberg 2019). This in turn meant that most contracts went to unpermitted projects that would not need to be implemented anytime until between late 2021 and early 2022 (Lieblang 2018). Further, these exemptions incentivised aggressive bidding, which forced down prices enormously. This also had to do with the fact that large commercial developers would found their own energy cooperatives or cooperate with existing ones to benefit from the exemptions (Wilts and Delzeit 2017). In sum, almost all contracted projects lacked the permit necessary for near-term implementation (Lieblang 2018). Further, many of these projects would have been designed to be built much later in time in order to benefit from future technology cost reductions. Lastly, future implementation is uncertain as the low winning prices may render projects unprofitable (Lundberg 2019). As a result of all these unintended outcomes, the exemptions for energy cooperatives were abolished after 2017. From then on, only permitted projects could be taken to the auction and every contract had a 24-month implementation deadline (Lundberg 2019).

How did auctions develop after 2017? One study investigated the ability of the auctions in bringing about reductions in the rates of renumeration for onshore wind energy until the end of 2018 (Grashof et al. 2020). It found that, in the beginning of the 2018, prices would recover from the extremely low levels of 2017 to, then, rise to the maximum permissible price of 6.2 ct/kWh and stay there. This had to do with a decrease in the level of competition at auctions: the capacity of projects for which bids were submitted would continuously be below the tendered capacity in the second half of 2018. The article speculates on a number of underlying reasons for this observed undersubscription such as a lack of permitted projects, longer licensing procedures and increasing lawsuits but notes that a meaningful analysis of these factors is beyond its scope. No other academic research was found that looked into the reasons for undersubscription in more detail or evaluated how participation at auctions would develop after 2018.

The second issue of this category identified in the literature is the inability of Germany's electricity grid to keep up with the increasing electricity output of onshore wind power. The lack of public investment and the absence of incentives for transmission system operators or utilities to invest in the grid has meant that the German electricity grid is outdated and overcharged (Nordensvärd and Urban 2015). This has led to a situation where in the windy north, wind farms sometimes generate too much electricity for the regional grid to handle, demanding that their grid feed-in is temporally curtailed. This curtailment of wind farms amounted to 5.2 TWh of generated electricity or 0.9% of Germany's gross electricity production in 2018 (vbw 2020). Theoretically, this excess electricity could be put to use in the energy-demanding south of the country. However, the required long distance transmission infrastructure is missing and still fiercely opposed in Germany (Nordensvärd and Urban 2015; Kühne and Weber 2018). Unsurprisingly, these grid bottlenecks have been a challenge for onshore wind power deployment, not least by stirring public debate about so-called wind-generated 'ghost power', that is, the curtailed electricity from wind farms and the associated redispatch costs (Wetzel 2019).

Socio-cultural challenges for onshore wind power generally have to do with questions of public acceptability of the technology (Wüstenhagen et al. 2007). Wind turbines radically alter existing landscapes, which can clash with people's aesthetic preferences (Pasqualetti 2011; Veelen and Haggett 2017). This has sparked increasing local resistance to onshore wind power in many countries, with community members organising to obstruct new projects due to their visual appearance and noise pollution (Devine-Wright 2009; Nadaï 2007; Christensen and Lund 1998). Beyond aesthetic values, however, acceptability of wind energy also seems to depend on issues such as the wind farm's economic impacts (e.g. by harming tourism), its perceived danger to biodiversity and habitats and its effect on human health (e.g. through infrasound emissions) (Leiren et al. 2020). Finally, also a lack of trust and poor communication between developers, local politicians and affected communities has been found to contribute to social resistance to wind farm development (Firestone 2019; Krohn and Damborg 1999).

What does research tell us about the socio-cultural challenges for onshore wind power development in Germany? While acceptability has been a key concern throughout the evolution of wind energy in Germany, resistance seems to have been increasing in recent years, with hundreds of citizens' initiatives against wind power having emerged all over the country (Roßmeier and Weber 2018). The underlying factors of acceptability of wind farms in Germany have been extensively researched. Resistance seems to be driven by certain ideals surrounding the homeland and the landscape; concerns for health, conservation and economic harm; a failure to identify with the goals of the energy transition and the perception of unfair, exclusive and non-transparent planning and implementation procedures for wind farm development (Langer et al. 2018; Roßmeier and Weber 2018; Reusswig et al. 2016; Sonnberger and Ruddat 2017; Zoellner et al. 2008; Jobert et al. 2007). These challenges have been dominating the public and political discourse, with tangible consequences such as when minimum distance regulations moved on the Federal Government's political agenda. The impact of acceptability issues on deployment rates in 2018 and 2019 has not been researched, however.

Finally, let us discuss the environmental challenges of onshore wind power that frequently lead to clashes with conservation interests. Research has shown that wind turbines pose a danger to biodiversity, especially due to collisions with birds (Katzner et al. 2017) and bats (Frick et al. 2017). Further, the construction of a wind farm and the associated alteration of the immediate environment can lead to the degradation and destruction of natural habitats (Marques et al. 2019; Barré et al. 2018), shifts in weather (Baidya Roy and Traiteur 2010) and changes in the behaviour of terrestrial and aerial species (Łopucki et al. 2017; Fernández-Bellon et al. 2019). Preventing environmental harm has required the development of sophisticated mitigation measures for turbine technology (May et al. 2015). Still, however, these issues have led to massive resistance against onshore wind power development from conservationists and their supporters across the globe. These clashes tend play out in costly lawsuits, which can delay or even halt the realisation of new projects (Katzner et al. 2019).

In Germany, these kind of issues have moved to the forefront of challenges facing wind power today. Consequently, they have attracted a lot of research, especially on the tension and conflicting goals between nature conservation and climate mitigation through wind energy (Schifferdecker 2014; Ammermann et al. 2019) and on practical solutions to reconcile these conflicts (Dorda 2018). Bird protection has been a key subject of concern, with its principles and goals repeatedly clashing with the development of wind farms in Germany (Frenz 2016; Ruß 2016; Reichenbach 2017). This is despite the fact that collisions between birds and turbines do in fact happen quite rarely in the country (Grünkorn et al. 2016). These conflicts have become so prominent in Germany that some have termed them the 'green-green dilemma' (Voigt et al. 2019). Aligning the goals of the spheres of nature conservation and climate mitigation is widely viewed as one of the major challenges for the continued deployment of onshore wind power (Köppel et al. 2019).

Table 4 shows the variety of challenges of institutional, economic, socio-cultural and ecological nature, which confront onshore wind power development in general and in Germany.

Table 4 – An overview of challenges for onshore wind power deployment

Challenges	General	Germany
Institutional and market challenges	• Dependence on effective support schemes (González and Lacal-Arántegui 2016) • Profitability and cost efficiency (Lüthi and Prässler 2011) • Administrative barriers and legal uncertainties (Lüthi and Prässler 2011) • Competition with conventional energy sources (Timilsina et al. 2013)	• Unintended consequences of initial design of the auction scheme: Almost all contracts went to energy cooperatives (Lieblang 2018; Lundberg 2019) • Undersubscribed auctions in 2018 (Grashof et al. 2020) • Grid bottlenecks (Nordensvärd and Urban 2015)
Socio-cultural challenges	• Diminishing public acceptance of wind farms (Wüstenhagen et al. 2007) • Clash with aesthetic preferences (Pasqualetti 2011; Veelen and Haggett 2017) • Organised opposition against wind farm development (Devine-Wright 2009; Nadaï 2007; Christensen and Lund 1998)	• Emergence of numerous citizens' initiatives against wind power (Roßmeier and Weber 2018) • Resistance on the basis of landscape ideals; health concerns, conservation, economic risks; opposition to the Energiewende & dissatisfaction with planning and implementation procedures (Jobert et al. 2007; Zoellner et al. 2008; Langer et al. 2018; Reusswig et al. 2016; Sonnberger and Ruddat 2017)
Environmental challenges	• Turbines endanger biodiversity (Katzner et al. 2017; Frick et al. 2017) • Degradation and destruction of natural habitats (Marques et al. 2019; Barré et al. 2018) • Shifts in weather (Baidya Roy and Traiteur 2010) • Changes in species behaviour (Łopucki et al. 2017; Fernández-Bellon et al. 2019)	• Tension between conservation and onshore wind power (Schifferdecker 2014; Dorda 2018) • Bird protection as a large barrier to wind power (Frenz 2016; Ruß 2016) • The 'green-green' dilemma (Voigt et al. 2019)

While much research exists on these general challenges, no study has attempted to explain their effect on the 2018/2019 slowdown in growth of onshore wind power in Germany. What concrete barriers to deployment have emerged from the above-mentioned challenges in Germany? How did these barriers develop over time and how did they interact to then, in some combination, lead to the sudden decrease in deployment observed after 2017? Which of these barriers are still at work, which have subsided? While the public discourse on these questions seems far from settled, the scientific literature provides little to no answers. Specifically, more needs to be known about the 2017 auctions; how many of the contracted projects have been permitted and built; whether undersubscription has persisted after 2018; why it even took place, that is, whether it was due to missing permits or lawsuits or something else; how social acceptability and conservation issues contribute here – and finally, what other challenges are there that have falsely been missing from the discussion but are essential to explaining the slowdown?

Also, while there is general acknowledgement in the public discourse that the slowdown represents a crisis, that is, a persistent decline in capacity growth, no research has verified this by looking at the slowdown in its long-term growth context. Connected to this question, there remains the need for an investigation into the 'crisis narrative' and the underlying expectations and their origins. What is needed, then, is a comprehensive account of the dynamics of onshore wind power development in Germany, including of the technology's growth trajectory, the discourse around the slowdown and the underlying barriers to deployment. In terms of the latter, this means identifying the combination of barriers obstructing deployment at each step of realisation, from planning, licensing and auctioning to implementation, and analysing these barriers in terms of their interactions and concrete impact on the 2018/2019 slowdown.

3. Theory & Methods

3.1. Theoretical framework and methodology

3.1.1. Analytical framework for understanding the diffusion of onshore wind power in Germany

Let us have a closer look at the theoretical framework of this thesis and the thesis' contribution to this framework. Technology diffusion theory offers an appropriate framework for pinpointing German onshore wind power on its path from a technological niche in the 1990s to market saturation at some point in the future. Through this exercise, the 2018/2019 slowdown in deployment can be contextualised, that is, examined within its long-term growth context, allowing us to judge how irregular and worrying the slowdown really is. Concretely, this means locating German onshore wind power on its diffusion curve to be able to say whether its growth has already started to steadily decline. That is, while a slowdown is understood here as a temporary growth anomaly, a decline is understood as a persistent and steady state. If growth is declining, the technology is well on its way to the saturation phase – indicating that the trends observed in 2018/2019 would persist and indeed represent a 'crisis'. If it is not declining, the technology is still far away from its saturation phase – meaning that the years of 2018/2019 would be nothing more than an anomaly within a long and ongoing growth trajectory of the technology in the country.

After having located German onshore wind power on its diffusion curve, the second step, is to identify and describe the specific challenges that underly the technology's particular position on the diffusion curve. This goes hand in hand with identifying the concrete barriers that result of out of those challenges and have led to the 2018/2019 slowdown. Importantly, the German case allows us to bring together research on general challenges to renewable energy technologies in later phases of diffusion and findings on specific challenges to onshore wind power development. This allows us to concretise the general renewable energy diffusion model for the specific case of onshore wind power, which can be expected to differ from other renewables in terms of its underlying challenges (Diógenes et al. 2020).

In sum, this thesis advances the scientific knowledge on the technology diffusion framework for renewable energy technologies in two ways. First of all, the technology diffusion theory is underpinned by the empirical case of onshore wind power in Germany. By locating the technology on its specific point on the diffusion curve and deriving the growth dynamics, a concrete real-life example of a renewable energy technology in the later stages of diffusion is investigated. Second of all, analysing the German case allows for the expansion of the diffusion theory, in that new insights about the underlying challenges for onshore wind power at the later growth stages are generated. Figure 3 illustrates this research agenda. It shows how the slowdown in growth of onshore wind power in Germany serves as an empirical example of technology diffusion theory. While growth has recently slowed down, the concrete position on the S-curve is unknown. Depending on this position, the slowdown represents a temporary anomaly or the start of a persistent decline. An explanation for the crisis narrative is sought in the interplay between growth expectations and actual growth. And, lastly, the barriers to growth need to be identified to explain the 2018/2019 slowdown. These barriers are thought to emerge out of general challenges, which renewable energy technologies face at their growth phase.

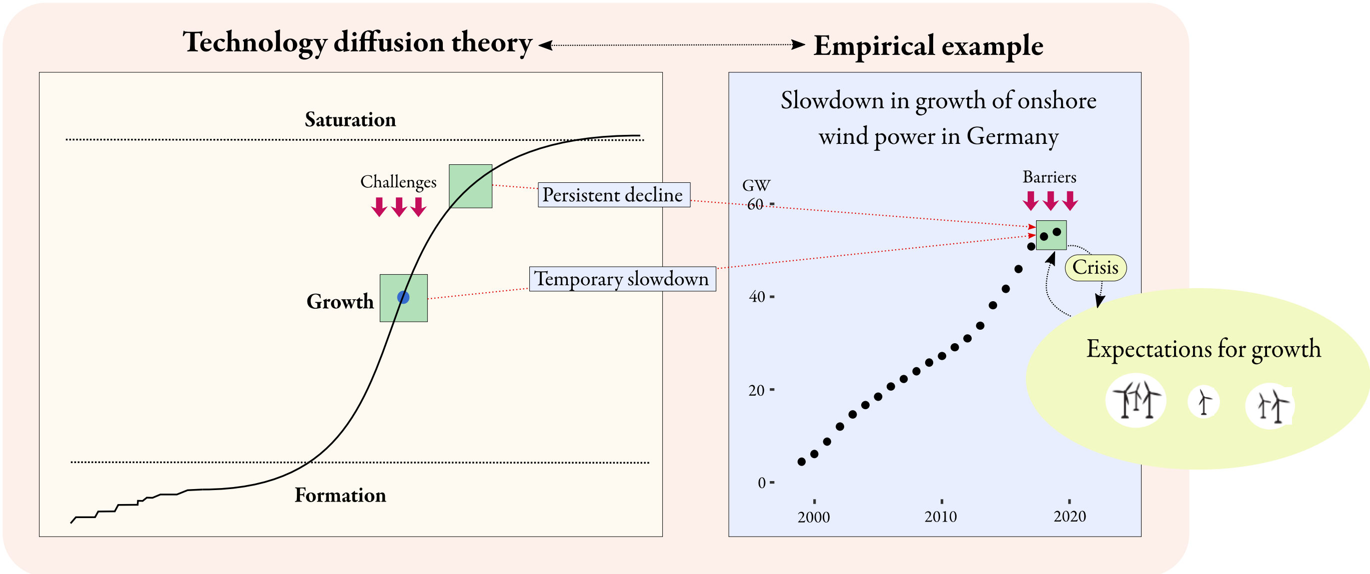


Figure 3 – Illustration of the research agenda

This figure shows the research agenda of this thesis. The first research question aims to locate the 2018/2019 slowdown (green box in the blue square) within the long-term growth trajectory of the technology (green boxes in the yellow square). The slowdown may just be a temporary anomaly in the middle stage of the growth phase, after which growth will rise again. But it could also be part of a persistent decline at the late stage of the growth phase towards market saturation. The second research question tries to explain the crisis narrative by investigating the interactions between growth expectations and actual growth. The third research question aims to identify the underlying growth barriers, which have caused the 2018/2019 slowdown. These barriers are thought to emerge out of general challenges that renewable energy technologies face when they diffuse. Source: own representation.

3.1.2. Multi-stage analysis of the barriers to onshore wind power development

For the analysis of the underlying reasons for the 2018/2019 slowdown, a methodology was developed, which aims to identify the underlying barriers to each of the four stages of the process of realisation for an onshore wind farm in Germany (Table 2). Taking such a project developer's perspective was deemed as most productive in revealing the concrete on-the-ground barriers to deployment and determining when and where disturbances and disruptions emerge. In this methodology, barriers are first identified, then linked to the respective stage of realisation, analysed in terms of their timeline and interactions and finally assessed for their concrete impact on deployment. Let us consider each of these steps in detail.

Starting off, it should be mentioned that this approach focuses mainly on what are called first-order barriers, that is, those barriers that impede development in a direct and tangible way. In contrast, the challenges to the development of renewable energy in general and onshore wind power in specific – social resistance, grid bottlenecks, conservation conflicts and policy changes – which we have discussed at length in the previous sections, are considered to impede development in a more indirect manner. For the purposes of this analysis, such challenges will be called second-order barriers. Generally, first-order barriers are thought to emerge from these second-order barriers. Put differently, second-order barriers are understood to influence deployment through a first-order barrier. To provide an example, the switch of the support scheme for renewable energy, as with the introduction of the auction system for onshore wind power in Germany, has been mentioned as a common challenge in later phases of diffusion. As the literature review has shown, this change in Germany was accompanied by certain issues such as underbidding at auctions. As understood here, underbidding may negatively affect future deployment as a first-order barrier by making projects unprofitable, but is in turn affected by the switch of the support scheme, a second-order barrier. Another example would be lawsuits, which directly obstruct deployment as a first-order barrier, but are in turn caused by a second-order barrier such as for example the diminishing social acceptability of onshore wind turbines.

After identifying the first-order and second-order barriers to deployment through the interview, content and data analysis, the next step requires linking the barriers to the respective stage of realisation, at which they have their effect. Let us illustrate this step with examples: If designated areas for onshore wind power development are missing, developers are obstructed at the planning stage and cannot even get to filing a permit application. If new permits are missing, developers cannot partake at auctions and are stuck at the licensing stage. If auctions are undersubscribed, not as many developers will be able to move toward implementation. And, finally, if implementation is impeded by an increasing number of lawsuits, developers are stuck there with their contracted projects. Only an investigation that systematically looks at each of these stages separately can aim to uncover where and when exactly the bottlenecks lie for the deployment of onshore wind power in Germany.

After all barriers are identified and linked with their respective stage, they need to be analysed in terms of their respective timelines. That means figuring out when a certain barrier starts eliciting its effect and when this effect subsides. We already know, for example, that the exemption clauses for energy cooperatives at the auctions, which led to underbidding and other issues, were active all through 2017 but abolished from 2018. Other possible barriers such as lawsuits or missing permits may also have a specific timeline. Understanding these timelines and thus knowing whether a certain barrier is still active or has already subsided is key for being able to say whether growth will rise again or not. Also, this timeline is essential for the next step of the analysis, which looks at the interactions between different barriers.

To understand the need for analysing interactions, let us consider the following: Auctions may be undersubscribed, but is the problem really located here? Or may undersubscription be due to missing permits? And if it is, are missing permits in turn caused by a lack of designated areas? Evidently, all stages of onshore wind power development are connected with one another and understanding the slowdown requires knowing where exactly issues arise. Implementation builds on successful participation at the auctions, which will have required a valid permit that could only have been granted for a project that was successfully planned. Just as the different stages are interconnected, so are the underlying barriers of these stages linked with each other. More specifically, barriers within and across stages can be expected to trigger and reinforce each other. If we want to know the real cause of the slowdown in growth, we need to trace these interactions down to the root of the problem. Importantly, this requires keeping in mind the average duration of realisation and the duration of each individual stage.

The final step of the analysis lies in determining and weighing the effect of the barriers on actual deployment over time. Firstly, this requires analysing the chain of interactions between different barriers and identifying which ones affect deployment most directly. Secondly, the effect of these barriers on deployment has to be assessed with temporal accuracy. While different barriers may underly the lack of deployment in different years, we need to be able to distinguish between 2018, 2019 and beyond. For example, although undersubscribed auctions in late 2018 may be worrisome, they cannot be expected to have an effect on deployment until 2020 – given that implementation takes 15 months. Again, we are required to closely follow the average timeline of realisation to judge the effect of each barrier on capacity growth. Finally, this impact of different barriers on deployment needs to be weighed on the basis of the available data. This will allow us to make a meaningful statement about which barriers are key to understanding the slowdown in growth of onshore wind power in Germany.

3.2. Research methods

3.2.1. Modelling capacity growth

Locating German onshore wind power on its diffusion curve is achieved by modelling actual capacity growth with three different growth functions and comparing their fit. Before discussing the mathematical operation, let us look at the underlying idea. As a technology moves along its growth phase, its rate of growth varies. While it grows exponentially at first, it will soon meet the inflection point, after which growth stabilises and finally slows down. The early stage of the growth phase, where growth accelerates, can be modelled by an exponential function (Creutzig et al. 2017). For the middle stage of the growth phase, where growth stabilises, the exponential function is no longer a well-fitting model (Madsen and Hansen 2019). At the same time, the logistic function does not fit here either, since growth is not yet slowing down but still advancing nearly linearly (Kramer and Haigh 2009). Therefore, a logistic-linear function was used to model this middle stage of the growth phase. Finally, the later stage of the growth phase, where growth does slow down, was modelled by a logistic function. The three functions – logistic, logistic-linear and exponential – were fitted to actual data on net installed capacity of onshore wind power in Germany between 1990 and 2019. Figure 4 visualises these three growth models.

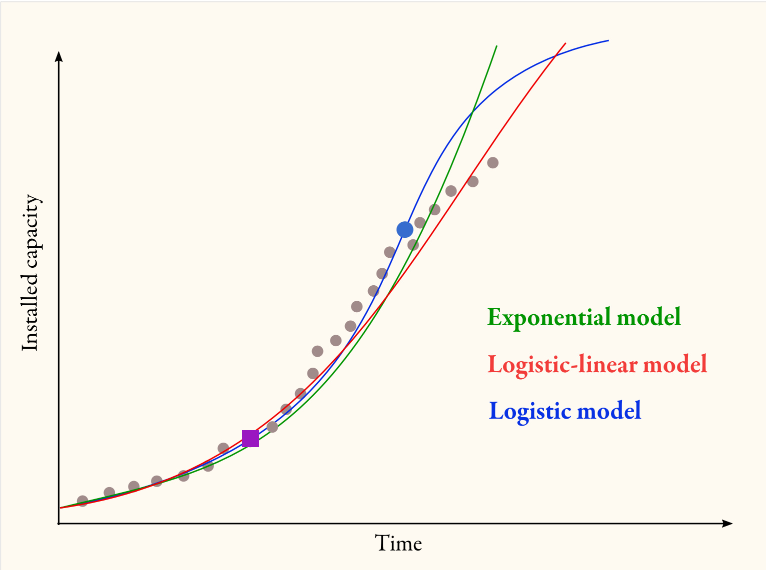


Figure 4 – Approximating capacity data with three different growth models
As the position of Germany's onshore wind power technology on the S-curve is unknown, empirical capacity data is approximated by three different growth models. The early stage of the growth phase is modelled by an exponential function (blue), the middle stage by a logistic-linear function (red) and the later stage by a logistic function (green). The violet square shows the take-off point, the blue circle shows the inflection point. Source: own representation.

The logistic growth function that was used in the analysis has been borrowed from the technology diffusion literature, where it has long been employed to model technological growth (Griliches 1957). This function has been used to approximate capacity growth of historical energy technologies and also of wind power (Wilson et al. 2013; van Sluisveld et al. 2015; Bento and Fontes 2015). It goes as follows:

$$f(t) = \frac{L}{1+e^{-k(t-t_0)}}$$

where L is the curve's maximum value, e is the natural logarithm base, k is the logistic growth rate, and t_0 is the inflection point, at which the technology reaches half of the curve's maximum value ($L/2$) and its growth becomes nearly linear before it slows down.

The logistic-linear function aims to account for the fact that actual technology growth does not always follow the logistic curve perfectly. Instead, especially in expanding markets, growth may continue at a nearly linear rate even after having reached the inflection point (Kramer and Haigh 2009). As a result, the inflection point can be dissimilar to $L/2$, creating an asymmetrical curve. To represent such growth, we used the following function:

$$f(t) = \begin{cases} \dfrac{L}{1+e^{-k(t-t_0)}}, & t < t_0 \\ \dfrac{L}{2} + Lk(t-t_0)/4, & t \geq t_0 \end{cases}$$

Finally, the exponential function tries to model capacity growth at the early stages of the growth phase, where growth is accelerating. It goes as follows:

$$f(t) = L * e^{-k(t-t_0)}, \text{ when } e^{-k(t-t_0)} \gg 1$$

To fit these three functions to capacity data, the *nls* function in the R software package was used (Bates and Hunter 2014). This is a non-linear least squares approach based on the Gauss-Newton algorithm (Bates and Watts 1998). Further, the *nlsLM* function from the *minpack.lm* package was employed to implement the more robust Levenberg-Marquardt algorithm (Bates and Watts 1998). By comparing the fit of three functions, that is, by finding out whether capacity data is best modelled by the logistic, logistic-linear or exponential curve, we can locate German onshore wind power on either the early, middle or later stage of the growth phase. Residual sum of squares (RSS) was used as an indicator for the goodness of fit among the three functions. The fitting of growth models and RSS calculations are complex mathematical operations and were kindly performed by Vadim Vinichenko from the University of Bergen.

3.2.2. Interviews

3.2.2.1. Selection of interviewees

Interviews were deemed as essential for answering the second and third research question, so that first-hand accounts of the dynamics of onshore wind power development and the associated expectations shaping the crisis narrative could be incorporated into the analysis. An elite interview approach was used to select interviewees, with the elite representing experts on onshore wind power in Germany (Tansey 2007). Such expertise was offered by two different groups of interviewees, each of which would contribute a different perspective on the 2018/2019 slowdown. The first group would comprise project developers, which plan, license, auction and implement new wind farms in Germany and sometimes even operate and maintain them. A study looking at the diversity of actors involved in the development of new wind farms estimated that between

64% to 72% of all new projects in Germany are realised by project developers (BWE and Deutsche WindGuard 2015). Consequently, this group of actors is particularly familiar with the on-the-ground dynamics of onshore development and thus able to share personal insights on the trends and challenges associated with realisation. The second group is more heterogenous, comprising actors that occupy expert or advisory positions on onshore wind power in companies, industry associations or think tanks. This group of actors was considered to provide a broader and more detached view on the state of onshore wind power development in Germany, which is less affected by experiential biases and regional disparities. The insights gained from both these groups complement each other in that they combine the developer's personal account with the expert's wider perspective. Together, this provides for a comprehensive and balanced picture of the dynamics of onshore wind power development in Germany. Further, these two groups were considered as most likely to offer valuable perspectives about the wide-spread narrative of the 2018/2019 slowdown representing a crisis. Although this narrative is of course also shaped by other interest groups, people working within or with the wind energy industry are most directly affected by the slowdown and thus most likely to label it as a crisis.

Potential interviewees were partly suggested by a personal contact in the German energy sector and partly identified on the websites of businesses, associations and organisations relevant associated with the German wind energy industry. In total, 21 people were reached out to for interview requests, of which 11 agreed to participate in an interview. Of the 11 interviewees, 7 were project developers. The 4 others were policy advisors and experts working at wind energy industry associations, a turbine manufacturer, a wind energy policy think tank and an energy industry association. The profiles of all interviewees are shown in Table 5. They are presented in the chronological order at which they were interviewed. As interviewee 9 and 10 specifically asked to remain anonymous, they are assigned code names and their companies are not named.

Table 5 – List of interviewees

No.	Interviewees	Position	Organisation
1	**Christen**, Jens	Head of Project Development	*Enertrag* A large company based in Brandenburg with a core business in developing and operating onshore wind farms, a yearly turnover of €250 million and around 460 employees.
2	**Quentin**, Jürgen	Advisor on Energy Economics and Policy	*Fachagentur Windenergie an Land (FA Wind)* A Berlin-based wind energy think tank which specialises in research, consulting, education and stakeholder engagement with

			the purpose of promoting the deployment of onshore wind power in Germany.
3	**Alex**, Peter	Head of Investor and Public Relations	*EnergieKontor* A Bremen-based medium-sized renewable energy developer and supplier. The company focuses on wind and solar in Germany, other European countries and the US, makes a yearly turnover of €110 million and employees 150 people.
4	**Müller**, Eric	Head of Project Management and Planning	*VSB Energy* A large company based in Saxony that develops, operates and manages wind and solar power projects in Germany and abroad and employs 300 people.
5	**Schmedding**, Sabine	Energy Policy Expert Former: Political Advisor	*VDMA Power Systems* A German business association for manufacturers of technology used for electricity and heat supply, including wind turbines. Former: *German Wind Energy Association (BWE)* A business association representing the entire wind energy industry in Germany – including everyone from the engineering industry's manufacturers and suppliers, project developers to businesses specialised in logistics, construction and maintenance of wind farms.
6	**Schütte**, Daniel	Head of Project Development	*Energiequelle* A Bremen-based medium-sized business focusing on developing and operating renewable power plants – mainly wind, solar and biomass. The company makes a yearly turnover of €100 million and has around 200 employees.
7	**Lorenzen**, Dr. Jan Christian	General Manager	*L-projekt* A small local business in Schleswig-Holstein, which specialises in developing, operating and maintaining community wind farms.
8	**Klingemann**, Andreas	Strategy and Policy Advisor	*German Association of Energy and Water Industries (BDEW)* The largest association of its kind, including around 1900 companies including power producers, grid operators, suppliers of natural gas and district heating and water supply and sanitation industries.
9	**Berger**, Lukas	Public Relations Manager	*Company X* A large Bremen-based company specialising in developing and operating both onshore and offshore wind farms and operating in over 21 countries with 2,200 employees.

10	**Klein**, Tim	Energy Policy Advisor	*Company Y* One of the largest wind turbine manufacturers in the world and a market leader in Germany since the mid-1990s. It makes a yearly turnover of €5.6 billion and has around 18,000 employees worldwide.
11	**Hünefeld**, Sven	Head of Project Development	*WKN Group* A medium-sized company based in Schleswig-Holstein, which develops and operates wind farms in Germany, other European countries, South Africa and the USA. It has 140 employees and makes a yearly turnover of €60 million.

3.2.2.2. Conducting the interviews

All interviews were conducted over the phone in March and April 2020. They generally lasted between 60 and 120 minutes. At the beginning of each conversation, the interviewees received an explanation about the research background and agenda and were asked to give consent to their participation in my study and them being recorded. Then, the interview would follow a structured approach, which was guided by a set of questions. These questions varied from the first to the second group of interviewees, as the focus for developers lay more on personal accounts and experiences while for the experts it lay more on general Germany-wide issues. Further, the set of questions was divided into two parts, with the first inquiring about the challenges to development and the second going into the discourse surrounding the slowdown, including the perceptions of and expectations for capacity growth.

The first part of every interview would start with the general question of which factors were seen as responsible for the slowdown in onshore wind power deployment in 2018 and in 2019. After this general inquiry, interview questions got more specific to explore themes such as the switch from feed-in tariffs to auctions, licensing challenges, undersubscribed auctions, exemption clauses for energy cooperatives, planning issues, lawsuits, political support or the lack thereof, regional barriers and minimum distance regulations.

The second part of every interview would start with the question of whether the interviewee would claim that growth of German onshore wind power capacity is in persistent decline. The following questions would build on the answer and explore the interviewees' perceptions of growth. More specifically, the reference point in the past, the expectations for the future and the associated growth targets were the main focus of the inquiry. Also, the ability or inability to foresee the slowdown as it happened was a focus of the questions. Finally, the public discourse surrounding the slowdown was discussed. While this pre-determined structure was consistently abided by, it was made sure that enough space remained for open conversation. Thus, interviews would often diverge from the structure to allow for follow-up questions and discussion. Also, if a certain theme was highlighted by one interviewee that was missing from the structure, it would be integrated to have it discussed in the following interviews. This helped with highlighting both the common and conflicting perspectives between different interviewees.

This structure differed for the first two interviewees, who were already interviewed in December 2019 in the context of a pre-assignment for this thesis. As the research questions were not determined by then, no division between the challenges to development and the discourse was made. Instead, the interviews were more general, following a semi-structured approach in order to investigate the interviewees' perspectives on the reasons behind the recent slowdown in capacity growth.

3.2.2.3. Analysis of information

Recordings were made for each interview. The provided information was analysed through an inductive coding approach, which differed for the second and third research question. For the second research question, the interview accounts were scanned for information relevant to the discourse and narrative surrounding the 2018/2019 slowdown. This information would be coded into several layers of themes. The top layers sort the points discussed by all interviewees into two overlying thematic categories: "perceptions of growth" and "forecasting ability". The underlying layers of themes represent the provided information. The higher the level of the theme, the more consistently would it be brought up by interviewees. The bottom level theme would group a number of statements, which could not be classified any further.

Let us look at this procedure with an example. The top layer "perceptions of growth", for instance, had a sublayer called "expectations for future growth", which had a sublayer "climate and renewable energy targets", which had a sublayer called "stronger growth is needed for a successful energy transition", which grouped a number of statements such as "stronger growth is needed to safeguard electricity supply, while coal is being phased out" and "onshore wind power needs to grow as it is the main energy source of the future". Each theme and statement was assigned the number of the interviewee that mentioned it, so that the higher level themes have more assigned numbers. That is, while only one interviewee may have pointed to the coal phase-out to appeal to stronger growth of onshore wind power, many others have referred to climate and renewable energy targets, and most of them have brought forward expectations for the future when discussing their perceptions of growth. By grouping these statements into a total of five levels of layers, common patterns in the perception of growth, the ability to foresee the crisis and the opinions on the public discourse could be discerned. This picture would then have to be to complemented by the content analysis, which will be discussed in the next section.

For the third research question, the information provided by the interviewees about the barriers to onshore wind power development and their consequences for the 2018/2019 slowdown was collected and coded into overlying themes, similar to the approach used for the second research questions. Themes would be further categorised into higher level themes up to the top layer theme, which had the largest amount of assigned numbers and thus would be the most recurring theme brought up by interviewees. In the end, there were eight top layer themes with up to five levels of underlying layers. While some of the top layer themes corresponded to the stages of realisation, as with "area availability and development plans", "permitting issues" and "auction issues", others also emerged such as "costs and risks", "lawsuits" and "secondary barriers".

Let us again try to understand the procedure with an example. The top layer "auction issues" had a sublayer called "undersubscription", which had a sublayer called "lawsuits", which would group a number of statements such as "I had to wait two years for one of my projects until I could go to the auction because a conservation group sued it" or "I have recently been notified about a lawsuit against a project, which we're now waiting out before proceeding to the auction". Statements could also take the form of extended concrete examples, which were taken as empirical evidence of the overlying theme. Again, in order to explain, while only one person may have had to wait two years due to a lawsuit by a conservation group, many have had or have heard of lawsuits holding up bidders, while almost all agreed that undersubscription is a big issue. Grouping these themes would reveal interesting patterns in the opinions on the barriers to onshore wind power development in Germany. The next step of the analysis would lie in linking these barriers with the four stages of realisation for an onshore wind farm, analysing the interactions between the barriers and evaluating their consequences on actual deployment over time. As this step also requires the input from the content and data analysis, it will be described in a later section.

3.2.3. Content analysis

The content analysis supplemented the information provided by the interviewees, drawing a more comprehensive picture on the dynamics of onshore wind power development in Germany. Content analysis was viewed as the right tool, as it allowed to study both the perspectives on the barriers to development and the discourse surrounding the slowdown by looking at publicly accessible documents and other communication artefacts (Mayring 2000). Through a systematic content analysis of the information provided in such sources, recurring patterns could be identified and then combined with the output of the interview analysis. The sources used include conference proceedings, publicised interviews, industry reports and press releases, as well as newspaper articles. These were found by checking the websites of relevant actors in the German wind industry such as the BWE, VDMA Power Systems and the FA Wind and browsing for articles on German onshore wind power in the media. Articles were identified through Google searches using different combinations of the following German keywords: "*Windkraft an Land, Windenergie an Land, Zubau, Zubaukrise, Zubaustopp, Ausbau, Rückgang, Einbruch, Flaute, eingebrochen*". A list of the specific sources used can be found in Table 6.

Table 6 – List of sources used for content analysis

Type of document	**Outlet**	**Source**
Blog post	Blog of former politician Hans-Josef Fell	(Fell 2020)
Conference proceedings	FA Wind	(FA Wind 2019)
Magazine article	Neue Energie	(Hildebrandt 2019)
Magazine article	Treffpunkt Kommune	(Markus 2020)
Magazine article	Erneuerbare Energien	(Weinhold 2020)
Magazine article	Treffpunkt Kommune	(Markus 2020)
News article	Deutschlandfunk	(Bandermann 2019)
News article	Die Tageszeitung (taz)	(Janzing 2019)
News article	Norddeutscher Rundfunk (NDR)	(NDR 2020)
News article	Mitteldeutscher Rundfunk (MDR)	(mdr.de 2019)
News article	Der Spiegel	(Spiegel 2020)
Position paper	German Wind Energy Association (BWE)	(BWE 2019b)
Press release	German Wind Energy Association (BWE)	(BWE 2018a)
Press release	German Wind Energy Association (BWE)	(BWE 2018b)
Press release	German Wind Energy Association (BWE)	(BWE 2019a)
Press release	German Wind Energy Association (BWE)	(BWE 2019c)
Press release	German Wind Energy Association (BWE)	(BWE 2020b)

The data was scanned for information relevant to both the second and the third research question and separated accordingly. It was then coded following the same procedure as used for analysing the interviews. To answer the second research question, the output of the content analysis now had to be combined with that of the interview analysis. This was achieved by combining the themes of both outputs into one by condensing the information further and framing the analysis along three main questions: What creates the perception of the crisis? Was the crisis expected? How are expectations and targets for onshore development formed? By answering these three questions, the final analysis explains the narrative surrounding the 2018/2019 slowdown and provides a meaningful to answer to question of why there exist expectations for stronger growth of onshore wind power capacity.

The procedure for the third research question was the same. The statements identified through content analysis were grouped into several layers of themes. However, to ultimately answer the third research question, the output of this analysis had to be combined not only with that of the interview analysis but also with that of the supplementary data analysis, which will be described in the next section.

3.2.4. Supplementary data analysis and consolidation of results

This last piece of the puzzle aimed to provide a quantitative foundation for the analysis of barriers to wind farm development, supplementing the interviewees and content analysis. This was necessary because although the personal accounts from interviews and public documents offer meaningful and experience-driven perspectives on the on-the-ground challenges to development, they are also subject to bias and regional differences. However, by underpinning these accounts with quantitative data, insightful personal perspectives can be combined with hard facts and general trends. This improves the validity of the analysis, enabling us to clearly depict the dynamics of onshore wind power development in Germany.

Quantitative information was sought out for issues highlighted through the literature review, the interviews and content analysis. This followed a grounded theory approach, in that information about the barriers to deployment of onshore wind power in Germany was collected inductively through qualitative analysis (Thomas and James 2006). This information was then, whenever possible, be assessed on the basis of quantitative data, as for issues such as area availability, distance regulations, lawsuits, permitting rates and barriers, effects of the 2017 exemptions for energy cooperatives, undersubscription, regional discrepancies with respect to deployment, changes in timeline of realisation and repowering. Some of the data had been readily prepared and available in non-academic scientific publications, mostly by German energy policy think tanks. Most other data, also sourced from similar publications as well as publicly accessible databanks, had to be plotted and interpreted for noticeable trends and interactions. The insights drawn from this data analysis were then grouped according to the specific stage of realisation that they concern. In the final step, they would have to combined with the output of the qualitative analyses.

This final step would be concerned with analysing the themes of barriers identified through interview, content and data analysis in light of the different stages of realisation for an onshore wind farm in Germany. Further, the interactions between different barriers had to be analysed and their ultimate impact on deployment had to be assessed over time. A mind map was used to lay out the three dimensions necessary for analysis (Figure 5): (1) the four stages of realisation (planning, licensing, auctioning and implementation); (2) the barriers to onshore wind power development and (3) a timeline beginning well before the 2018/2019 slowdown and spanning beyond 2020.

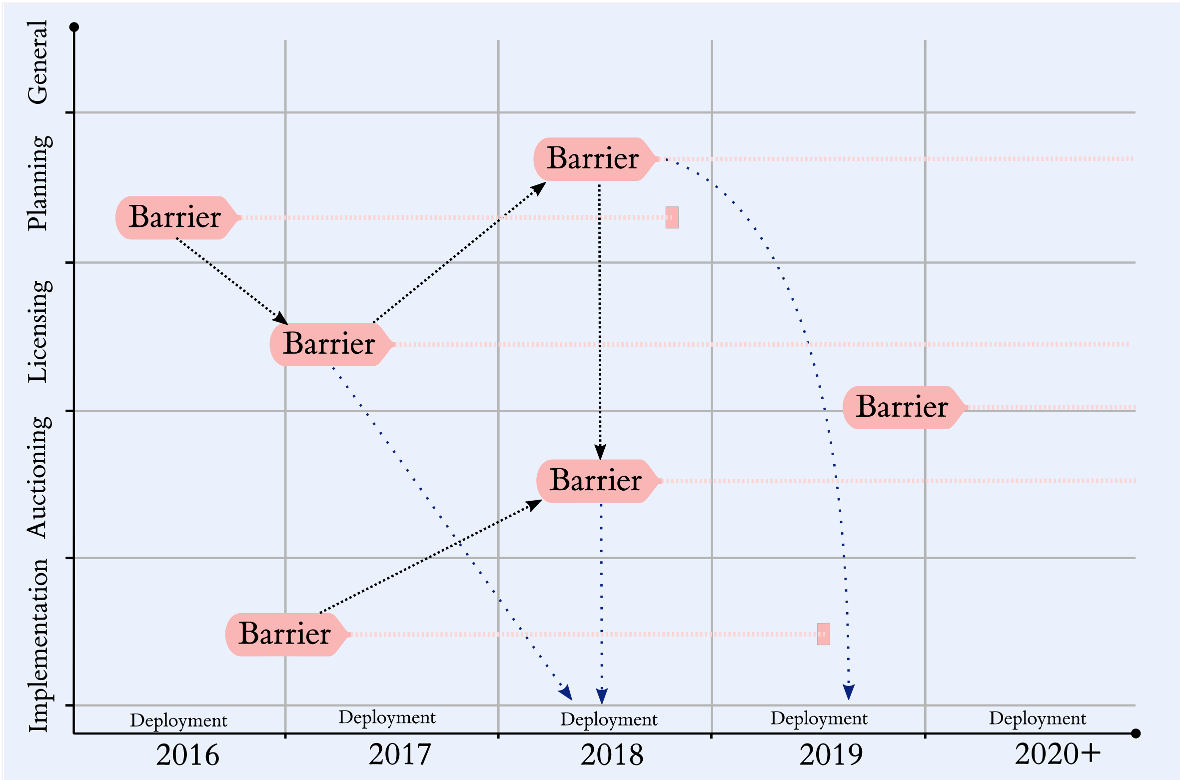


Figure 5 – The three level matrix for the identification of barriers to deployment
The matrix shows the three levels of analysis: (1) the four stages of realisation for an onshore wind farm in Germany; (2) the barriers to deployment and (3) time. Barriers are located within their stage and assessed for their timeline, interactions and impact on deployment. Multi-stage barriers can be located across stages or in the general category. Source: own representation.

The procedure began with identifying the most consistent themes of barriers from the qualitative analyses and cross-checking them with the findings of the data analysis. These barriers could then be linked with their respective stage of realisation. For example, the recurring barrier of state-specific distance regulations was placed within the stage of planning, as these regulations shrink the available area within which new onshore wind farms can be planned. The overall output was a list of concrete barriers underlying each stage of realisation. Some barriers were identified as multi-stage barriers, that is, impeding development across stages. This is for example true of lawsuits, which impede new projects both during planning, auctioning and implementation.

Next, the analysis had to consider the interactions between the different barriers underlying each stage over time. How would one barrier affect another, both within its stage and across stages?

Through identifying these interactions, a number of so-called key barriers were revealed. These were the final hubs, where many barriers would come together to then directly affect deployment in some way. Besides these, however, certain individual barriers were also found to have a direct effect on deployment. But how and when would all of these barriers have their effect? Revealing this demanded the close consideration of the average timeline of realisation. Also, the intensity of the impact of different barriers had to be evaluated based on the qualitative and quantitative findings. The final result shows with what intensity (mild, moderate or strong) the identified barriers impacted deployment in 2017, 2018 and 2019 and are likely to impact deployment in 2020 and beyond.

4. Results

4.1. Has growth of onshore wind power capacity slowed down?

The empirical data on onshore wind power capacity in Germany was approximated by three different growth functions (logistic, logistic-linear and exponential). Figure 6 shows the results: The black dots indicate the empirical data, the blue curve shows the logistic model, the red curve shows the linear model and the green curve shows the exponential model. The red circle indicates the inflection point for the linear model and the blue circle shows the inflection point for the logistic model.

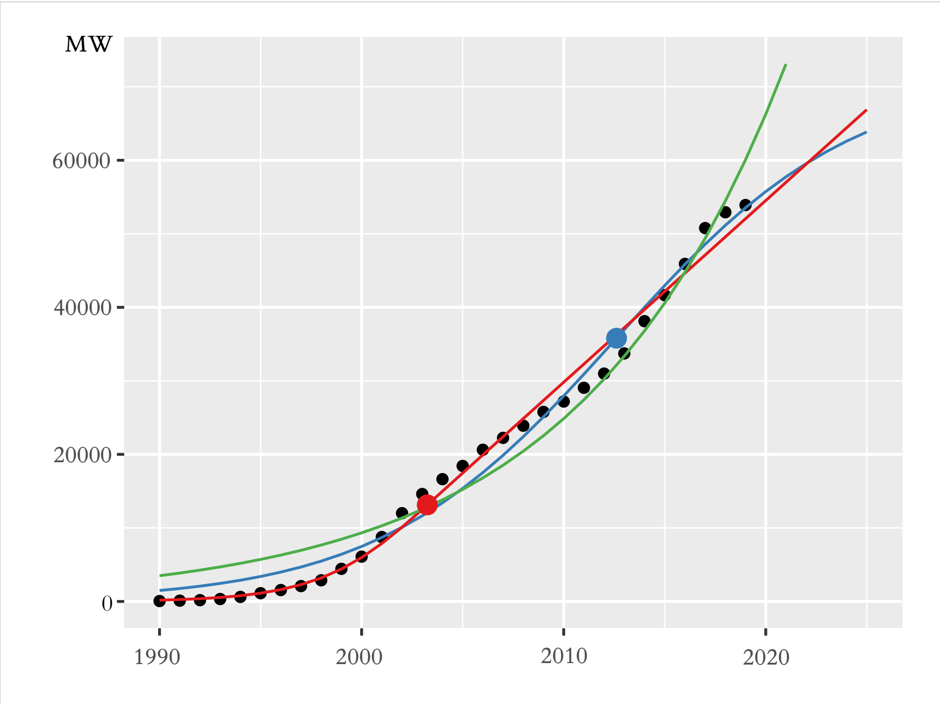


Figure 6 – German onshore wind power capacity data modelled by different growth functions
Capacity data (dotted line) is modelled by a logistic (blue), logistic-linear (red) and exponential (green) function. The red circle shows the inflection point for the logistic-linear function, the blue circle for the logistic function. The analysis was performed by Vadim Vinichenko from the University of Bergen. All data from: (BWE 2020a)

For the logistic model, onshore wind power showed a peak growth rate of around 3 GW/year and reached its inflection point in mid-2012 (G = 3048.8 MW/year; t_0 = 2012.6). For the linear model, onshore wind power showed a peak growth rate of around 2.5 GW/year and reached its inflection point in early 2003 (G = 2471.4 MW/year; t_0 = 2003.3). The relative quality of fit for the three growth functions is estimated on the basis of residual sum of squares (RSS), with the smallest RSS representing the best fit and models with larger RSS fitting progressively worse. The RSS value is smallest for the linear model (RSS: 92,780,667), second-smallest for the logistic model (RSS: 135,046,852) and largest for the exponential model (RSS: 331,044,443). Through calculating the ratios between these values, we find that the RSS of the logistic model is

1.46 times larger than that of the linear model and that the RSS of the exponential model is 2.45 times larger than that of the logistic model and 3.57 times larger than that of the linear model.

Clearly, then, the exponential model fits the empirical data worse than the other two models. Further, although they are closer to each other, the linear model fits the data slightly better than the logistic model. Based on these findings, we can assume that German onshore wind power has certainly passed its inflection point, which will be somewhere between 2003 and 2012, after which growth continued at a rate between 2.5 to 3 GW. This evidence suggests that growth of onshore wind power capacity has stopped accelerating in Germany. At the same time, however, there is no evidence that growth is in decline.

4.2. Why are there expectations for faster capacity growth?

4.2.1. Results from the interviews

Two main themes emerged from the analysis of interview data with regard to the second research question: (1) perceptions of growth and (2) forecasting ability. They will be covered one after another. In terms of **perceptions of growth**, all interviewees unanimously believed in a decline of capacity growth of onshore wind power in Germany. When being asked whether this perception builds on observations of past growth or expectations for the future, most interviewees claimed that it was both. Quentin, Müller, Schütte, Lorenzen, Klingemann, Berger and Hünefeld specifically referred to past growth rates. Quentin stated that 3 to 4 GW was easily possible in the past, while Klingemann pointed to the strong growth years of 2014 to 2017 as proof that much more is possible. Müller, Schmedding and Schütte emphasised the discrepancy between the EEG growth corridors for 2018 and 2019 and actual growth rates[3]. According to them, this gap alone should be reason enough to worry about German onshore wind power.

Importantly, however, many interviewees emphasised that looking at capacity alone is insufficient, but that growth of the number of installed turbines is more telling (Quentin, Müller, Schütte, Klingemann, Klein and Hünefeld pers. comm.). This is due to the enormous increases in average capacity of individual turbines in recent years, from around 2 to around 5 MW (Klein and Hünefeld pers. comm.). For Quentin, this explains why the slowdown in growth is much more visible when looking at the number of annually added turbines, which dropped to 280 turbines in 2019 but was at 1000 turbines in the past. Quentin, Schütte and Klein emphasised that due to the increase in average turbine capacity, overall installed capacity would grow even if the number of added turbines stagnated. And Müller and Hünefeld stressed this point further by highlighting that the current slowdown would be much more pronounced if it had not been for these recent

[3] EEG growth corridors – 2018: 2.7 GW; 2019: 3.7 GW. Gross added capacity – 2018: 2.5 GW; 2019: 1.1 GW

increases in average capacity. That is, for them, increases in average turbine capacity have compensated for the immense decrease in annually added turbines to paint a more subtle picture of the slowdown in installed capacity growth.

Quentin, Schmedding, Lorenzen, Schütte, Klingemann, Berger and Klein referred to future targets when discussing their perceptions of what growth of onshore wind power is necessary. Climate and renewable energy targets were mentioned most often here, with Quentin, Klingemann and Klein referring to Germany's 2030 renewable energy target for a 65% share of renewables in the power mix. The necessary yearly growth to reach this and other climate targets was estimated at 4 GW (Quentin and Klingemann pers. comm.), between 4 and 5 GW (Müller and Klein pers. comm.) and at 5 GW (Schmedding and Berger pers. comm.). Müller and Berger stressed how it is the discrepancy between these required additions and the 2019 gross additions of 1.1 GW, which signals the severity of the slowdown. Lorenzen brought up state-specific targets for Schleswig-Holstein, where 3 of the 10 GW expansion target for 2025 are still missing. Finally, Schütte and Hünefeld did not have specific numbers in mind for the yearly expansion of onshore wind power.

Instead of referring to specific climate targets, some interviewees would point to the larger-scale transformations necessary for the success of the Energiewende when discussing the need for stronger growth of onshore wind power. Schütte claimed that wind energy is the main electricity source of the future and essential for the energy system as coal is being phased out. To avoid future power blackouts, much higher growth of onshore wind energy would be necessary. Klingemann referred to Germany's ambitions regarding sector coupling and the production of green hydrogen, which demand much faster growth of onshore wind power than at the moment. Further, Klein argued that only gradually increasing rates of yearly onshore wind installations would be able to safeguard the success of Germany's energy transition.

Also, wind energy-specific challenges of the future seemed to influence the interviewees' perceptions on the required growth. Klingemann pointed to the fact that during the 2020s, many old turbines will stop receiving the feed-in tariffs that they were granted according to the EEG in the early 2000s for a period of 20 years. According to him, many of these plants will neither be profitable enough to continue operating nor be available for repowering and thus have to be removed. To compensate for these losses in capacity, future gross additions would have to be even higher. Klein underlined this statement, saying that a sufficiently high rate of net additions can only be secured by overcompensating for the removed capacity.

Perceptions of growth of onshore wind power also seemed to derive from the general conditions for onshore development and the potential of the wind energy industry. While

Lorenzen simply noted that much more would be possible, Quentin claimed that technically there is more than enough land for increased deployment of onshore wind power. Hünefeld said that the German wind energy industry had grown substantially in recent years and cannot be compared to what it once was, which would technically allow for much more installations. Schütte noted the much higher level of the industry compared to in the past, especially due to new technological developments such as increased capacity factors and integrated energy storage solutions, which would allow for much stronger deployment.

Finally, also certain negative developments in the wind energy industry seemed to shape the perceptions of growth for the interviewees. These trends were highlighted by interviewees as proof for diminishing growth of onshore wind power. Schmedding mentioned the increasing loss of jobs in the industry as a clear signal for a decline in deployment growth rates. Quentin added that small project developers are 'dying out' as they lose against large and internationally-oriented companies in the competition for a shrinking number of new wind farm projects.

The second main theme **forecasting ability** captured the interviewees' ability to see the 2018/2019 slowdown coming, also describing whether there were certain surprises and unexpected developments. Müller, Schmedding and Klingemann pointed out that a reduction in deployment was inevitable after 2017, given that the EEG growth corridors that were introduced with the auction scheme limited yearly expansion at an average of 3.2 GW. Quentin confirmed that 2017 was an exceptional year and that it was obvious that 2018 would be worse. Müller, Schütte, Lorenzen and Klein agreed that a slowdown in capacity growth was expected, however, not at this scale. For 2018, Schmedding said that despite her low expectations, she was still disappointed. Quentin described how sobering it was to have his expectations for 3.5 GW of new installations in 2018 fallen short of. Certain risks to deployment were foreseen such as the large number of contracts for unpermitted and underbid projects as a result of the exemption clauses for citizens' energy cooperatives in 2017 (Müller, Klingemann, Berger and Klein pers. comm.). Müller added that the exploitation of these exemptions by large developers was obvious.

For 2019, there was disagreement among interviewees on whether the increasing slowdown was foreseeable. Klingemann, Berger and Klein agreed that expectations were closer to reality this time, in that it was clear that 2019 would not bring any improvements in deployment. For them, this was due to the fact that not enough was being done to improve the situation. Müller agreed here, adding that the issues around permitting only really clarified after the exemptions for energy cooperatives were cut in 2018. Having realised this, it was obvious to him that deployment levels would not improve in 2019. Several interviewees claimed the opposite, however, saying that they were surprised by how much worse growth turned out in 2019 than in 2018. Schmedding and

Berger expressed that their expectations were let down even more in 2019. For Quentin, the scale of the slowdown in capacity growth in 2019 only became truly visible in fall when he noticed that a lot of the expected new capacity could not be built in time anymore. Quentin also pointed to the fact that the wind energy industry associations had to lower their expectations for capacity throughout the year, indicating how common misperceptions surrounding the slowdown were.

Some interviewees also shared insights on challenges that they personally did not see coming. Berger noted his surprise at "the increase in the exploitation of legal procedures in order to stall wind farm development, often on the basis of species protection regulation". Klein added that next to the resistance from conservation organisations, he was taken aback by the scale of the pushback by increasing number of citizens' initiatives against wind power. Further, Müller and Klein emphasised the political backlash against wind power, both on the regional, state and federal level, which continued to baffle them.

Finally, some interviewees shared experiences that indicated the severity of the challenges to deployment to them on a personal level. Schütte stated that during 2018 and 2019, all of the risky projects would fail in his company, whereas typically three out of ten risky projects would have been realised in the past. Hünefeld added that him and his company noticed the slowdown personally in increasing resistance to development, their own failure to realise new projects and in the necessity to compensate losses on the domestic markets with business activities abroad. However, he also noted that the personal experiences of project developers are very context-dependent (e.g. whether development plans have been published or not) and can therefore deviate from Germany-wide deployment trends.

4.2.2. Results from content analysis

Content analysis allowed for further insights on how perceptions of growth circle around past references and present and future challenges. Newspaper articles continually mention the 65% target and the deployment necessary to reach it (NDR 2020). But also, the future challenges of Germany's energy transition, such as the electrification of the transport sector and the production of green hydrogen, have been raised to underscore the need for stronger growth of onshore wind power (Weinhold 2020). At the same time, future challenges for onshore wind power are drawn into the discussion about current deployment levels. Norbert Allnoch, for example, the head of the renewable energy research think tank IWR in Münster, referred to the undersubscribed auctions in 2018 and 2019 to highlight the severity of the situation, even though these do not directly affect deployment in those years (Janzing 2019). Also, the BWE pointed to the expiring feed-in tariffs for a large share of installed onshore wind power capacity during the 2020s, stressing the unstable conditions for onshore wind power. As it is questionable how much of this capacity will continue to operate or be repowered, the BWE deems much higher expansion rates as needed.

Similarly, past deployment rates are continually mentioned in comparison to the rates of 2018 and 2019. Here, it is noticeable that the good years of 2014 to 2017 (average of 4.6 GW of yearly gross additions) are mentioned to contrast the much lower rates in the years after (mdr.de 2019). Especially 2017 (gross additions of 5.5 GW) is often highlighted. In an interview, the CEO of the BWE, Hermann Albers made such a comparison when he said that "additions in 2019 are down by 80% compared to 2017" (Markus 2020). Although these comparisons seem common, they are not ubiquitous. Other voices provide contrasting examples, when they compare the growth in 2018 and 2019 to much earlier. Reiner Priggen from the State Association for renewable energy in North Rhine-Westphalia, for example, stated that growth in 2019 is the lowest it has been for 20 years (Bandermann 2019). A newspaper article echoed this perspective, noting that lower growth than that of 2019 was last observed back in 1998 (NDR 2020).

Another pattern found through content analysis was how frequently the troubling German wind energy industry is highlighted in discussions on the slowdown. Hermann Albers noted the impact of the slowdown in pointing to the loss of 40,000 jobs in the industry in recent years (Markus 2020). This number has also been brought up frequently in newspaper articles (NDR 2020). Reiner Priggen agreed on this point, claiming that devastating "job losses are already a real issue in the industry today" (Bandermann 2019). And in his interview, Norbert Allnoch described how the diminishing domestic market for onshore wind power is forcing the German manufacturer Enercon to lay off workers (Janzing 2019). Finally, another article points to the dangers of losing the German wind energy industry to booming foreign markets, as domestic losses force companies to internationalise (Weinhold 2020).

Lastly, content analysis was also used to identify the official predictions for annual capacity growth of onshore power by the German wind industry and compare them with actual deployment. This would allow for assessing the industry's ability to forecast the slowdown. Official predictions are always published together by the industry-wide association, the BWE, and the association for manufacturers, VDMA Power System, once at the start and once in the middle of the year. In January 2018, these forecasts estimated the newly gross added capacity for the year at 3.5 GW (BWE 2018a). In July of that year, they had adjusted this forecast to something between 3.3 to 3.5 GW (BWE 2018b) – still too optimistic for 2018's actual growth of 2.5 GW. In January 2019, industry predictions saw for an growth of 2 GW in 2019 (BWE 2019c). These predictions were then lowered down to 1.5 GW in July 2019 (BWE 2019a), falling short of the actual growth of 1.1 GW in 2019.

4.3. Why does capacity not grow as fast as expected?

4.3.1. Results from interview data

Through the analysis of the interviews, eight main themes emerged as relevant for explaining the 2018/2019 slowdown: (1) area availability and development plans; (2) permitting issues; (3) auction issues; (4) implementation issues; (5) lawsuits; (6) costs and risks; (7) political resistance and (8) industry trends. Let us look at them one by one.

4.3.1.1. Area availability and development plans

Several issues were highlighted with regard to this theme by the interviewees. Many of them agreed that designated areas for onshore wind farm development were generally limited (Christen, Quentin, Müller, Klein and Hünefeld pers. comm.). Hünefeld noted that these areas have gotten sparser over time. Müller stressed that this presents a missing planning basis for project developers, which then translates into a missing investment basis. That is, as new projects can generally only be permitted within designated areas, planning centres on these areas and is restricted by the lack thereof. Hünefeld added that for projects planned outside of designated areas, permit applications tend to be rejected by the authority. Müller recalled that when there were once more areas available, his company would file more permit applications.

According to the interviewees, the lack of designated areas for onshore wind power development has to do with the fact that development plans are unfinalized, delayed, outdated, sued or overturned. Both Klein and Hünefeld emphasised how long it usually takes for these plans to be finalised and they claimed that in many regions plans still remain missing. While the regional development plan for Greater Braunschweig in Lower Saxony took 12 years to finalise, the plans for Brandenburg and Mecklenburg-Western Pomerania are still missing (Hünefeld pers. comm.). According to this interviewee, this is due to overly long and careful procedures, with planning authorities meticulously following all legal criteria in order to anticipate resistance and avoid potential lawsuits. When finished, the draft of the development plan is presented in public display with the opportunity for the public to raise objections (Hünefeld pers. comm.). Usually, around 3000 to 4000 objections are then reviewed, the draft is adjusted and publicly displayed again – a process that takes around a year (Hünefeld pers. comm.). This process is repeated over and over again – while two public displays used to be normal, now four displays are the norm (Hünefeld pers. comm.). To get an idea, what kind of objections may come up, Quentin provides an example: In Rhineland-Palatinate, a municipality objected the development plan as the designated areas for onshore wind power development were adjacent to the Roman monument Limes, seen as a danger to the monument's UNESCO status.

Development plans can also be outdated, however (Quentin, Müller and Hünefeld pers. comm.). This may be when they specify limits for the allowed rotor heights of new turbines, which do not account for the increases in average rotor heights of turbine technology (Müller pers. comm.). Also, however, they may be outdated in terms of the climate targets that they are tailored around (Müller pers. comm.). If development plans are designed on the basis of old targets, they do not designate enough area for the required onshore wind power capacity to meet current targets. Also, regional plans cannot account for every little detail, especially as certain issues are subject to change (Quentin pers. comm.). Quentin gives the example of a protected red kite, observed to be breeding within a part of the designated area for onshore wind farm development, as assigned by the development plan. Consequently, this part of the designated area would be cancelled without alternative, meaning that, effectively, the area designated for wind power will shrink. Finally, development plans can be obstructed or even overturned by lawsuits, which will be discussed in a later section (Müller and Hünefeld pers. comm.).

Lastly, planning options are also restricted by specific barriers that vary according to the respective state or region in Germany. Indeed, Quentin and Klein emphasised that different Länder have very different barriers when it comes planning. Bavaria has its own distance regulation, which translates to required average distances of 2000m from turbines to settlements (Quentin and Alex pers. comm.). Quentin notes that this regulation forces turbines to be planned in closer vicinity to conservation-sensitive areas, increasing conflicts with conservation interests. He claims that the number of new permits in Bavaria decreased by 95% following this regulation. In North Rhine-Westphalia, recently a 1500m distance regulation was introduced that now obstructs new planning ambitions (Klingemann pers. comm.). In Schleswig-Holstein, regional development plans were overturned by the Higher Administrative Court in 2015 on the grounds of procedural errors (Quentin, Lorenzen and Klingemann pers. comm.). For the duration of the drafting of new plans, a moratorium was laid on new permits, allowing only few exceptions (Quentin and Lorenzen pers. comm.). According to these interviewees, as a result, the number of new permits declined drastically in Schleswig-Holstein from 2015 onwards. The new regional plans are expected for the end of 2020. In the meantime, only already permitted projects could be realised (Quentin pers. comm.).

4.3.1.2. Permitting issues

All interviewees criticised the decline in the number of new permits for onshore wind power projects. Permit procedures were often mentioned as a barrier here. Most interviewees (Christen, Quentin, Alex, Müller, Lorenzen, Klingemann, Berger, Klein) claimed that these procedures have been getting more complex and time-intensive. While permit applications would only be 10 pages long, now they would be at 40 pages (Lorenzen pers. comm.). The requirements for species protection assessments seem to have become particularly complex over time (Quentin, Schütte, Lorenzen and Klein pers. comm.). The increasing complexity of these procedures seems to translate into rising costs for developers (Quentin and Schütte pers. comm.) Among the several reports and assessments required for the permit application, the species protection assessment alone can cost up to 100,000€ (Schütte pers. comm.).

Schütte criticised that existing species protection regulation does not pursue population protection but individual protection in that not a single individual may be harmed by a wind farm. He gave the example of one of his projects, which is stalled in so-called land-use analysis – a part of the species protection assessment, which scans the area where the future wind farm is to be built for endangered species such as red kites. Such a procedure could take up to two years and if only a single bird is found, the project would be delayed until this individual has left. These and other issues lead Klingemann to claim that the resistance against new projects has increased in these procedures. And often such resistance would require compromises such as, for instance, a lower rotor height (Christen pers. comm.). Further, the increasing length of procedures caused by this resistance has meant that project developers would often miscalculate their development time schedules (Müller pers. comm.). And these delays mean that when the permit is finally granted, the turbine type could have become outdated, pressuring developers to seek the alteration of the permit in order to change the turbine type (Schütte pers. comm.).

Another factor to consider in licensing procedures are the authorities. Alex claimed that they are understaffed and that they do not benefit from granting a permit, but that they rather could suffer backlash against newly permitted projects. Müller and Klingemann expressed that authorities have become more cautious over time, aiming to deter the possibility of lawsuits by rigidly looking at every detail of the bureaucratic guidelines. Müller provides the example of one of his projects in Brandenburg, which is stuck in the licensing procedure due to a conflict with the species protection authority. As an impact balance, his company is meant to plant five trees in an area specified by the authority. However, as the area is private property and not necessarily accessible, the company wants to keep the option of being allowed to provide a compensation payment if it fails to plant the trees. The authority does not want to agree to this exemption. Müller noted that in the past, authorities had always agreed on such things, while recently they have become more concerned about such details and less willing to compromise. Finally, Müller also noted that authorities may sometimes be pressured by local politicians and district administrators to oppose new projects.

Another permitting issue raised by interviewees has to do with the switch from feed-in tariffs to auctions in 2017. This switch allowed for transition projects, which were still eligible for feed-in tariffs if they were permitted before 2017 and built before 2019 (Endell and Quentin 2017). Since project developers were apprehensive of the prices of future auctions, they wanted to still benefit from the feed-in tariffs and were rushing to get as many transition projects permitted as possible at the end of 2016 (Quentin, Müller, Lorenzen, Klingemann, Berger, Klein and Hünefeld pers. comm.). Quentin recalled personal conservations with representatives of licensing authorities, which reported of strong pressures to finalise applications during that time. Lorenzen said that authorities in his state were doing everything they could to finalise applications in 2016, receiving political backing by the government of Schleswig-Holstein. Müller recalled working overtime on weekends to finalise applications, in close cooperation with the licensing authorities that were willing to shift specific details of the application to the future so that the permit could be granted in time. Hünefeld echoed this willingness of authorities to speed up licensing procedures back in 2016. As a result, these interviewees claimed that a huge number of projects that would only have been permitted later in time was pulled forward to 2016, causing an imbalance in the annual permit statistics. This pull-forward effect meant that project developers were confronted with an unusually high number of permitted projects ready to be implemented in 2017 and early 2018 (Schmedding, Lorenzen and Klein pers. comm.). Or as these interviewees put it, "the pipelines were full" for developers at that time.

Several interviewees also mentioned a change in the number of permit applications over time. Schütte, Klingemann and Klein speculated that interest in new applications may have decreased due to increasing uncertainty, risks and financial burdens associated with the switch to the auction scheme. Berger claimed the opposite, however: enough potential projects exist, but they fail to receive their permits due to several barriers. Quentin, Müller, Schmedding, Schütte, Lorenzen and Hünefeld agreed, however, that there had been at least a temporary decrease in the permitting activity of developers during 2017 and early 2018. Having their pipelines full of permitted projects, developers would now focus primarily on implementation. This was incentivised by the gradually decreasing renumeration rates for transition projects between 2017 and 2018 – meaning that the later the transition project was built, the lower would be the tariff (Quentin, Schütte and Berger pers. comm.). As a result, especially small developers were working at full capacity on implementation and thus filed less new permit applications and delayed ongoing applications in 2017 and early 2018 (Quentin, Müller, Schmedding, Schütte, Lorenzen, Hünefeld pers. comm.) Large developers, with a sufficiently diversified staff base tackling all stages of realisation separately, were still able to pursue new and ongoing applications (Müller, Schütte and

Hünefeld pers. comm.). Quentin and Schmedding speculated that from mid-2018, permit applications recovered to normal rates. They also noted that this is impossible to verify as no data is publicly available on permit applications.

Other barriers next to the procedures and authorities, conflicts with conservation, the pull-forward effect and a reduction in permit applications were seen in flight safety regulations, monument protection and social resistance. Flight safety regulations, and in particular military restrictions such as low-level flying corridors for military helicopters, were mentioned by Klingemann, Berger and Klein as strong barriers to permitting new projects. Further, Klingemann provided an example for a case where monument protection impeded an onshore wind farm: on the Swabian Alb in Baden-Württemberg, the permit for a new wind farm was not granted as this project was perceived to deter the traditional Stone Age man's view out of a nearby cave. Unconvinced, Klingemann noted that this view already includes a four-lane road and a settlement. Finally, social resistance was mentioned as an issue, which arises during the public participation process of the licensing procedure (Christen pers. comm.). Christen recounted a situation, where him and his co-workers were invited to a discussion forum at the municipality in order to talk to opponents of a nearby wind farm project. The discussion ended with dissident members of the municipality throwing chairs at Christen and his co-workers.

4.3.1.3. Auction issues

This theme captures issues related to auctioning, especially with the exemptions for citizens' energy cooperatives in 2017 and the issues surrounding undersubscription at post-2017 auctions. Let us begin with the former. According to the interviewees, 2017's exemptions for energy cooperatives had several consequences on bidding behaviour. Firstly, large project developers would often pose as energy cooperatives or even found their own to benefit from the exemptions (Quentin, Müller, Schmedding, Schütte, Lorenzen, Berger and Klein pers. comm.). Berger claimed that these energy cooperative were "fake" and Lorenzen said that they were founded "in the cafeterias of large developer companies". Müller confirmed that his project developer company also "supported energy cooperatives" back in 2017 and that founding a cooperative was rather easy, requiring less than ten people.

The exemptions also led to speculative bidding on two levels. Firstly, energy cooperatives could submit bids for unpermitted projects. As a result, many bidders entered the auction with projects planned outside of valid designated areas, which could mean that they would fail to obtain the permit necessary for implementation (Lorenzen pers. comm.). Klein agreed that for many of these projects, it was uncertain whether the area in which they were planned would be accessible and thus whether their permit would be granted (Klein pers. comm.). Secondly, the heavy competition between energy cooperatives led to aggressive bidding, which forced down auction prices. According to Schütte, energy cooperatives were bidding at unrealistic prices. This underbidding had to do with the anticipation of future technological innovations and the associated cost digressions made possible through the overly long implementation deadline of 54 months (Klingemann and Klein pers. comm.). According to Lorenzen, it was mainly two large companies that exploited the exemptions, posed as cooperatives and forced down prices so that a large number of projects was contracted at unprofitable rates. Such underbidding was further incentivised through the reduced financial guarantees required from cooperatives, which large developers could easily afford (Klein and Hünefeld pers. comm.).

What consequences did this dominance of energy cooperatives at the 2017 auctions have? Most interviewees were of the opinion that the majority of the projects contracted in 2017 will not be realised as such (Quentin, Alex, Müller, Schmedding, Schütte, Lorenzen and Klein pers. comm.). This is due to the fact that many of these projects turned out to be unprofitable as a result of underbidding (Alex, Müller, Schmedding, Schütte, Lorenzen and Hünefeld pers. comm.). Also, many of them would have failed to receive their permit (Quentin, Müller, Lorenzen, Klingemann, Berger, Klein and Hünefeld pers. comm.). Müller provided his personal account here: His company contracted projects in 2017 on the hope of soon completion of the regional development plan. As this plan remains unfinalized, the permit applications for these contracted projects are still on hold. He estimated that there is not enough time left for realisation before the deadline in 2021, meaning that those projects are lost. Indeed, other interviewees claimed that most of these projects would be “dead” (Alex pers. comm.) or “lost” (Klein pers. comm.). For Christen and Quentin, these missing projects have largely contributed to the 2018/2019 slowdown in additions.

Others thought that these projects may return as different ones, in that the developer sacrifices the financial guarantee and seeks for the project to-be re-planned, re-permitted and re-auctioned and maybe even re-sold to another developer (Müller and Hünefeld pers. comm.). Quite a few interviewees (Quentin, Schmedding, Schütte, Lorenzen, Klein, Hünefeld) believed that many of these projects had already re-entered the auctions as different ones to achieve higher prices. As many of the contracts in 2017 were awarded to projects in ongoing permit applications, by the time the permits had been granted, much higher prices were common at the auctions. This set an incentive for re-participation (Quentin pers. comm.). The lost financial guarantee of 15,000€ per MW could then quickly be amortised through a higher premium from a later auction (Quentin, Müller and Schütte pers. comm.). Lorenzen described one of his wind farms, which was contracted in 2017 and recently re-entered the auction to achieve a higher premium. He said that this has been common practice.

According to the interviewees, even after 2017, auctions remained problematic due to undersubscription, meaning that that the tendered capacity was consistently larger than the capacity offered by bidders. In explaining the reasons for undersubscribed auctions, most interviewees blamed the lack of permitted projects for developers to bid with (Christen, Quentin, Schmedding, Müller, Schütte, Lorenzen, Klingemann, Berger, Klein and Hünefeld pers. comm.). Müller and Klingemann stressed that oversubscription was only once possible due to the exemptions for energy cooperatives to bid with unpermitted projects. The issue with missing permits could then only become apparent after this exemption had been removed (Müller pers. comm.).

Another reason for undersubscription mentioned by interviewees was lawsuits. Quentin, Schmedding, Schütte, Lorenzen, Klein and Hünefeld stated that for projects that are in ongoing lawsuits, most definitely, no bids are submitted at auctions. Although these projects could technically participate, developers choose to hold them back due to legal uncertainties (Schütte pers. comm.). Hünefeld described one of his company's projects that was sued by an conservation organisation. Although it was an expedited procedure, the lawsuit lasted two full years as the court was busy with other matters such as asylum procedures. During that whole time, the developers were holding back the wind farm from participation at the auction. Müller recounts how his company was recently notified of a lawsuit against one of their projects in North Rhine-Westphalia. As the reason behind the charge is not yet officially reported, the company will wait out to hear and assess this reason before entering the auction. Quentin, Schmedding and Lorenzen noted that missing permits and lawsuits combined lead to a situation, where there is a lack of permitted and non-sued wind farms that could participate at auctions.

Further, the interviewees suggested that some projects that could technically enter the auction are re-planned and re-permitted. For example, Quentin, Alex and Klein claimed that developers often try to change the type of turbine for a more efficient alternative in order to benefit from cost digressions. Depending on the federal state, such a change requires altering the existing permit or applying for a completely new one (Quentin pers. comm.). Projects are also sometimes resold to other developers and then re-planned and re-permitted by the buyer (Hünefeld pers. comm.) As the contract is tied to the permit, developers will tend to wait until they have the final permit for their project before taking it to the auction (Quentin pers. comm.). Hünefeld noted how the practice of changing existing permits or even re-applying has increased in recent years due to the rapid development in turbine technology, allowing for larger capacities, higher rotor heights and larger rotor diameters. Müller described how low prices during 2017's auctions incentivised re-permitting, as developers were better able to compete with cost-efficient turbines.

Several examples were described for this practice of re-planning and re-permitting. Schütte described an example, which shows that it is not only economic factors, which influence re-planning. In his case, a change in the noise protection directive lowered the permissible sound intensity for wind turbines, forcing his company to change the turbine type and alter the permit for the project – a procedure that led to a one-year delay in realisation. Another example was provided by Hünefeld, who reported that long licensing procedures can mean that one's turbine is outdated once the permit is granted, setting an incentive for changing the turbine and altering the permit – sometimes even twice. He told the story of one of his wind farms that was re-planned and re-permitted, which illustrates the time span of this practice: In June 2017, they received the initial permit for the type Vestas V-90. In August 2017, they re-planned for the types Vestas V-126 and V-136 and applied for the alteration of the permit. In mid-2018, this alteration was granted and the project was contracted. At the end of 2019, the wind farm was then finally commissioned. He said that this change made a difference of €500,000 per turbine.

Müller mentioned one of his projects, where his company is currently trying to change from a Vestas V-150 with 4.2 MW to one with 5.6 MW. While the permit for the 4.2 MW turbines is not yet granted, they already prepared the application for the alteration of the permit in order to upgrade to 5.2 MW. They are keeping both options open, however, in that they will take the 4.2 MW permit to the auction if the alteration is denied. Müller provides another example with a permitted Nordex N-117 (3 MW capacity, 200m height and 117m rotor diameter) for which they failed to be awarded a contract in 2017 through the "flood of energy cooperatives" forcing down prices. Realising that they would need a more efficient turbine to compete, they applied for altering the turbine type while continuing to try to contract the existing permit. They finally succeeded to alter the permit for a Nordex N-149 (4.5 MW, 240m height, 149m rotor diameter), were awarded the contract in May 2018 and hereby built the largest turbine in Thuringia (LandesWelle Thüringen 2019).

The interviewees emphasised that undersubscription was caused by these three issues – missing permits, lawsuits and re-planning. Importantly, they stressed that there were no issues with profitability, but instead that renumeration rates have been quite attractive, with bidders typically getting the maximum price as a result of undersubscription (Christen, Alex, Müller and Schmedding pers. comm.). Also, there does not seem to be a strategic advantage to waiting out auctions with your permitted projects. Instead, the interviewees reported to enter the auction as quickly as possible with newly permitted projects (Schütte, Lorenzen, Berger, Hünefeld and Müller pers. comm.). Müller claimed that there is no gain from waiting as other important steps in realisation have to be put on hold and new issues can arise while waiting. Also, he did not believe that any developer would have enough permitted projects at their disposal to let an auction slide. Quentin claimed that the majority of contracted projects received their permits no longer than eight weeks before the contract and that only a small minority did so more than one year ago.

4.3.1.4. Implementation issues

In this theme, the most strongly highlighted issue has to do with the above-mentioned pull-forward effect. After developers had been rushing to permit as many transition projects as possible in 2016, they had to now implement these projects until the end of 2018, as to still fall under the expiring feed-in tariff scheme. However, due to the gradually decreasing tariffs for projects built between January 2017 and December 2018, project developers were rushing to get their transition projects implemented as soon as possible, leading to very high rates of deployment in 2017 and early 2018 and a breakdown in deployment rates afterwards (Quentin, Schütte and Berger pers. comm.). Hence, the above-mentioned pull-forward effect in permitting now translated into to a pull-forward effect in implementation, leading to a shift in the annual deployment data. However, Hünefeld also noted that many of these transition projects were not built in 2017 or 2018. This was because the rates of renumeration typical for 2018 auctions were more profitable over a 20-year time span than what was offered by the feed-in tariffs. To participate at the auctions, transition projects had to wait until 2019, however.

Further, certain issues were mentioned by interviewees that can delay or impede implementation. Quentin, Lorenzen, Klingemann and Hünefeld pointed to lawsuits against contracted projects as a key barrier to implementation. This will be discussed in the next section. Issues with the timely delivery of turbines were also described. Quentin speculated that developers may suffer from longer turbine delivery times, as manufacturers are busy with an increasing number of orders from foreign markets. Schütte described a contracted project, which could not be built in time as the type of plant was suddenly taken out of the manufacturer's product line. Changing the type of plant required altering the permit, causing a one-year delay. Lorenzen recounted how the turbines for their wind farm could not be delivered, as the manufacturer Senvion went bankrupt. Re-planning and re-permitting was then necessary, causing immense delays. Klein, on the other hand, doubted that delivery was an issue as the contract between the developer and the manufacturer specifies the waiting period, allowing for no surprises. Müller also saw no issues with delivery, but noted that delays in implementation can sometimes arise when contracted projects are sold on to other developers. No other barriers were highlighted with regard to implementation by interviewees.

4.3.1.5. Lawsuits

Lawsuits were consistently mentioned as a key barrier to realisation (Christen, Quentin, Alex, Müller, Schmedding, Schütte, Lorenzen, Klingemann, Berger, Klein and Hünefeld pers. comm.). Further, Berger and Klein claimed that lawsuits have been becoming more of an issue in recent years. As these legal procedures can take a long time, they cause massive delays in realisation (Berger and Klein pers. comm.). Lawsuits can impede onshore wind power at various stages: Firstly, lawsuits can target development plans for onshore wind power (Müller and Hünefeld pers. comm.). Quentin claimed that almost all regional development plans are sued nowadays, with the increasing complexity of procedures making procedural errors very likely. Secondly, lawsuits obstruct individual projects at different stages in realisation. They impede permitted projects from entering the auctions, as developers wait out the result of the suit before bidding (Quentin, Müller and Hünefeld pers. comm.). This has to do with the developers' fears of losing the financial guarantee of €30,000/MW, which has to be provided for participation at the auction, as a result of delays caused by the lawsuit (Quentin and Müller pers. comm.). Further, lawsuits deter contracted projects from being implemented, as developers wait to see how a lawsuit plays out before they begin construction for fear of the immense costs attached to losing the permit afterwards (Quentin, Lorenzen, Klingemann and Hünefeld pers. comm.). As a result of long-lasting lawsuits, such projects may then overshoot the implementation deadline, lose their financial guarantee and turn out to be unprofitable (Hünefeld pers. comm.).

But who sues? According to Christen, Quentin, Alex, Berger and Klein, many lawsuits are filed by conservation organisations. NABU (Alex and Schütte pers. comm.) and BUND (Schütte pers. comm.) were mentioned especially. Hünefeld stressed that in the pursuit of lawsuits, conservation groups are the most persistent. Alex told a personal account of a project, where a lawsuit of a conservation group over one couple of breeding red kites endangered investments of more than €10 million. Quentin speculated that such resistance by conservation groups has to do with the fact that non-conflicting areas with conservation are becoming more sparse. Next to conservationists, another key actor in lawsuits are the citizens' initiatives against wind power (Schütte and Klein pers. comm.) Schütte stressed that they operate everywhere, Klein claimed that they sue against almost every project nowadays and Hünefeld mentioned that they are well connected and organised. Quentin and Lorenzen even claimed that these wind energy critics sometimes pose as conservation organisations to increase their legal leverage. As Lorenzen put it, "wind energy critics often wear the dress of conservationists to be more successful". Lastly, municipalities and rural districts may also act as a plaintiff in lawsuits against onshore wind power (Christen pers. comm.).

4.3.1.6. Costs and risks

Increasing costs and risks associated with onshore wind power development in Germany were also mentioned by interviewees as a barrier to realisation. Müller and Schütte noted the enormous amount of costs required to get a project to the point where it can participate at the auction. These costs include those for the permit, especially for the increasingly complex species conservation assessment, but also those for the financial guarantee necessary for auction participation. Finally, the costs for the landowner or lessee, the municipality and for the company's own personnel were also mentioned.

But also, the risks associated with development seemed to have increased with the switch of the support scheme. As Müller and Schütte stressed, the abolishment of feed-in tariffs increased the financial uncertainty for operators of onshore wind farms, since they cannot know the rates of renumeration beforehand but have to hope for a profitable auction round. This introduces an element of risk: while the awarding of the contract and the premium rate are uncertain, the prior financial concessions have increased (e.g. the financial guarantee). Klingemann states that this may inhibit investors. Hünefeld claims that especially during the beginning of the auction system, uncertainties for small developers may have been too high to plan and permit new projects. Risks could also be said to have increased due to the introduction of pre-determined annual growth corridors (Schmedding, pers. comm.). While annual expansion rates of more than 5 GW were possible in the past, now only a much smaller capacity of projects could be built each year. Further, while everyone could freely develop a wind farm before, developers would now have to compete with each other for a limited number of contracts.

Another factor increasing the risks associated with onshore wind power development is the lack of valid development plans. Without the designated areas for wind farm development specified by these plans, the planning of new wind farms is very risky. This is because a developer may wrongly anticipate which areas will be designated for development. This comes with the risk of costly planning efforts for a project that will turn out to be outside the designated areas (Müller pers. comm.). Schütte claimed to have noticed how all these increasing risks have caused the number of successful projects for his company to decline, with only 1 in 10 planned projects being realised. Also, the increasing risks have meant that banks do not offer loans to developers as easily as they did in the past, for example when it comes to providing the financial guarantee. However, despite all these increasing risks and costs, Berger and Hünefeld stressed that developing onshore wind farms in Germany continues to be a profitable business.

4.3.1.7. Political resistance

A consistent theme in the interview data was the perceived political resistance against onshore wind power. Müller, Berger, Lorenzen and Hünefeld pointed to an obvious contradiction in politics between the open support for the energy transition and the resistance against wind power development. While Schmedding noted that political support has been lacking, Hünefeld stressed that politicians are struggling with a balancing act between ambitious renewable energy expansion targets and the fear of excessive deployment of onshore wind power. Lorenzen claimed that political backing is often superficial, providing the example of local politicians praising renewables at podium discussions but refusing to visit him at his booth for discussion afterwards. Hünefeld noted that political support has shifted from wind power to other energy transition solutions such as hydrogen and energy storage. Müller pointed to the failure of politicians to realise that onshore wind power has developed from a niche to a strong and meaningful industry in Germany, with many jobs depending on it.

Especially local politicians are often seen as opponents of wind power development. Müller claimed that local politicians are often publicly against wind power development, especially in areas affected by structural changes as the coal phase-out. This lack in political support on the local level could translate into inaction in authorities, by for example deterring planning authorities from ambitiously pursuing development planning. Schmedding added that the change in the Energiewende discourse from fast deployment to efficiency and cost digression has increased caution in authorities and municipalities. Further, as Schmedding claimed, local politicians, especially among the CDU, are often against new wind farms due to fears of losing voters to the far right. As she put it, the conviction in these circles is that "Every turbine is a vote for the AfD (Alternative for Germany)". Schmedding, Klingemann and Berger stated that this sort of anti-wind energy rhetoric was particularly prominent during the state elections in Brandenburg, Saxony and Thuringia in 2019. As a result, almost all parties fought against wind power in the run-up to the election, hoping to gain votes (Berger pers. comm.).

Another important issue highlighted by interviewees were the political discussions surrounding a Germany-wide regulation for minimal distances between turbines and settlements of 1000m. Müller and Berger criticised that existing research, which shows that social acceptability of wind energy is unaffected by distance regulations, is disregarded by politicians. Further, according to Müller, the whole political discussion about public acceptability of wind turbines is exaggerated, while at the same time leading to less acceptability. Müller, Schmedding and Berger claimed that the idea of universal distance regulations are pushed by a small and identifiable group of wind energy critics within the economic wing of the CDU, which pressure the party's parliamentary group. This group would also have a strong influence in the Federal Ministry of Economy and Energy (Berger pers. comm.). The public debate around these regulations alone has led to increasing uncertainty in the industry, according to Schmedding and Klein. Lorenzen claimed that, as a result, small developers take less risks and thus file less permit applications. Quentin, Müller, Schmedding, Lorenzen and Klein also said that planning authorities are increasingly cautious as a result of the discussion. Quentin stated that some of them wait out the political developments before proceeding with their plans. Müller confirmed this, saying that the regional planning authority in Chemnitz has completely stopped its activities as a result of the debate. Schmedding added that, should the regulation be made voluntary for the Länder, planning authorities will wait to see whether their state government chooses to opt-in or opt-out, before proceeding with planning. Finally, the discussion also seems to cause uncertainty and hesitance in licensing authorities around the country (Schütte and Klingemann pers. comm.).

4.3.1.8. Industry trends

The interviewees also mentioned industry trends related to the 2018/2019 slowdown, especially with regard to the strategies for dealing with the failing domestic market. Quentin, Alex, Schmedding and Schütte claimed that thriving international markets are increasingly attractive for large actors in the German wind energy industry. Schmedding stressed that the European wind power market is booming, while Germany's is failing. Further, Alex, Schmedding, Schütte and Hünefeld noted that the market is shifting towards regions with higher demand and improved wind conditions. Especially large project developers were seen to shift their business activity towards foreign markets as a result of these developments (Quentin, Klein and Hünefeld pers. comm.). Schmedding warned that large manufacturers will outsource their production if the German market fails them. Schütte admitted that only with the projects on the German market, his company would not fare well, and that international projects are needed to compensate the domestic losses. Hünefeld agreed here, saying that his company would be in trouble without foreign business activity. Müller added that the results on foreign markets are much better than at home.

However, not everyone can move abroad. Hünefeld claimed that only around ten project developers on the German market are large enough to make the leap into foreign markets. As only these sufficiently large and diversified companies can do so, small developers are not able to compensate the failing domestic market with foreign business activity (Müller and Schütte pers. comm.). This means that small developers may have to give up some of their projects or sell them to larger developers in order to afford realising their remaining projects (Schütte pers. comm.). But it can also mean that small developers are forced out of the market as they are bought up entirely by larger ones or go bankrupt (Schütte pers. comm.). While Quentin noted that, due to the fragmentation of the industry, it is difficult to assess how grave the situation for small developers really is, he suspected that these small developers are already suffering. Schmedding warned that many companies will be lost if the slowdown continues.

4.3.2. Results from content analysis

The barriers underlying the 2018/2019 slowdown were explored further through content analysis. In terms of planning, Hans-Dieter Kettwig, the CEO of the German turbine manufacturer Enercon, noted that missing regional development plans are the largest barrier (FA Wind 2019). Further, the BWE criticised that areas designated for development through regional plans are often cancelled without alternative when new circumstances arise (BWE 2019b). This was evaluation was echoed by Dr. Petra Overwien, head of the regional planning unit at the joint state department of the states Berlin and Brandenburg, who said that no matter how large the designated area for onshore wind power development is initially, it is likely to shrink over time as issues with bird protection, flight safety or monument protection arise (FA Wind 2019).

Following up on this, Christiane Donnerstag from the Rhineland-Palatinate Ministry of Environment and Energy noted that areas are sometimes cancelled for three to five years when protected species suddenly settle there (FA Wind 2019). And according to an article, the majority of projects blocked through military and civic flight restrictions is situated within designated areas, meaning that these areas are unusable without alternative (Hildebrandt 2019). The president of the BWE, Hermann Albers added that "an area the size of Schleswig-Holstein would become available if the range for flight safety assessments were reduced to international standards" (Hildebrandt 2019). A mayor of a city in Brandenburg, Michael Knape, said that regional plans are not flexible enough to account for changes related to flight safety or species protection. As there is not enough legal leeway to make individual changes to a development plan as issues arise, often the whole plan is discarded or overturned. (FA Wind 2019). Prof. Dr. Priebs, professor of applied geography with 30 years of experience in regional planning, argued that it has become near impossible to draft a legally watertight regional plan as the requirements for the designation of area for wind power have tightened substantially over time (FA Wind 2019).

More issues were also highlighted for licensing. According to the BWE, these procedures have become excessively time-consuming, causing significant delays in realisation (BWE 2019b). This is due to the increasing complexity of the legal questions arising during the procedure but also the delays in the operation of involved authorities, who are not staffed and equipped accordingly. A recent article provided the example of a particular permit application for a wind farm, which required 30 folders with around 18,000 sheets of paper from the project developer

(Spiegel 2020). The article also mentioned that around 200 authority workers tend to be involved with assessing whether a permit can be granted or not. The former politician of the Greens and co-founder of the EEG, Hans-Josef Fell, claimed that these immense entry risks and costs associated with licensing, attenuated by uncertain auctioning outcomes, have made onshore wind power development increasingly unattractive for energy cooperatives, whose activity drastically declined after 2017 (Fell 2020).

Species protection was deemed as one of the main barriers to licensing, mainly due to insufficient data on species population developments, vaguely defined standards for the scope and interpretation of species protection assessments and very strict regulations that prohibit the endangerment of individual animals, rather than the population (BWE 2019b). Inga Römer, expert for conservation and energy transitions at the German League for Nature, added that permit applications tend to be rejected on the grounds of quality issues of species protection assessments – mainly methodological flaws, technical deficiencies and false inferences (FA Wind 2019). If this happens, the existing report is discarded, and a new assessment will have to be prepared, an undertaking that is quite costly and causes delays.

In terms of issues related to the switch of the support scheme from feed-in tariffs to auctions, Hans-Dieter Kettwig stated that he does not expect many of the projects contracted in 2017 to be realised (FA Wind 2019). According to him, as a result of underbidding, the majority of these projects are unprofitable, meaning that developers wait out the implementation deadline and then re-enter the auction. Further, the BWE noted that by the end of 2018, around 900 MW of transition projects – that is, those projects which were permitted before 2017 and had to be realised before 2019 to get feed-in tariffs – had not been built (BWE 2019c). This was because these projects were stuck in lawsuits, held back to participate at 2019's auctions or were being entirely re-planned and re-permitted. Another interesting fact was highlighted about lawsuits: Even if the developers wins the lawsuit, the project may be obsolete at the end of the process, as the type of plant for which the permit was granted is not profitable or commercially available any longer (BWE 2019b).

4.3.3. Results from supplementary data analysis

The results of the supplementary data analysis on barriers to onshore wind power development in Germany will be presented according to the stage of the development process that they obstruct: (1) planning, (2) licensing and (3) auctioning. As no other barriers than lawsuits were analysed for implementation, this theme is discussed, among others, in section (4): multi-stage issues.

4.3.3.1. Planning

In terms of area availability for onshore wind farms, a study by the Federal Environment Agency found that the capacity potential of areas designated for onshore wind farms outweighs the tendered capacity until 2030 – with the difference between the capacity potential and the required capacity decreasing from 2025, thereby increasing uncertainties (UBA 2019a). This means that, technically, there is just about enough land available to realise the tendered capacity. Importantly, this study took into account currently legally valid designated areas as well as future areas still in planning. At the moment, the available area is much smaller. A study from October 2019 found that only for 46% of the German land area, there existed legally valid development plans (both on the regional and municipal level) (Bons et al. 2019). For 36% of all area, development plans were still being drafted. For 18%, there was no information on the state of the planning process available. Further, 30% of all legally valid developments are in ongoing lawsuits and 20% have been overturned by the court as a result of these. Specifically, the study reported ongoing lawsuits against 11 planning regions – with 8 of them (for which there was available data) providing the space for a potential of 10.4 GW of wind farms. This leaves the share of German land area for which there exist legally valid development plans that are free of lawsuits at only 23%. Figure 7 illustrates these data.

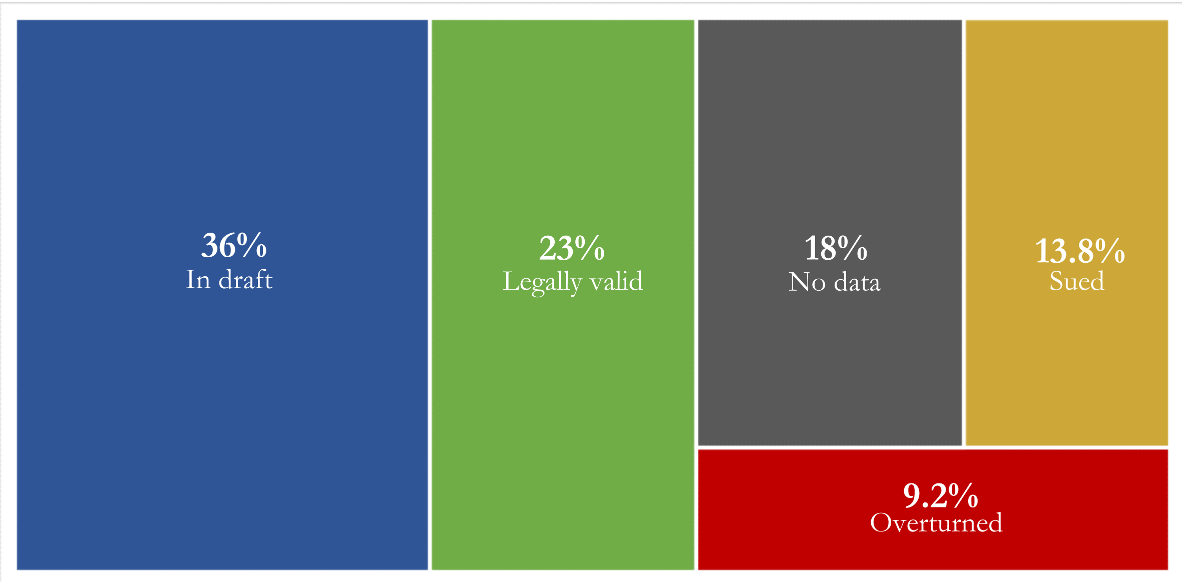


Figure 7 – State of development plans for onshore wind farms by share of German land area
For 36% of German land area, development plans are in draft, for 23% plans are legally valid, for 13.8% plans are being sued, for 9.2% plans are overturned and for 18% there is no data available. Source: own representation. Data: (Bons et al. 2019)

Further, area availability has been increasingly restricted by state-specific barriers such as minimum distance regulations. While the BImSchG permit, noise protection regulations and building law combined generally require average minimal distances of turbines to settlements of

600m, different Länder have their own policies (FA Wind 2020). With the '10H-rule', Bavaria introduced the most stringent distance policy in November 2014: the distance between the turbine and the settlement has to be ten times the height of the turbine. In Bavaria, with average turbine heights of 200m, this translates to 2000m distance restrictions. A study showed that this policy led to a drastic fall in the number of new permits of up to 90% (Stede and May 2019). In July 2019, North Rhine-Westphalia introduced a 1500m distance regulation (FA Wind 2020). Hesse, Rhineland-Palatinate, Mecklenburg-Western Pomerania and Saxony-Anhalt require 1000m minimal distances and Brandenburg has a recommendation for 1000m. Other states have minimal distances of less than 1000m or no policy at all. A study also found that, should a Germany-wide distance policy of 1000m be enforced, this would decrease the available area for wind farms by 10% to 40% depending on what counts as a settlement (Bons et al. 2019).

4.3.3.2. Licensing

The capacity of newly permitted onshore wind farms drastically fell after 2016 and has continued to stay at a low rate (Table 7).

Table 7 – The capacity of newly permitted wind farms between 2014 – 2019
Source: (Quentin 2020a).

Year	2014	2015	2016	2017	2018	2019
Capacity (GW)	4.31	3.69	9.41	1.38	1.49	1.94

The sudden drop in new permits after 2016 can also be visualised through monthly permitting data (Figure 8). The newly permitted capacity per month averaged at 340 MW between 2014 and 2016 if we leave out December 2016. The exceptionally high newly permitted capacity of almost 5 GW in December 2016 had to do with the switch to auctions, with developers rushing to permit as many transition projects under the old feed-in tariff scheme as possible. After 2016, there was a decline without recovery, with the newly permitted capacity per month averaging at 140 MW between 2017 and 2019. According to a study by the FA Wind, the Germany-wide decline in the new number of permits is 62% when comparing the rates of new permits from 2014 to 2016 with those of 2017 to 2019 (Quentin 2020a). More serious declines were observed for Bavaria (-85%), Baden-Württemberg (-76%) and Saarland and Saxony-Anhalt (-75%).

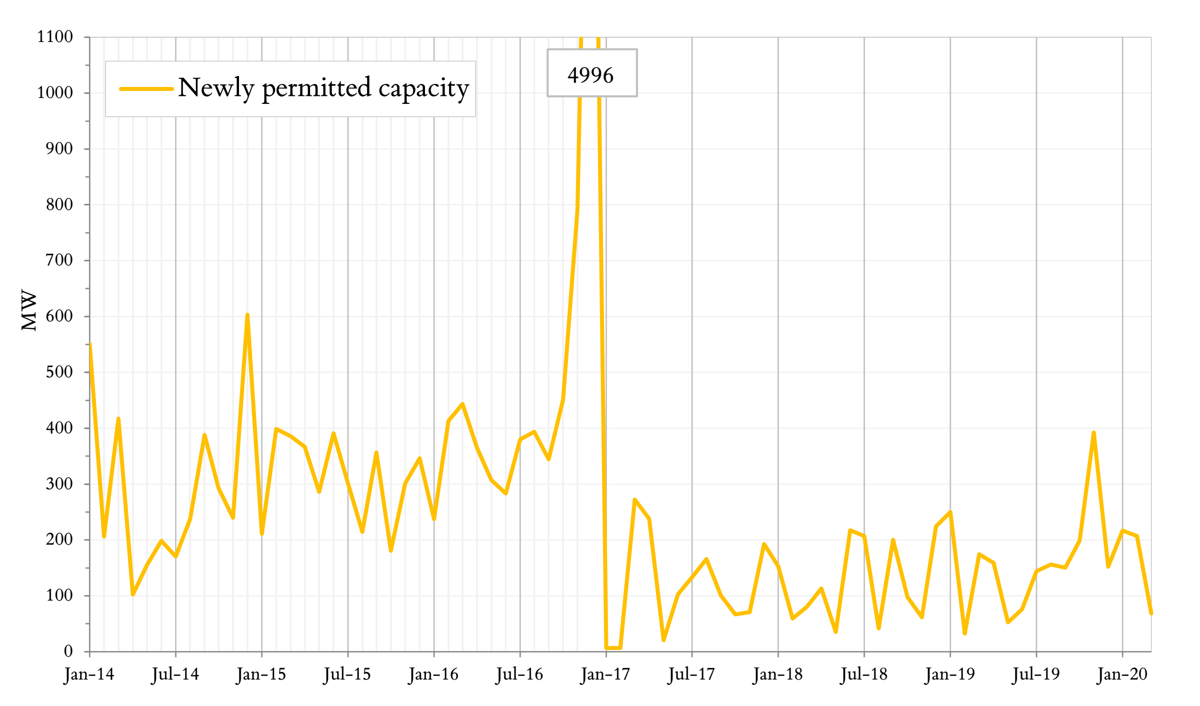


Figure 8 – Monthly permitted onshore wind power capacity between 2014 and 2020
The figure shows the capacity (in MW) of the newly permitted onshore wind power projects per month in Germany. Source: own representation. Data: (Quentin 2020a; Quentin 2020c)

According to a study by FA Wind, around ⅓ of permit applications were unsuccessful between 2010 and 2017 (Quentin 2018a). Given the many barriers to licensing, it is unlikely that this success rate has improved over time. At the same time, barriers lead to delays in licensing: The BWE estimated the total capacity of projects in ongoing licensing procedures to be at 11 GW in July 2019 (BWE 2019a).

In terms of concrete barriers, flight safety and military restrictions stood out particularly in the data. The FA Wind found that around 1000 turbines with a capacity of 4.8 GW were held back by flight safety restrictions in May 2019 (Quentin 2019b). This is because in Germany, flight safety infrastructure such as VORs and DVORs, of which 59 exist in Germany, require 3km minimum distances to turbines (Bons et al. 2019). Also, the regulation sees for a 10km testing range for VORs and a 15km testing range for DVORs. If a wind farm is to fall within this range, a special authorisation based on expert assessment is necessary for the permit. The above-mentioned 4.8 GW of held back projects cannot be permitted due to negative assessments. Many countries have much lower testing ranges, including Belgium (7km), Spain (3km) and Australia (1.5km). Strikingly, 360 turbines with a capacity of 1.45 GW alone are held back by the German special provision for a 15km testing range around DVORs (Quentin 2019b). Military restrictions held back 900 turbines with a capacity of 3.6 GW in May 2019. This was mainly due to required low-flying areas for helicopters and planes as well as radar surveillance for flight safety and air defence. Further, the majority of projects blocked through military (59%) or flight safety (72%) restrictions is situated in designated areas for onshore wind power deployment, rendering these areas unavailable (Quentin 2019b).

4.3.3.3. Auctioning

For this theme, two different issues will be discussed: (1) the 2017 auction outcomes following the exemption clauses for energy cooperatives and their consequences for deployment as well as (2) the undersubscribed auctions after 2017. Figure 9 helps us to understand both of these issues. The data can be found in Table 9 in the Appendix.

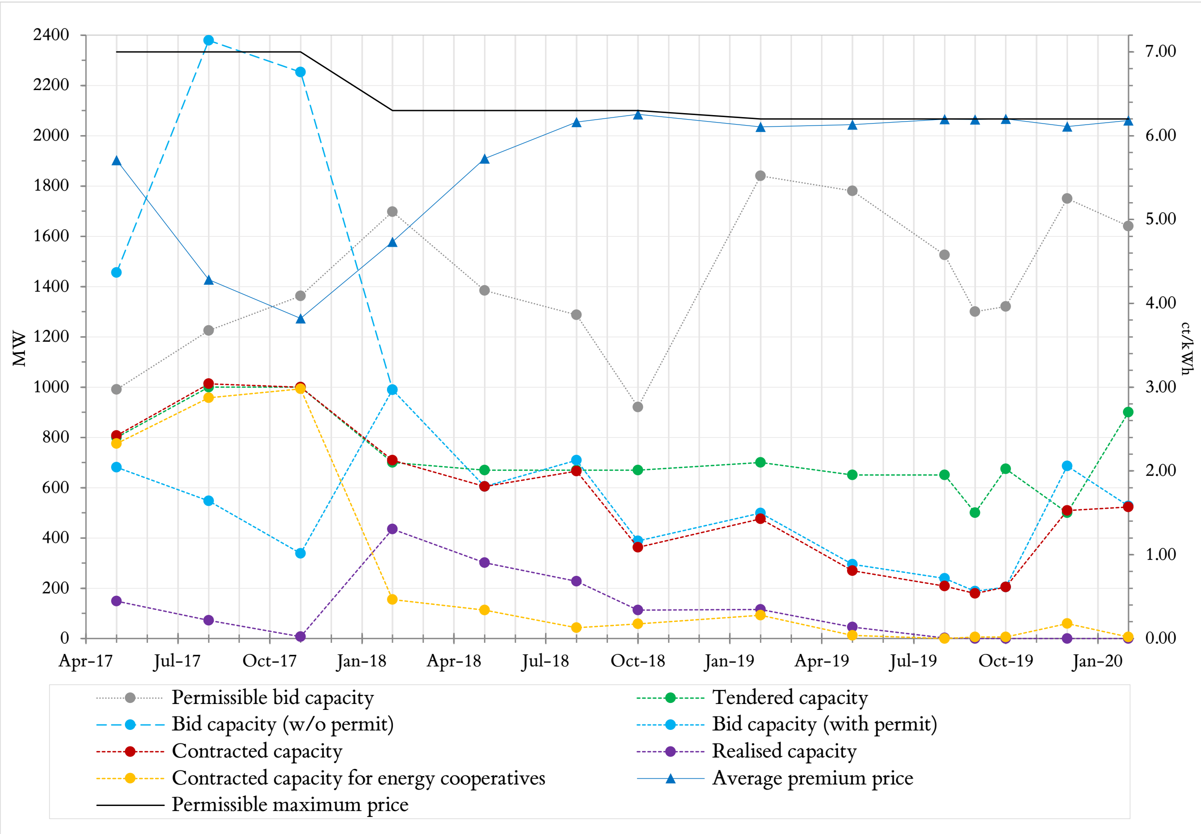


Figure 9 – Auctions for onshore wind power in Germany between 2017 and 2020
The figure shows trends for prices, bids, contracts, implementation and non- participation. Right y axis shows the price range and left y axis the capacity range. The permissible bid capacity shows the capacity of permitted projects eligible to participate at each auction. The tendered capacity is the capacity of all contracts offered at the auction. The bid capacity is the capacity of all projects for which bids were submitted at the auction. Since bidding without permits was allowed before 2018, this distinction is shown with the bid capacity with and without permit. The contracted capacity shows the total capacity of awarded contracts at each auction. The realised capacity is the capacity from each auction which has been realised. The average premium price is the average rate of remuneration, at which contracts were awarded. The permissible maximum price is the highest price allowed to be bid. Source: own representation: Data: (Quentin 2017a,b; Quentin 2018b-f; Quentin 2019c-g; Quentin 2020b,d) (see Table 9 in Appendix)

The figure illustrates various trends related to auctioning, including for prices, participation and bidding, contracts and implementation. The green line shows the tendered capacity, that is, the onshore wind power capacity offered by the regulator at each auction. It has remained fairly stable over time, ranging between 500 and 1000 MW. The light blue lines show the bid capacity, that is, the capacity of projects for which bids were submitted at each auction – for permitted and unpermitted projects. As is shown, the majority of submitted bids in 2017 was for unpermitted projects (6.09 GW in total) and the minority for permitted projects (1.57 GW in total). Due to this large bid capacity without permit, the tendered capacity was largely exceeded at each 2017 auction. This strong competition between developers forced down prices, with the average premium price dropping from 5.71 ct/kWh at the May 2017 auction to 4.28 ct/kWh in August and 3.82 ct/kWh in November. Further, with 96.7%, virtually all contracts were awarded to energy cooperatives (yellow line) during 2017. Almost all of these were unpermitted: 95.3% of all contracts awarded in 2017 went to unpermitted projects.

So, what happened to the projects contracted at 2017's auctions? As is shown in Figure 9, the realised capacity (purple line), that is, the capacity of contracted projects from each auction that is already in operation, is disproportionately low for 2017. Specifically, a total capacity of 2.82 GW was contracted in 2017. Of this capacity, 2.54 GW (89.9%) still remains without permit until today (Figure 10). Of the remaining 285 MW (10.1%) that was permitted, only 230 MW (8.2%) has been realised.

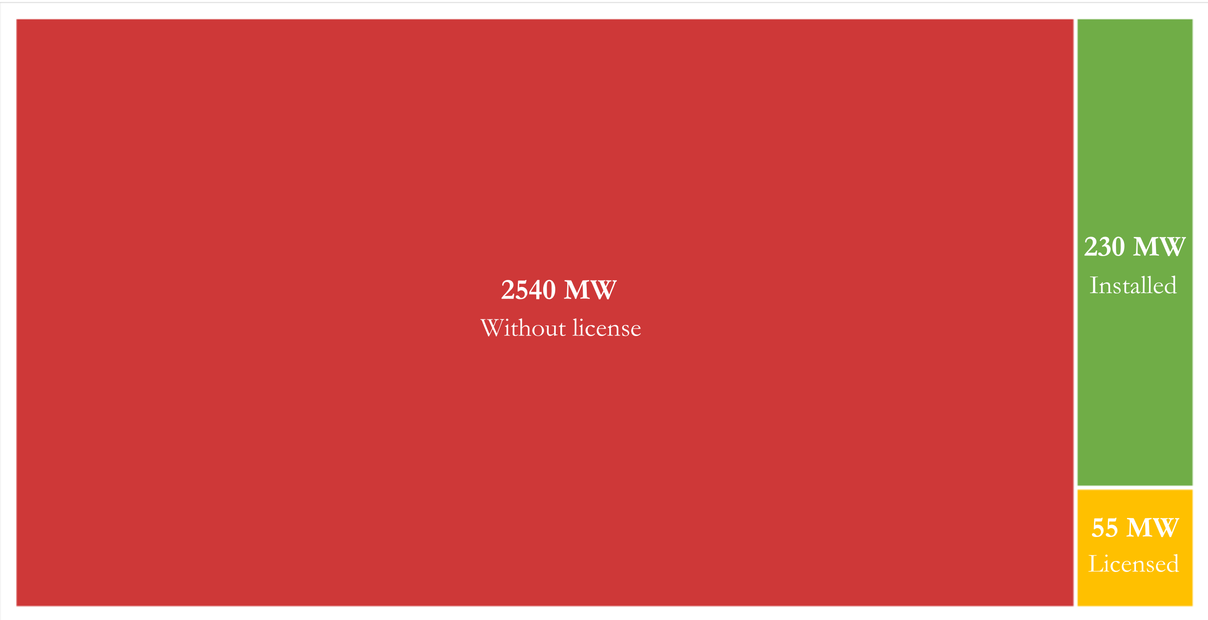


Figure 10 – The outcome of contracted projects from 2017
What happened to the projects contracted at 2017 auctions? Of the total of 2.82 GW, 2.54 GW remain without license, 285 MW have been permitted and only 230 MW have been realised. Source: own representation. All data from: (Quentin 2020b).

Interestingly, if we take the average implementation duration of 15 months, that is, the time from receiving the contract until the plant is typically in operation, we find that most of these projects should have been realised by now. Even taking into account the extended 54-month implementation deadlines, these projects only have until November 2021 to May 2022 to be built. Given that the majority is still without permit, and that licensing and implementation combined takes almost three years, we can assume that many of these projects are running out of time.

Further, we do not know how many of these projects turned out to be unprofitable as a result of the low premium prices of 2017. In terms of the 2018/2019 slowdown, these findings show the extent of lost capacity from 2017: The exemptions for energy cooperatives enabled the contracting of projects that would overwhelmingly not be permitted and thus not be built in 2018 and 2019.

Let us again look at Figure 9 to track how auctions developed after 2017. From 2018, the exemptions for energy cooperatives were abolished, meaning that only permitted projects could be bid at auctions. As a consequence, the bid capacity drastically decreased, falling slightly above the tendered capacity in February 2018 and then almost consistently below afterwards. Only the August 2018 and December 2019[4] auction were oversubscribed, all others were undersubscribed[5]. As a consequence of this decrease in competition, auction prices soared to stabilise near the permissible maximum price of 6.2 ct/kWh. Also, the share of contracts awarded to energy cooperatives dropped drastically after 2017. At the same time, the realised capacity would increase: 46% of all contracted projects from 2018 are in operation. It is likely that this has to do with the fact that these projects had been permitted, were subject to shorter implementation deadlines and contracted at higher premium rates.

Also, a large capacity of permitted projects seems to stay in the background from auction to auction. The grey line shows the permissible bid capacity, that is, the total capacity of permitted and uncontracted wind farms at the time of the auction. Comparing the permissible with the actual bid capacity, it seems that more than enough permitted projects are available for participation at each auction. However, there are alternative explanations. When being asked about this discrepancy, interviewees noted that many of the permitted and uncontracted projects shown in the permissible bid capacity are inaccurate and cannot participate for two reasons: Firstly, they may currently be stuck in a lawsuit or have had their permit removed as a result of one. Either way, such projects would remain in the official statistics for the permissible bid capacity (Quentin pers. comm.). Secondly, projects may have been re-permitted a second (or even a third) time but stay in the statistics (Müller pers. comm.). According to the interviewees, this is also proven by the fact that a large share of the permissible bid capacity is quite old. Quentin and Lorenzen agreed that many of these projects were permitted long ago. Quentin said that 550 MW was permitted in 2016 but still not built nor contracted, emphasising that "there is something wrong with these projects". Schmedding and Lorenzen agreed that, whether it is due to lawsuits, re-permitting or other issues,

[4] For the oversubscription of the December 2019 auction, Quentin (pers. comm.) provided the explanation that the permissible maximum price for 2020 had not been released until shortly before this auction. As a price reduction of 10% was possible for 2020 auctions, bidders were rushing to the December auction for fear of lower prices next year.

[5] It is worth noting that the grid development area's tendered capacity has been consistently undersubscribed after 2017 as well, except for one auction in February 2019 (Quentin 2020b)

most of this permitted capacity from the past will not proceed to the auction but still remains in the permissible bid capacity statistics over the years. Seemingly, then, the permissible bid capacity is inaccurate as it includes sued, cancelled and re-planned projects. Also, the idea that there are other barriers such as missing permits holding back developers from participation at the auction is corroborated by the fact that rising prices have not incentivised increased bidding. Thus, a lack of profitability cannot be the barrier here.

4.3.3.4. Multi-stage issues

This section covers several issues such as transition projects, repowering, lawsuits against individual projects, changes in the average duration of realisation, and state-specific trends. Beginning with transition projects, let us recapitulate: Transition projects were those projects that, when permitted before 2017 and built before 2019, could still get feed-in tariffs instead of entering the auctions. Estimating the share of transition projects in the added capacity of 2017 and 2018 is important to understand the impact of the switch to auctions on deployment. Unfortunately, no official data was found on this. Instead, this share can be estimated through a data source showing the capacity of realised projects from auctions until September 2019 (Quentin 2019c). Omitting the realised projects from 2019's auctions, we find that a total of 660 MW of projects, which had been contracted at 2017's and 2018's auctions, were built until September 2019 (Figure 11). This stands in contrast to the gross added capacity in 2017 (5.5 GW) and 2018 (2.46 GW). The caveat is that we do not how much of the 660 MW was built in 2017, 2018 and 2019. If we assume that all of these projects were built in 2017 and 2018, we find that 8% of added capacity came from the auctions. If we assume that the total 660 MW was built in 2018, we find that 27% of added capacity came from the auction. It is important to stress that these are 'at most' estimations: For the 8% estimate, we do not know how much of the 660 MW was built in 2019, and for the 27% estimate, we do not know how much of the 660 MW was built in 2017 or 2019. This means that the percentages are likely to be smaller. If at most 8% of projects built in 2017 and 2018 came from the auctions, this in turn means that at least 92% of added capacity in 2017 and 2018 represented transition projects. Further, at least 73% of added capacity in 2018 represented transition projects. Importantly, this shows that the minority of projects built in 2017 and 2018 came from the auctions but that the majority represented transition projects. Therefore, deployment would have been much lower if it had been for the auctions alone. 2019 also shows this: As transition projects can no longer be built, the deployment rates cave in even more.

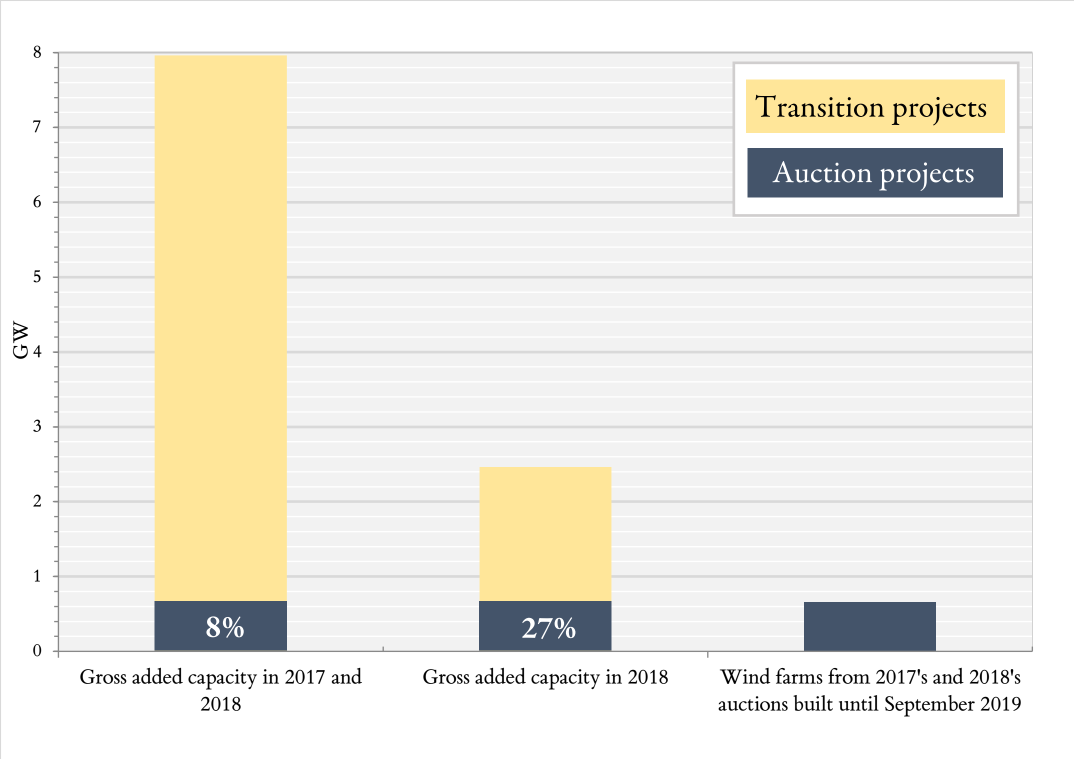


Figure 11 – Estimating the share of transition projects in the gross added capacity of 2017/2018
The share of transition projects in the new additions of 2017 in 2018 is estimated through a data source, which specifies the capacity of projects which had been contracted at the auctions in 2017 and 2018 and were built until September 2019: 660 MW. It is unknown how much of this capacity was built in 2017, 2018 or 2019. Assuming that all of it was built in 2017 and 2018, this 660 MW represents 8% of the gross added capacity. Assuming that all of it was built in 2018, the 660 MW represents 27% of the gross added capacity. This means that at the very least 92% of realised projects in 2017 and 2018 were transition projects. Further, at the very least 73% of realised projects in 2018 were transition projects.

Let us now briefly consider some data on the expiring feed-in tariffs for installed wind farms and the options for repowering. According to the BWE, around 4 GW of plants will lose their feed-in tariffs until the end of 2020 (BWE 2020b). Until 2025, this will amount to 16 GW (BWE 2019a). As it seems, many of these plants will not be able to be repowered. A study by the Federal Environment Agency estimated that 60% of wind farms, for which feed-in tariffs expire until 2021, cannot be repowered as they are located outside of current designated areas for wind farm development (UBA 2019a). Further, a survey by the FA Wind found that for 40% of plants, for which feed-in tariffs expire until 2025, operators reported that they cannot be repowered (Quentin et al. 2018). The reported reasons included a missing planning law basis, licensing and area restrictions and a lack of profitability

Furthermore, there is interesting data on lawsuits against individual projects. According to a survey by the FA Wind, a large share of permitted projects that is not yet in operation is facing lawsuits (Quentin 2019b). These lawsuits affect projects either before or after auctioning. The survey, conducted in May in 2019, finds that permitted and uncontracted projects with a capacity of at least 330 MW were in ongoing lawsuits at the time. For 75% of these projects, the developers claimed that the primary reason for not entering the auction with the project was the lawsuit. This indicates that lawsuits are a substantial barrier to auctioning. The survey also found that contracted and not yet implemented projects with a capacity of at least 380 MW were being sued. For 40% of these projects, the developers stated that the project was already being sued at the time of bidding. This shows that certain developers do seem to take the risk of contracting a sued project. It should be mentioned that this survey only offers an uncomprehensive account of the capacity of sued projects, since it was based on a sample of project developers that owned only 32% of all permitted projects in Germany at the time. To estimate the actual share of permitted and unrealised projects facing lawsuits, Figure 12 should be consulted.

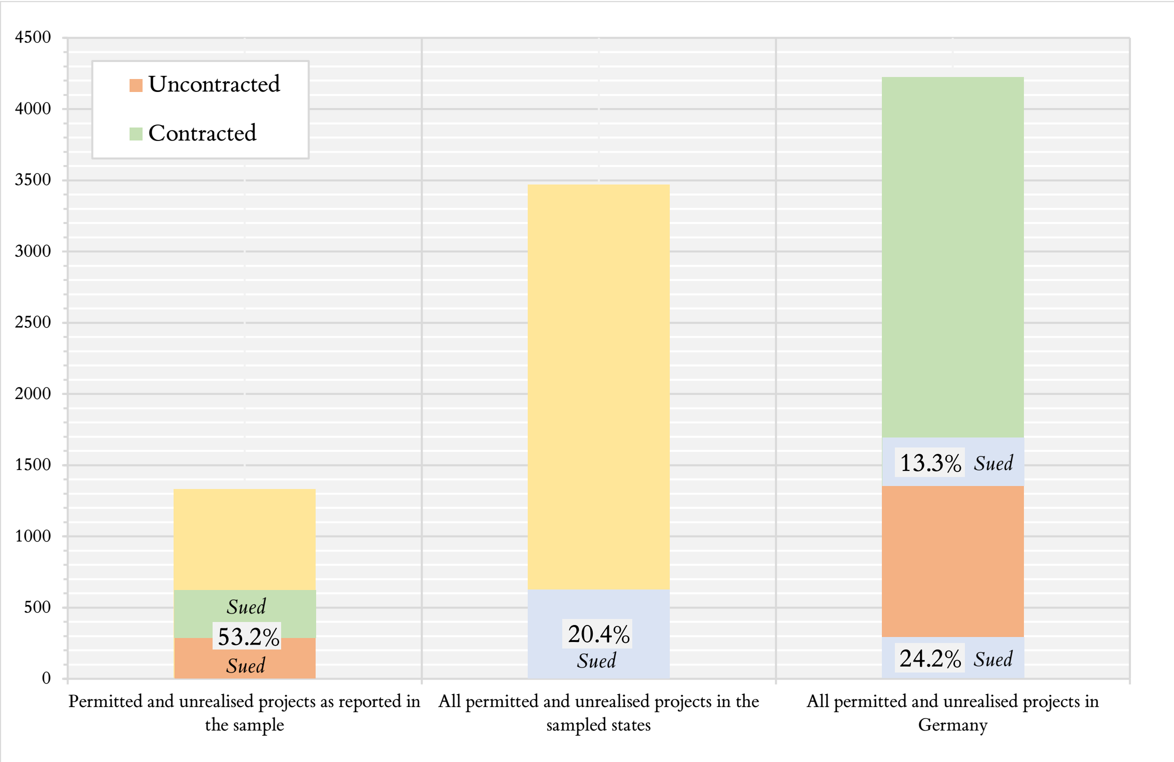


Figure 12 – The share of permitted and unrealised capacity facing lawsuits
The share of permitted and unrealised projects in lawsuits depends on the population value. Bar 1 shows the capacity of contracted and uncontracted projects, which are in ongoing lawsuits. It also shows their joint share in the total permitted and unrealised capacity of the participants in the sample: 53.2%. Bar 2 shows the share of these same projects in the total of permitted and unrealised capacity in the participant's states at the time: 20.4%. Bar 3 shows the share of the same projects in all of the permitted and unrealised capacity in Germany, for uncontracted (24.2%) and contracted projects (13.3%). Source: own representation. All data from: (Quentin 2019b), Data from May 31, 2019, N=40

The first bar shows the total capacity of permitted and unrealised projects of the 40 developers participating in the survey: 1.3 GW. It also shows the capacity of projects from these developers, which are in ongoing lawsuits: 380 MW of contracted projects and 330 MW of uncontracted projects. In total, then, 53% of the developers' permitted and unrealised projects were in ongoing lawsuits. However, we may assume that only those developers participated in the survey that were actually affected by lawsuits. Thus, we may want to estimate the share of sued projects in all the permitted and unrealised projects existing at the time in the states, where the participating developers operated. These were only 9 from Germany's 16 states, with a capacity of permitted and unrealised projects of 3.5 GW. We find that the share drops down to 20%. Finally, if we take all permitted and unrealised projects in Germany at the time as the basis for our calculations (4.2 GW), we find that the share drops to 17%. This effectively means that at a minimum 17% of unpermitted and unrealised projects were being sued at the time. Further, at a minimum 24% of uncontracted projects and 13% of contracted projects were in lawsuits in Germany at the time. If the study is thought to be representative, however, we find that more than half (53%) of permitted and unrealised projects was facing lawsuits in May 2019.

Lastly, who sues according to the data and why? In 61% of all cases, environmental and conservation groups were listed as the plaintiff of the lawsuit. For 36% of cases, it is private individuals, for 14% citizens' initiatives against wind power and for 12% it is the municipality (Quentin 2019b). In terms of the underlying reasons, 48% of lawsuits were due to bird and bat protection, 32% due to procedural errors with the species protection assessments, 25% due to conservation in general, 17% due to noise protection and 10% due to municipal planning issues[6] (Quentin 2019b).

In terms of delays in realisation, we find that the average duration between the grant of permit and commissioning has increased substantially over time. While this process took almost 22 months in 2019 and 2020, it took only about 11 ½ months between 2014 and 2017 (Quentin 2020a). Around 6 ½ months of this increase can be accounted to auctioning, which began in 2017. The remaining 4 months point to the fact that delays in implementation have become more common.

Let us finally look very briefly at regional discrepancies. As of February 2020, only 10% of contracts went to projects in Southern Germany, including Baden-Württemberg, Bavaria, Rhineland-Palatinate, Saarland and Southern Hesse (Quentin 2020b). Around 20% of newly installed projects between 2010 and 2019 was built in these regions. This indicates that deployment of onshore wind power is unequally distributed across states and has been getting more so under the auction scheme. However, the difference does not seem large enough for explaining the 2018/2019 slowdown in development across the country. Figure 13 confirms that the slowdown in growth is a Germany-wide trend, showing the annually net added capacity for each of Germany's Länder.

[6] Note that the percentages provided both for plaintiffs and reasons do not add up to 100% since multiple responses were allowed in the survey. That is, several plaintiffs can sue a project for several reasons.

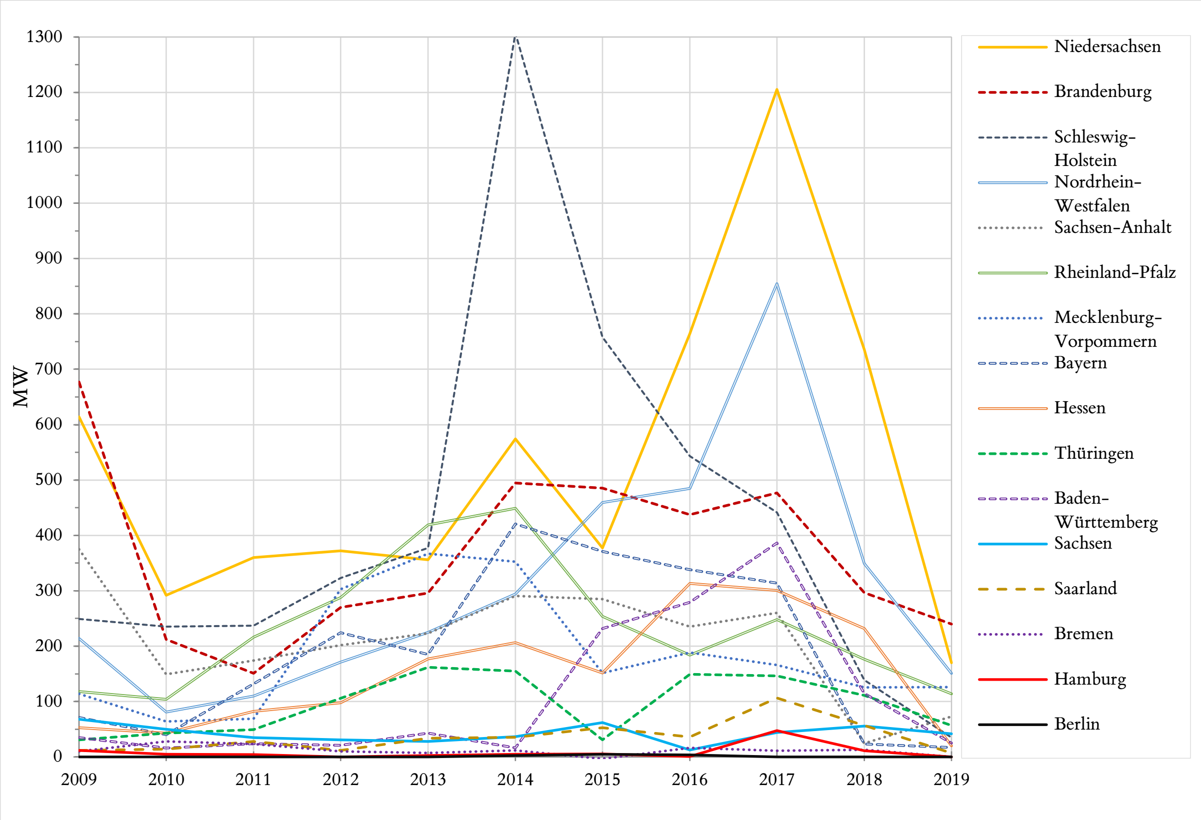


Figure 13 - Yearly net added onshore wind power capacity for Germany's Länder 2009 - 2019
Source: own representation. All data from: (Bundesnetzagentur 2020)

As is shown, the drop in deployment after 2017 was universal across Germany. All states but one built less capacity in 2018 than in 2017. Only Saxony added slightly more in 2018. However, the slowdown was more pronounced in some states than in others. Especially Lower Saxony (Niedersachsen) and North Rhine-Westphalia showed large decreases after 2017. Capacity growth also broke down severely in Brandenburg, Baden-Württemberg, Bavaria and Saxony-Anhalt. Schleswig-Holstein's case also stands out, with capacity growth peaking in 2014, decreasing afterwards and plummeting in 2018. In 2019, most Länder showed even slower capacity growth, with only Saxony-Anhalt and Mecklenburg-Western Pomerania (Mecklenburg Vorpommern) adding slightly more. In sum, it can be said that, first of all, the slowdown is a universal phenomenon, with consistently declining deployment rates across many states impacting Germany's overall situation. Second, the more pronounced slowdown in previously strong states such as Lower Saxony, North Rhine-Westphalia but also Schleswig-Holstein has accentuated the overall slowdown.

5. Discussion

5.1. Has growth of onshore wind power capacity slowed down?

The first research question aimed to establish whether German onshore wind power is really in crisis. A crisis was defined as a situation, where capacity growth is in steady and persistent decline. In order to judge the crisis character of the 2018/2019 slowdown in capacity growth, we would need to know whether it is the beginning of a such a long-term decline or only a temporary anomaly that will subside for rebounding growth. To do this, German onshore wind power was located on its technology diffusion curve. Specifically, three different growth models (logistic, logistic-linear, exponential) were fit to actual capacity data of onshore wind power to find out whether the technology is in its early, middle or later stage of the growth phase.

As the results showed, growth of onshore wind power capacity has stopped accelerating in Germany. Indeed, the technology seems to have reached peak growth at some point between 2003 and 2012. Yet, there are no signs of a decline in growth either. Instead, growth is nearly linear, with a long-term growth rate of 2.5 to 3 GW. That means that the technology is in the middle stage of its growth phase and still at distance from the saturation phase. Therefore, the 2018/2019 slowdown is not yet the beginning of a steady and persistent decline in growth. Instead, the slow growth observed in 2018 and 2019 may merely compensate for the above-average growth rates observed between 2014 and 2017 (3.5 to 4.9 GW). In other words, while growth in 2018 and especially 2019 was unusually slow, growth between 2014 and 2017 was unusually fast. This means that the 2018/2019 slowdown and the 2014-2017 upswing are temporary fluctuations on a long-term growth trajectory that averages at around 2.5 to 3 GW.

Judging from this analysis, the 2018/2019 slowdown in capacity growth does not represent a crisis in the way that we defined it. Instead, technology diffusion theory suggests that, when observed within its long-term growth trajectory, German onshore wind power is still growing steadily with no evidence of a persistent decline towards saturation. This signals that the recent slowdown may only represent a momentary phenomenon. Also, it can be seen as a reaction to the overly strong deployment rates in the years prior, which were exceptional when viewed within the technology's long-term growth context. In sum, we can say that the growth story of onshore wind power in Germany can be expected to continue for some time into the future, albeit not at the speed typical between 2014 and 2017 but instead at a rate of 2.5 to 3 GW.

5.2. Why are there expectations for faster capacity growth?

The second research question was concerned with the discourse around the 2018/2019 slowdown and especially its framing as a crisis. This required an investigation into the expectations for growth of onshore wind power and the underlying assumptions, targets and points of reference. Understanding these factors then allowed us to trace and explain the origins of the wide-spread crisis narrative.

As was shown, there was the ubiquitous belief in all interviewees in the longer term decline of growth of onshore wind power capacity in Germany. In looking at this perception, we find growth is judged on the basis of expectations that are shaped both by past experiences and observations, present conditions as well as future visions and targets. As was shown, the exceptional growth years of 2014 to 2017 are often taken as a reference for comparison. For many, especially the year of 2017, with the highest capacity growth in the history of German onshore wind power, seems to stand in an alarming contrast to the years that followed. This seems to indicate that, generally, growth is perceived not as long-term continuous process but rather on a year-to-year basis, with very recent years colouring the expectations. However, at the same time, references are often based a broader perspective that look far into the history of the technology. We find this in the common reference to the year of 1998 – the last time when capacity growth was as slow as in 2019. Taken together, it may be said that while the recent and strong years of 2014 to 2017 are particularly vivid in the collective memory, the comparison with early growth is not uncommon either.

In looking at past growth, however, many interviewees took issue with a sole focus on installed capacity. They emphasised that a comparison of capacities between different years would be distorted, since the average capacity of individual turbines has increased so much in recent years. That is, they were of the opinion that the increase in individual turbine capacity acts as a buffer for the decrease in turbine growth, painting an overly optimistic picture of Germany's situation. This is why they thought that the number of annually added turbines would be a much better indicator of growth of onshore wind farms. Figure 14 shows us the difference between turbine growth and capacity growth, displaying added capacity, added plants and average capacity per annum for 1992 to 2019. When viewed this way, the discrepancy between added turbines and added capacity becomes visible. At around 2000, the average individual capacity of added German turbines rose above 1 MW. The gap between added turbines and added capacity then continued to widen, with average capacity rising above 2 MW at 2010 and 3 MW at 2017. If we look at turbine growth alone, growth in 2018 is the slowest since 1993. Turbine growth in 2019 is the slowest in all of German history of onshore wind power. For capacity growth, however, 2018 was the weakest year since 2012 and 2019 the weakest since 1998. These discrepancies help explain the interviewees' criticism of capacity growth as an indicator: Germany's situation appears much worse if we look at turbine growth alone. Considering that most interviewees referred to turbine growth in estimating the severity of the situation, it becomes clear why they all speak of declining growth.

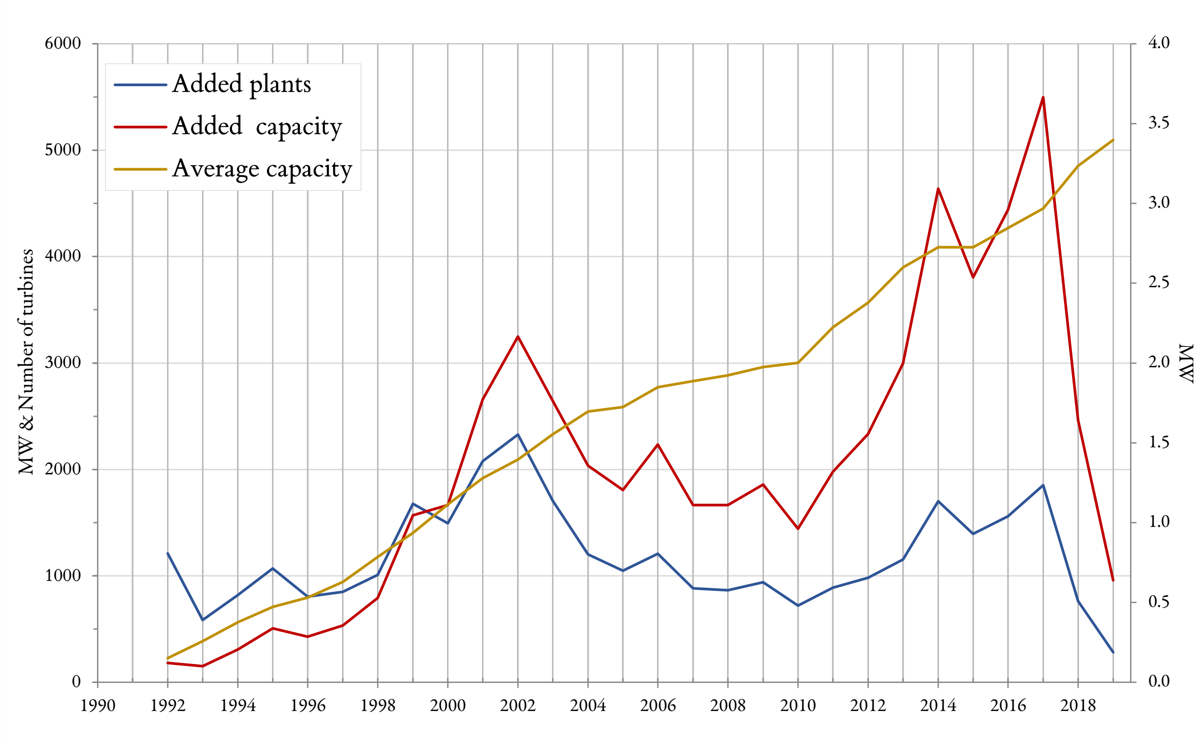


Figure 14 – The gap between turbines and capacity of onshore wind power in Germany
This figure shows added capacity and added turbines (left y axis) and average capacity (right y axis), which is the ratio of the former two, that is, the average individual capacity of newly installed German turbines for each year. Source: own representation. All data from: (Quentin 2020d)

Perceptions of the speed of growth also have to do with the ability to anticipate growth correctly. If growth is overestimated, expectations are let down and actual developments are perceived as anomalous. And indeed, growth expectations were found to diverge from actual deployment rates in 2018 and 2019. Most interviewees claimed that while a decrease from earlier rates was foreseeable, the scale of the slowdown was still a surprise. While certain developments such as the issues with regard to 2017's auctions were expected, many others could not be predicted. These included the increasing difficulty to obtain permits, the intensifying resistance from citizens' initiatives against wind power and the lack of political support. This also helps to explain the diverging growth expectations for 2019 – with some interviewees expecting the year to be worse and others expecting it to be better. What this shows is how the industry was taken of its feet by the 2018/2019 slowdown in capacity growth. As one interviewee pointed out, this may also have had to do with certain barriers being invisible in the background for some time. For instance, the lack of new permits seemed to only really crystallise after permits were made mandatory for participation at auctions from 2018. The tendency for the industry to misperceive barriers and overestimate growth also becomes visible through the consistently mistaken official growth predictions of the wind energy industry associations and their need to correct them retrospectively. This inability to predict the slowdown as it happened may have then fed into the crisis discourse, as industry actors were ill-prepared for the slowdown and could not adapt to it in time.

Another recurring pattern was the reference to alarming trends in the German wind energy industry. Mounting job losses and lost revenue across the industry, the relocation of large developers' business activity to foreign markets, the bankruptcy of small developers – all these developments were consistently highlighted as proof of the crisis. The severity of the situation was also stressed by personal accounts of increasing numbers of risky projects that fail and of the need to compensate domestic losses on foreign markets. What is suggested here is that the industry's struggles signify that there must be a decline in growth of onshore wind power. And given the threat that the decline poses to the industry, it is perceived as a crisis. Further, also the observation of current industry challenges and the anticipation of future challenges seem to feed into the crisis perception. Undersubscription consistently comes up in the discourse, even though, according to the average timeline of realisation, it has not affected deployment yet. Future challenges such as expiring feed-in tariffs and uncertainties regarding re-powering were also brought up in my cases, pointing to the anxiety in the industry caused by these challenges. This illustrates that the crisis discourse is mixed, soaking up very different kinds of challenges to onshore wind power and intensifying the perception of the decline, regardless of which challenges lead to lower deployment now or in the future. The crisis, then, is assumed to be a persistent situation that is not going to change anytime soon but will threaten onshore wind power deployment for some time to come.

The potential of the industry and the area was another salient theme associated with growth perceptions. Frequently, there were references to the enormous development of the German wind energy industry in recent years, both in its economic dimension and its technological sophistication. Many of the interviewees stressed that these advances would technically allow for much faster expansion. It seems, then, that the industry's economic and socio-technical development and the deriving potential decisively shape the expectations of observers. As the industry's potential increases, the expectations for the speed of deployment increase. Importantly, also the geophysical potential was highlighted, emphasizing that technically there is enough area available for continued large-scale deployment. Combined, these references to the economic, technological and geophysical potential point to a striking contrast between what is possible and what is realisable. Whereas the industry and the area would technically allow for faster expansion, a number of political, economic, social and ecological barriers are in the way. Given that the interviewees are either from within the industry or working closely with it, it is not surprising that they are bewildered and even irritated by this gap, wishing for the industry to realise its potential. In turn, the observation of the untapped potential for deployment may intensify the perception of the crisis.

Further, the analysis revealed that expectations for faster growth are often grounded in the comparison of actual, planned and required deployment. In terms of planned deployment, frequently mentioned were the EEG growth corridors that were introduced with the auction system, limiting annual onshore wind power deployment at an average of 3.2 GW. According to some interviewees, the crisis is obvious due to the large gap between the growth corridors and actual deployment: While ~3.2 GW of annual gross additions are planned, only 2.5 GW and 1.1 GW was achieved in 2018 and 2019, respectively. But, while actual growth does not meet planned growth, it falls even more short of the growth required by climate and energy targets. Virtually every interviewee brought up these targets to stress why current growth of onshore wind power is deficient. Especially the 2030 target for the 65% share of renewables in the power mix was mentioned consistently. To reach this goal, most interviewees deemed annual additions of 4 to 5 GW as necessary. It seems plausible that they are referring to the estimates of the earlier mentioned studies, which modelled the required annual growth to meet the 65%-target (Agora Energiewende 2018; BEE 2019; Oei et al. 2019; BDEW 2019). Indeed, the average of these studies' estimates is 4.2 GW, close to the interviewees' suggestions.

The constant reference to these targets shows that growth expectations are very much influenced by a sense of urgency for climate action and a devotion to the success of the energy transition. This also become evident through the allusions to the wider transformations coming up in Germany's energy transition. Whether it is the country's ambitions to electrify transport and heating through sector coupling, the need to safeguard power supply in times of the coal-phase out or the future production of green hydrogen for the decarbonisation of industry – all these missions of the Energiewende seem to be on the minds of those that label current deployment rates as insufficient. According to these people, a much stronger fleet of onshore wind power is a necessary foundation for the success of Germany's energy transition. We find, then, that growth expectations do not only circle around typical past deployment rates and the economic needs and potential of the industry. More than that, they are grounded in scientific assessments of what is needed for Germany to meet its climate targets. And further, they take into account the scale of the challenges lying ahead in the country's energy transition and delineate the role of onshore wind power in facing these. Let us consider these positions in terms of our results that growth of onshore wind power is not yet in decline but still advancing steadily at a nearly linear pace. What the analysis of growth perceptions and expectations shows is that the industry does not settle for linear growth. Instead, they call for much faster growth of onshore wind power that is line with what has been typical in the past, what is possible in the present and required for the future.

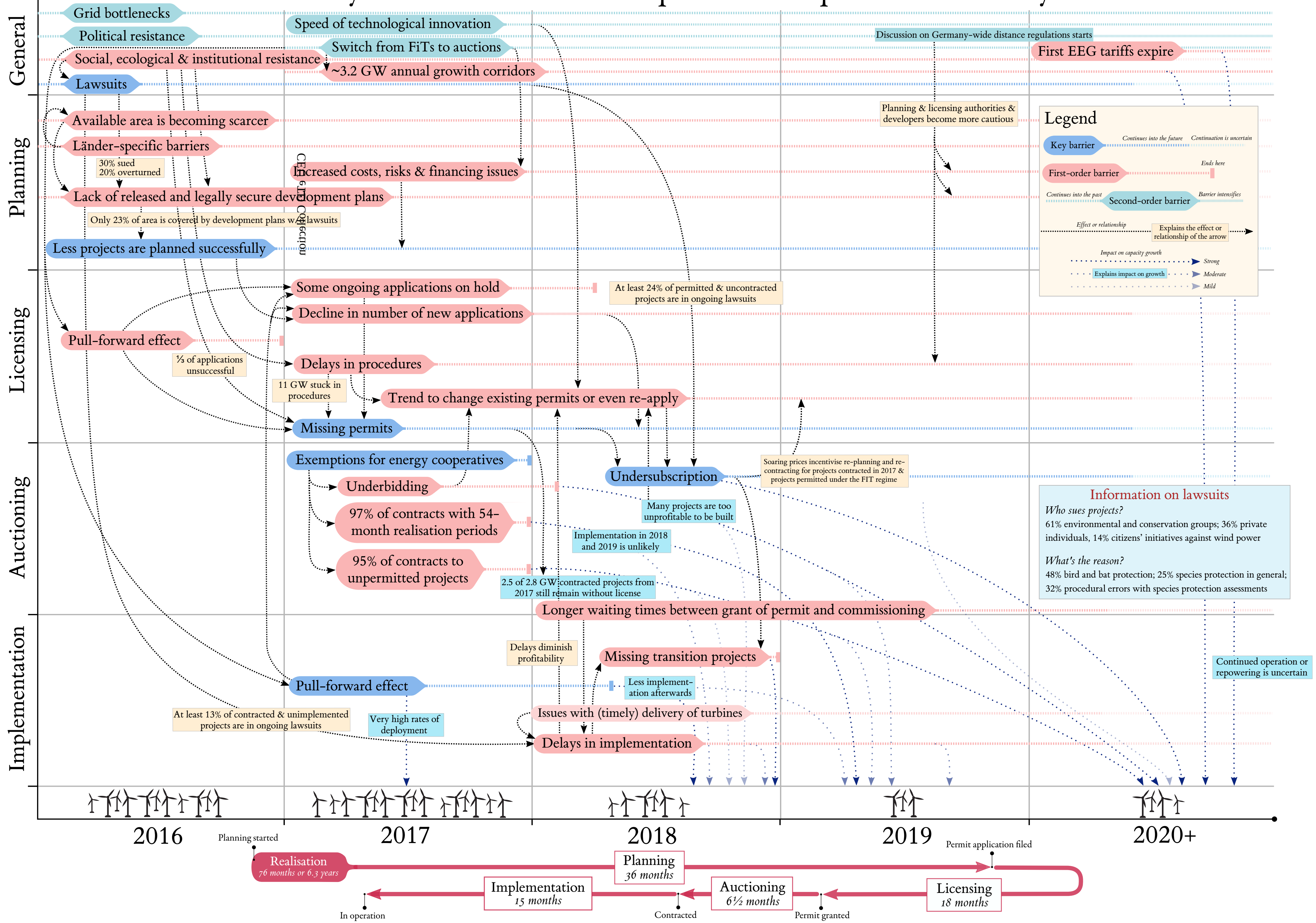
5.3. Why does capacity not grow as fast as expected?

The third research question and core project of this thesis looks at why onshore wind power capacity does not grow as fast as expected in Germany. To explain this, barriers to deployment were identified, matched with their respective stage(s) of the realisation process, analysed in terms of their interactions and timelines and assessed in terms of their impact on actual deployment over time. The result of the analysis is displayed in

Figure 15 – The dynamics of onshore wind power development in Germany**,**

which is displayed on the next page and shows a three-level matrix that separates the three factors: (1) stages of realisation, (2) time and (3) barriers. The figure shows all relevant barriers to deployment that were identified in the analysis, for each of the four stages of realisation – planning, licensing, auctioning and implementation – as well on a general multi-stage level, from 2016 to 2020 and beyond. Three types of barriers are shown: (1) key barriers, that is, the greatest barriers in each stage, as well as (2) first-order barriers and (3) second-order barriers, which have been explained before. The timeline of each barrier is indicated by the dotted line that leads into the barrier (from the past) and emerges from the barrier (into the future). The interactions between barriers are shown by the black arrows, explained by a yellow box covering the arrow. The impact of a barrier on deployment is shown by the blue dotted arrows, explained by a blue box covering the arrow. The strength of the impact (mild, moderate, strong) is differentiated by the intensity of the arrow's colour. For further clarification, the legend should be consulted.

The dynamics of onshore wind power development in Germany



5.3.1. Multi-stage barriers

All second-order barriers are found in this general section. These are deemed to impede onshore wind power deployment not in a direct and immediately tangible sense but by creating and reinforcing first-order barriers. A very decisive second-order barrier is found in the switch from feed-in tariffs to auctions in 2017. The uncertainty regarding future prices and levels of competition at the auctions led to apprehension in the industry. As a result, developers attempted to benefit as much as possible through the so-called transition projects from the expiring feed-in tariff scheme. These projects had to be permitted before 2017 and built before 2019, in order to be eligible for feed-in tariffs. As a result, developers were finalising as many permits under the old support scheme as possible in 2016 – often in close cooperation with the licensing authorities. Basically, this meant that developers were pulling forward a lot of projects to 2016, which they would have only tried to permit in 2017 and even 2018. This pull-forward effect led to the spike in the number of new permits in 2016 and to the drastic and sudden drop afterwards. In 2017, the pull-forward effect in licensing then translated into implementation. Developers now had a large number of permitted projects at their disposal, which would have to implemented before 2019. However, gradually digressing feed-in tariffs were put in place between January 2017 and December 2018. The sooner the transition project was commissioned, the higher the tariff. This created a strong incentive for prompt implementation, which translated into very high and disproportionate rates of deployment in 2017 and early 2018 and much lower rates after. This caused a distortion in the deployment statistics: Without the switch of the support scheme and the associated pull-forward effect, deployment rates would have stretched more across 2017, 2018 and 2019 – instead of being squished into 2017 and early 2018. That is, the same capacity would have been deployed over a longer range of time, smoothening the annual growth trend line. In other words, growth in 2018 and 2019 would not have been so slow if growth in 2017 had not been so fast.

The switch to auctions has created another barrier, however. These are the annual growth corridors (Table 1), which specify the annually tendered capacity at onshore wind power auctions. While there are slight variations in the growth corridors between 2017 and 2021, the average rate is 3.2 GW until 2030. Given that the time between contracting and commissioning takes 15 months, these corridors would technically restrict deployment in 2018 and beyond. However, the contracted projects from 2017 had much longer implementation periods (54 months) and could therefore not be expected to be built in 2018 anyway. At the same time, auctions started to be undersubscribed from 2018 onwards, meaning that the tendered capacity was not claimed. Even if it had been higher, this would not have made a difference. Thus, so far, the corridors have not represented a barrier to deployment. Should the bid capacity approach the tendered capacity again in the future, the corridors could start representing a barrier. Depending on how these trends develop, the growth corridors are likely to strongly impact deployment in the 2020s.

Another second-order barrier is the inability of the German electricity grid to integrate the increasing wind-generated electricity output in Northern Germany. As mentioned earlier, as a result of grid bottlenecks, the tendered capacity of onshore wind power has been reduced in Germany's so-called grid expansion area. While this could represent a very direct barrier to development in Northern Germany, it is not one as of yet, given that the grid expansion area's tendered capacity has also been consistently undersubscribed in past auctions. Rather, grid bottlenecks can be expected to have more indirect impacts on deployment. For example, as discussed, they come at immense costs necessary for the redispatch of wind-generated electricity. Critics then refer to these costs in their rhetoric against wind energy, as for example in the previously mentioned debate about wind-generated 'ghost power'. This can then further intensify the already widespread perception of the Energiewende as excessively expensive (Unnerstall 2017) . Such scepticism may fuel public opposition against wind power. Another issue is the required expansion of the grid infrastructure to resolve the bottlenecks – an undertaking that is heavily opposed in Germany. If wind energy is seen as driving the need for this expansion, the opposition may spill over to the technology. However, these are just speculations. As this analysis mainly focuses on first-order barriers, a more comprehensive explanation of the impact of the lacking grid infrastructure on deployment cannot be provided here.

Political resistance – a recurring theme in the analysis – is another second-order barrier. Interviewees complained about resistance on the local, state and federal level. Especially salient was the perceived contradiction in politics between concrete and ambitious climate and renewable energy targets and the personal opposition of politicians and administrators against new wind farms. Wind energy critics were judged to be highly influential in policy-making, all the way up to the CDU's economic wing and the Federal Ministry of Economy and Energy. These actors were also seen as driving the political discussion on a Germany-wide 1000m minimum distance policy. This discussion is considered to have increased the political resistance against wind power in Germany, having wide-reaching effects, which will be discussed in the next sections. Another final second-order barrier is the speed of innovation in turbine technology, the effect of which will also be discussed in later sections.

There are also some first-order barriers within the general section. One is called social, ecological and institutional resistance. It includes the increasing social opposition against wind energy, as observed in the rise of citizens' initiatives across the country, the conflicts with species protection and conservation, as well as issues with monument protection, flight safety and military interests. This was deemed to be a first-order barrier since it immediately affects planning and licensing, to be explained later. It also lies behind lawsuits, which is considered a key barrier. Lawsuit can affect planning, auctioning and implementation and will therefore be discussed in their separate sections. Finally, there is the barrier of expiring feed-in tariffs for installed onshore wind power projects, which affects 4 GW of projects already in 2020. As was shown, there is the concern that many of these wind farms will not be profitable enough to continue operating. They will need to be repowered or replaced somewhere else, if capacity is to continue to grow. At the same time, our results show that repowering is often restricted, mainly because the affected wind farms are situated outside of currently designated areas for onshore wind power development. This makes it likely that more and more installed capacity will be removed in the 2020s. As a result, the gross added capacity will need to be even higher to secure the same net added capacity: If more wind farms are removed, more need to be added to achieve the same rate of growth. The impact of expiring feed-in tariffs on growth is thus judged to be strong for 2020 and beyond.

5.3.2. The planning stage

For the planning stage, a key barrier is that less projects are planned successfully. That is, less projects are brought to the point of applying for the permit. This has to do with a range of issues. One of the main barriers is that the land that is generally available for the development of onshore wind power has been constantly declining. This is simply due to the fact that land is limited and that the German onshore wind power fleet has been growing rapidly. At the same time, Germany is very densely-populated and there exist conflicting interests for the use of the available land. As the onshore wind fleet grows, conflict-free areas become more sparse and finding space for wind farms becomes increasingly difficult. At the same time, land has become more scarce due to Länder-specific barriers such as strict distance regulations as in Bavaria or the cancellation of the regional development plans as in Schleswig-Holstein.

These dynamics feed into the next barrier: the lack of released and legally secure development plans, which provide the basis for planning a new wind farm in Germany. As the analysis has shown, planning procedures tend to be rigid, inflexible and time-consuming and have been getting more so with time. Authorities seem to be overwhelmed, understaffed and unequipped, on the one hand, and increasingly meticulous and cautious in order to anticipate objections, on the other. And apparently, they can also be paralysed by political resistance, especially on the municipal and rural district level. These issues seem to have increased with the onset of the political discussion surrounding Germany-wide distance regulations, increasing the uncertainty in planning authorities. These delays have meant that for 36% of German land area, development plans are not yet released but still in draft. Delays are also exacerbated by resistance coming from conservation, monument protection, flight safety and military interests. Such objections seem to have been increasing – stalling the planning process in the attempt to hear everyone out. These delays have also meant that existing development plans can be outdated, failing to designate large enough areas to account for today's climate targets.

Further, even if the development plan is released, it is very likely to be sued. Half of all released plans in Germany have been sued, again based on the same social, institutional and ecological resistance. Indeed, for only 23% of German area, there exist legally valid development plans that are not sued. And, as development plans are not legally watertight, they can get overturned by the court – which is the case for every fifth released plan in Germany. Areas designated by the plans for onshore wind power development are then sometimes cancelled due to arising issues such as a new sighting of a protected species in the area or a request by the military to use the area as a low-flying zone for helicopters. Strikingly, this cancellation sees for no alternative, effectively meaning that the designated area shrinks over time. Evidently, then, the development plans are vulnerable to dynamic changes and on-the-ground circumstances and too inflexible to make later adjustments. The scarcity of designated areas was also highlighted by the study of the Federal Environment Agency, which showed that existing and planned designated areas deployment are just about enough to build the capacity planned by the tendered capacity (UBA 2019a). Right now, only a fraction of the areas considered in the study are legally valid – indicating how constrained area availability really is.

Next to the lack a designated areas, another barrier to planning is found in the increasing costs and risks associated with realising an onshore wind farm in Germany. As indicated by the interviewees, the high costs for the permit, the auction, staff, the landowner and the municipality have to some extent discouraged ambitions for planning, especially among small developers. At the same time, risks have increased. Planning a wind farm without the basis of a development plan is risky as it comes with opportunity costs and upfront investments. Risks particularly increased with the introduction of auctions in 2017, as development was now dependent on a limited number of contracts, for which developers had to compete. Further, costs have increased with the financial guarantee required for auction participation. Together, these developments have made onshore wind farms a much more risky investment. As a result, financing has become increasingly difficult, with banks refusing to provide the necessary loans.

Combined, the lack of designated areas for onshore wind power and the increasing costs and risks associated with development have meant that less projects are planned successfully to be taken into licensing. While it is uncertain when exactly this issue emerged, it is located at around

2016, shortly before the introduction of auctions. This is because many project developers would have put their planning efforts aside in order finalise their licensing procedures for already planned wind farms, so that they could take as many transition projects as possible into 2017. The increasing costs and risks attached to the new support scheme and the lack of designated areas would then have prevented the recovery of planning activity to past levels.

5.3.3. The licensing stage

The key barrier in this stage has been the decrease in the number of newly permitted wind farms since 2017. There are several reasons for this decline in permits. As outlined, the drastic fall in the new number of permits after 2016 is due to the pull-forward effect. However, this pull-forward effect is also assumed to have led to a temporary decrease in permitting activity by especially small developers. As these were busy implementing transition projects in 2017 and early 2018, they filed less new permit applications and delayed ongoing applications. The delay would have meant that even less permits were granted in 2017 and early 2018. The lack of new applications would have led to a lack of new permits 18 months later – in 2018 and 2019. It is worth noting that these effects on application numbers were additional to the general and persistent problem with the lack of successfully planned projects ready to be taken into licensing.

After most of the transition projects had been implemented by early 2018, permitting activity should have recovered somewhat. Still, the number of new permits stayed at low rate. This is likely due to increasing delays in procedures and rejections of applications. Similar to planning procedures – the delays in licensing also appear to have to with the increasing complexity and time-intensity of the procedures, the understaffed and ill-equipped authorities and their pedantic and cautious work ethic. The distance regulation discussion seems to have reinforced the uncertainty and caution in these authorities. As a result, around 11 GW of projects were stuck in licensing procedures in July 2019.

Further, delays and rejections are also affected by the increasing social, ecological and institutional resistance to new wind farms. Conflicts with conservation tend to materialise in costly and complex species protection assessments, the rejection of these on the grounds of quality issues and long-standing arguments with species protection authorities. Further, flight safety restrictions impede 4.8 GW and military concerns 3.6 GW of new wind farms. Monument protection was also mentioned as a barrier here. These increasing conflicts likely have to do with the decreasing available area for deployment. As Germany's onshore wind fleet grows and the remaining area becomes more sparse, conflicts with other interest groups increase. In sum, these conflicts have meant that only every third permit application is successful.

Another barrier in the licensing stage is the practice of re-planning projects with existing permits, seeking to either alter the permit or re-apply for a new one. This practice is affected by several other barriers. First of all, the speed of technological innovation has meant that, upon being granted the permit for a project, project developers may decide to re-plan the project in order to change to newer and more cost-efficient turbine technology. This is exacerbated by delays in licensing procedures, which make it more likely that the type of turbine is outdated once the permit is granted. However, re-planning was also incentivised by aggressive competition in the first auctions. Realising their inability to compete at such low prices, many developers chose to re-plan their projects to change to more cost-efficient turbines. The contracted projects from 2017, which were too unprofitable to be built, are also likely to be re-planned. Later in 2018, re-planning was incentivised by the undersubscribed auctions, as developers were comparing the soaring prices to their premium rates from 2017 auctions. As a contract is tied to a specific project, either the implementation deadline has to be waited out or the project has to re-planned to re-enter the auction. Further, the financial guarantee will be lost. Still, for many of the contracted projects from 2017, it made more sense to go through this procedure than to build at the low premium rate from 2017. Also, for the transition projects, the digressing feed-in tariffs would sometimes be worse than the premium rates from 2018. If choosing not to build, developers could either wait until 2019 to enter the auction or re-plan and re-permit these projects. Lastly, re-planning is also reinforced by delays in implementation, as when a project overshoots the implementation deadline and loses its financial guarantee. If a project seizes to be profitable as a result of delays, re-planning and changing the permit is a good option.

5.3.4. The auctioning stage

There are two key barriers in this stage. The first are the exemption clauses for citizens' energy cooperatives, which lasted throughout 2017. These included (1) the right to submit bids for unpermitted projects, (2) longer realisation periods (54 instead of 24 months) and (3) not your own bid, but the highest winning bid specified the premium rate for your contract. As discussed, these exemptions had wide-reaching consequences. To benefit from the exemptions, large developers either cooperated with or posed as energy cooperatives. Further, the auctions were massively oversubscribed due to aggressive competition, which forced down prices and led to underbidding – down to 3.82 ct/kWh at the November 2017 auction. This aggressive competition by energy cooperatives was partly driven by the guarantee to get the highest premium independent of one's own bid and partly by speculative bidding on the part of large and financially strong developers. The speculation was two-fold: (1) Submitting bids for projects that may or may not receive their permit and are even planned outside of designated areas and (2) bidding at prices that only become profitable if turbine technology advances quickly enough to bring about the required cost reductions.

In the end, about 97% of contracts went to energy cooperatives that year – all of which could benefit from the longer implementation deadlines. 95% all of contracts were awarded to unpermitted projects. These developments have had real consequences for deployment. First of all, the fact that virtually all contracts benefitted from longer implementation deadlines meant that there was no intention to build them in 2018 or 2019. On the contrary, as mentioned, many of these project were designed based on speculations about highly cost-efficient turbine technology to be released in the future. Implementing these projects in 2018 and 2019 would have turned them unprofitable. The impact of this on deployment is judged to be strong for 2019 and moderate for 2018, since the average implementation period of 15 months would have meant that most projects would have been built in 2019, if it was not for the 54-month long deadlines.

Further, the vast majority of contracted projects from 2017 – a staggering 2.5 GW – has remained without permit. Indeed, only about 10% have been permitted and 8% have been built. The analysis suggests that is unlikely that more will follow, also because of the many barriers to licensing and the fact that many of these projects were at odds with existing development plans. Further, these projects are starting to run out of time given the long time it takes for permitting and implementation and that the first implementation deadlines expire in 2021. What does this mean concretely for deployment levels? Unpermitted projects cannot be built and given the large share of contracted capacity that still remains without permit, we can expect a heavy dent in deployment in 2020 and beyond. The impact on 2019 and 2018 was judged to be moderate and mild, given that the longer implementation periods meant that these projects were unlikely to be built this early anyway. For the minority of projects that would have been built this early, missing permits would become an issue.

Further, the third barrier to deployment associated with these exemptions was underbidding. As a result of the low premium rates common at 2017 auctions, many of the contracted projects will turn out to be unprofitable and not be built. As these projects were still before or in the midst of licensing as they were contracted, it is likely that, upon observing the higher premium rates at 2018's and 2019's auctions, developers would decide to re-plan, re-permit and re-enter the auction. This will mostly reduce deployment in 2020 and beyond and less so for 2019 and 2018. Again, this is because these projects were designed to be built in line with their 54-month implementation deadline. Combined, these three barriers – missing permits, longer implementation deadlines and underbidding – have led to a situation where about 92% of the capacity contracted in 2017 has not been realised. This is central to explaining the low deployment rates in 2019 (but also late 2018) – given that it takes an average of 15 months for implementation and the first auction was in May 2017.

As the exemptions for energy cooperatives were removed, another key barrier emerged. This was undersubscription, which began with the May 2018 auction and has persisted. All but 3 of 11 auctions after 2017 were undersubscribed. Undersubscription seems to be due to three different barriers. Firstly, the decrease in newly permitted projects from 2017 has meant that permits are lacking for participation. However, this issue could only come to the forefront when permits were made mandatory for bidding at auctions. Secondly, there is the issue with lawsuits against permitted and uncontracted projects. At least 24% of such projects were in ongoing lawsuits in May 2019. Overwhelmingly, the research shows that developers choose not to participate with sued projects, instead waiting out the results to avoid financial risks. However, lawsuits can also lead to the cancellation of permits, reducing the number of projects eligible to enter the auction. Thirdly, many projects are being re-planned and re-permitted even though they could technically participate at auctions. As mentioned, this has to do with a range of issues. Undersubscription drives this practice, too, as the high prices incentivise developers to enter the auctions with transition projects or already contracted projects.

In sum, these three barriers effectively mean that there is a lack of permitted projects without lawsuits that can participate at auctions. Further, for those projects that could participate, there is an incentive to rather re-plan and re-permit. What does all this mean for deployment? Undersubscription is going to strongly impact capacity growth in 2020 and beyond, when the lack in new contracts translates into a lack in new additions. It only affects growth in 2020 and beyond because, although the May 2018 auction was already undersubscribed, it was only slightly. From October 2018, undersubscription increased – with a range of the proportion of the contracted capacity to the tendered capacity between 30% and 58% (see Table 9 in Appendix). As implementation averages 15 months, we can expect a serious dent in deployment rates from around March 2020.

5.3.5. The implementation stage

There are only few barriers in this stage. The pull-forward effect, which squished the number of newly installed wind farms into 2017 and early 2018 has already been outlined. Another barrier regards the transition projects: 900 MW of these projects had not been realised until 2019. As mentioned, this had to do with the profitable rates of 2018 auctions, with developers choosing to rather re-plan, re-permit and participate at the auction than to build under feed-in tariffs. However, many of these projects were also held back by lawsuits. This is an important barrier to implementation, with at least 13% of contracted and unimplemented projects being held back by lawsuits in May 2019. Lawsuits can cause delays in implementation, which can make projects unprofitable. In the case of transition projects, obstructions through lawsuits could have made implementation impossible until 2019, thus losing the claim to feed-in tariffs.

Delays in implementation have also become increasingly common with the introduction of the auction scheme. This is indicated through the earlier presented data on recently commissioned wind farms, for which it took about 22 months between the grant of permit and commissioning instead of the 11 ½ months typical for wind farms built between 2014 and 2017. Delays in implementation may to some extent be explained by issues with turbine delivery. However, as no consensus existed on this barrier, it is to be considered with caution and is displayed accordingly. Overall, delays in implementation were considered to moderately affect deployment in both 2018 and 2019, by stretching the installed capacity over longer time periods. That is, projects that would have been installed in 2018 or 2019 may have been delayed to 2019 and 2020.

5.4. Integration of findings with technology diffusion theory

This study has located German onshore wind power in the middle stage of its growth phase and has identified several barriers to deployment. These findings need to now be integrated into technology diffusion theory. Concretely, that means describing the general challenges, which lie behind the specific barriers to wind farm development in Germany and compare them with what we would expect according to diffusion theory. This helps us to better understand what kind of challenges renewable energy technologies such as onshore wind power face as they move along their growth phase. Comparing the findings of this study with theory, we find that many of the barriers to German onshore wind power are what we would expect to see for a renewable energy technology in its advanced stage of diffusion. Thereby, this study corroborates existing ideas in technology diffusion theory. Other identified barriers in this study point to further challenges affecting established renewables. This adds to existing knowledge within technology diffusion theory.

When looking at the barriers to deployment of onshore wind power in Germany, we can discern a number of underlying general challenges that the technology faces at it moves along its growth phase. These challenges are summarised in Figure 16.

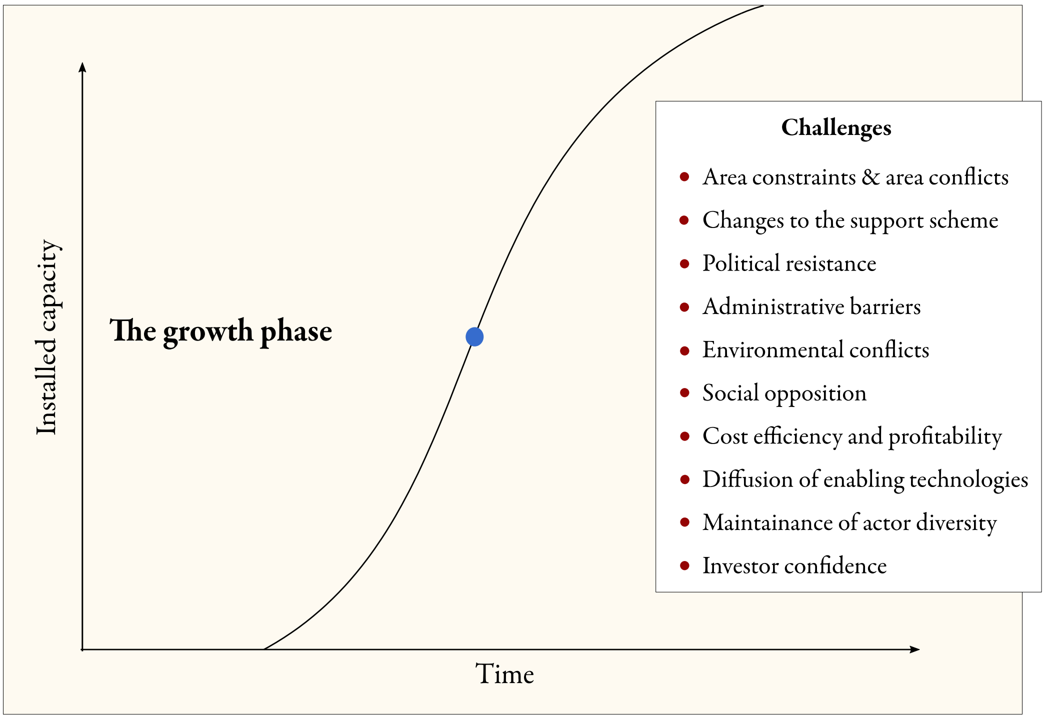


Figure 16 – The key growth challenges for onshore wind power in Germany
This figure displays the middle part of the S-curve – the growth phase – and the underlying challenges for renewable energy technologies such as German onshore wind power at this point diffusion. The blue circle shows the inflection point. Source: own representation.

A major challenge for onshore wind power in Germany seems to have been the switch of the support scheme from feed-in tariffs to auctions. According to the technology diffusion theory, this is not surprising given that renewables struggle to cut costs quickly enough when support schemes change (Kramer and Haigh 2009). Studies on specific challenges to onshore wind power also point to the challenge of continued economic viability (González and Lacal-Arántegui 2016; Lüthi and Prässler 2011). And indeed, we have learned that financial uncertainties and risks have intensified for project developers with the switch to auctions. However, this barrier cannot explain the slowdown, which had to do with the wide-spread apprehension in the industry of the auction scheme and the resulting urgency to benefit as much as possible from the last feed-in tariffs. Further, it was due to the specific initial design of the scheme, which had the unintended consequence of awarding 95% of contracts to projects that were underbid, unpermitted and designed to be built only about 4 years later. This underscores the challenge for renewables to successfully transition from one support scheme to the next, but it also shows that it is not only about costs but also about the design of the scheme. In Germany's case, we see the danger of well-intentioned regulations that backfire: While the support for energy cooperatives was meant to maintain the bottom-up character of the Energiewende and foster public acceptability of wind energy, it led to the exploitation of the exemptions, a decrease in new installations and the abolishment of support for energy cooperatives, whose activity drastically declined after 2017. The switch to auctions thus slowed down growth and jeopardised the acceptability of wind farms by forcing out energy cooperatives. Trying to integrate these findings into technology diffusion theory, we find that, beyond cost-cutting, the switch of the support scheme presents a much greater and complex challenge for renewables, which includes maintaining the diversity of actors in the socio-technical network, sustaining planning security for investors and ensuring growth despite deficiencies in the design of the scheme.

This case underscores another challenge highlighted in technology diffusion theory: area constraints and conflicts. For onshore wind power in Germany, this challenge seems to have been lingering in the background for some time until the undersubscribed auctions helped highlighting it: Even though, developers have been able to get exceptionally high prices at recent auctions, they have not been able to bid due to missing permits and lawsuits. These issues are in turn rooted in area constraints for new wind farms and the conflicts that arise out of the competing interests for the available land. This is very much in line with existing research, which shows that due to the decentralised nature of renewable energy, its area requirements become increasingly difficult to fulfil in the later stages of diffusion (Markard 2018; Kramer and Haigh 2009). The nature of this challenge become clearer by comparing onshore wind power to conventional energy technologies: A coal-fired plant also needs to go through a complex planning and licensing procedure and deal with objections from competing interest groups before it can be built. But all it takes is one to power a small city: Germany's newest coal plant, commissioned on May 30, 2020, has a capacity of 1.1 GW (Uniper 2020). To generate the same amount of power with onshore wind power, we would need around 325 turbines of Germany's 2019 standard (Figure 14). Each one of these turbines has to be planned and permitted successfully. And for every piece of land that those turbines claim, there will be competing interest groups ready to object – conservation groups, the military, flight safety and monument protection authorities, municipalities and citizens' initiatives against wind power. These area constraints may be particularly relevant for Germany, since it is very densely populated and its land is thus sparse and sought-after. Indeed, it has been claimed that it is not because but in spite of its limited area, dense population and suboptimal wind resources that Germany has built one of the largest onshore wind fleets in the world (Ohlhorst and Schön 2010). A study, which compared the proportional land eligibility for the deployment of onshore wind power in different European countries found that Germany ranks sixth to last behind countries such as Spain, the UK, France and Poland – even though it has the largest fleet on the continent (Ryberg et al. 2020). Especially the many environmental and social challenges facing onshore wind power in Germany translate into concrete area constraints such as development bans within protected landscapes and minimum distances to settlements (Permien and Enevoldsen 2019). But area is not only scarce but also very popular. Lawsuits by conservation groups, stakeholder opposition during licensing, blocked areas through military and flight safety restrictions – these are concrete issues that arise when conflicting institutional, environmental and social interests compete for the land claimed by a wind farm. Combined, these issues explain why area availability for the continued deployment of renewable energy is seen as one of the key challenges to the success of the Energiewende (Schmid et al. 2016). For technology diffusion theory, these findings underscore the scale of the connected challenges of area availability and area conflicts, both of which renewable energy technologies such as onshore wind power have to face in their later stages of diffusion.

An issue very related to area conflicts are the environmental challenges for onshore wind power – another highlighted point in the literature (Katzner et al. 2019). We find that these are key in explaining the opposition against wind farms in Germany: The majority of wind farms are sued by conservation groups, mainly on the grounds of bird and bat protection. At the same time, these challenges materialise in all kinds of other ways: Uncompromising species protection authorities that refuse to meet developers halfway; costly, time-intensive and complex species protection assessments that lead to the delay or rejection of the permit; the cancellation of designated areas due to nearby breeding red kites – all these are fitting examples for the 'green-green dilemma' (Voigt et al. 2019). The principles and goals of conservation and climate mitigation seem to have become so out of touch in Germany that the former now represents one of the greatest challenges to the latter. We may also assume that these environmental challenges increase as onshore wind power diffuses. This is because developers will gradually run out of easily available and conflict-free sites with time. This forces them to build wind farms closer to conservation-sensitive areas, increasing the potential for conflict. Since technology diffusion theory does not yet acknowledge environmental growth challenges, it is suggested that they are integrated for onshore wind power.

Social opposition is another challenge for onshore wind power repeatedly mentioned in the literature (Wüstenhagen et al. 2007). This study cannot provide a definitive answer on the scale of this challenge for Germany. While lawsuits seem to primarily come from conservation groups, citizens' initiatives against wind power are only responsible for a minority. At the same time, the interviewees suggested that wind energy critics often disguise as conservationists. Still, it seems that deployment seems to have primarily been affected by other barriers than public resistance. This is also backed up by acceptability research. A survey by the Federal Environment Agency found that over 90% of people deemed new installations of renewables such as wind and solar as important and reported to never have opposed the nearby construction of a wind farm (UBA 2019c). Another recent survey found that 86% of residents with nearby wind farms are not or hardly bothered by them, with support for wind power increasing with the number of nearby wind farms (Kantar 2019). Based on the wide-spread public acceptance of onshore wind power and the low share of lawsuits coming from citizens' initiatives against wind power, one recent study has suggested that the false perception of diminishing acceptability is created by a small minority of the population (Fischer and Kube 2020). Taken together, these findings indicate that social opposition is only a moderate challenge to onshore wind power in Germany. Still, it should be included in the list of challenges potentially facing renewable energy technologies in their later growth stages.

The findings on wide-spread acceptance of onshore wind power in Germany take us to a more pressing challenge to the technology's growth: political resistance. If wind power is so widely accepted, how come the 2018/2019 slowdown is framed as a consequence of diminishing acceptability – as it is done by the government coalition and especially the Federal Ministry of Economy. Framed as an instrument that will foster acceptability, the German-wide minimum distance policy now appears to lack a purpose.[7] If we tie these considerations together with the interviewees' perception that wind energy critics are quite influential up the top of political decision-making, we are brought to a question: May the social opposition to wind farms, as stressed in the political debate, be a mere cover-up for a lack of political acceptance? One recent article suggest so, criticising how wind energy critics occupy central positions of power in the Federal Ministry of Economy (energiezukunft 2019). This underlines the contradiction in politics pointed out by the interviewees: Politics is both characterised by the public affirmation of the Energiewende and the effective stalling of the deployment of onshore wind farms. But would politics stall the energy transition if the public supports it? To understand why this could be the case, we need to get back to the notion of the Energiewende being an institutional battle between different political parties (Jacobsson and Lauber 2006). The Greens and the SPD[8] can be said to have been at the forefront of supporting renewable energy, as when they founded the EEG in 2000 (Lauber and Jacobsson 2016). The CDU and FDP, on the other hand, have been closely tied to the big utilities and the conventional energy industry, arguing in favour of an affordable energy transition that set bounds to the 'excessive' deployment of renewable energy (Lauber and Jacobsson 2016). Especially the CDU's influential business wing would increasingly criticise the costs of the Energiewende over time, setting the stage for the abolishment of the feed-in tariff scheme (Leiren and Reimer 2018). This conflict has also become visible in the seven-month debate

[7] This is besides the fact that there is no scientific evidence for a relationship between distances to settlements and higher acceptability of wind power (Hübner and Pohl 2015).

[8] Traditionally, the SPD has also been closely tied to the coal industry.

of the government coalition on the 1000m distance regulation, which ended in May 2020: While the CDU was in favour of the regulation, the SPD opposed it. Eventually, they came to the agreement that individual Länder may opt-out of the policy (Die Zeit 2020). We see, then, that political resistance to onshore wind power has been and still is a decisive factor in the dynamics of onshore wind power deployment in Germany. And, as we have seen, such political resistance has wide-reaching consequences: Planning and licensing authorities seem to be pressured by local politicians, on the one hand, and unsettled by the discussion of Germany-wide distance regulations on the federal level, on the other. As a result, they become more cautious and attentive to details, rejecting permit applications or delaying the drafting of development plans. The industry is also affected: Especially small developers seem to have been become less willing to take planning risks since the discussion on Germany-wide distance regulations began. Combined these findings point to another challenge for renewable energy technologies in advances stages of diffusion: Maintaining the support of the political regime.

Another challenge outlined in the literature were administrative barriers to the development of renewables (Lüthi and Prässler 2011). This study has shown that these are highly relevant for onshore wind power in Germany. Lengthy and complex procedures, repeated public participation, the requirement for authorities to regard every objection seriously – these dynamics cause immense delays in the drafting of development plans for wind farms. The authorities themselves have been described as uncompromising, meticulous and overly cautious. If issues arise, the bureaucratic structure does not allow for retrospective changes such as cancelling a designated area here and adding a new one there. Instead, the area is cancelled or sometimes even the whole plan overturned. These hurdles very much constrain the planning potential for new wind farms. Barriers continue during licensing: The sluggish interactions between understaffed and ill-equipped authorities, the consideration of stakeholder complaints; detailed requirements and high costs for the species protection assessment – these and other factors have led to a situation where 11 GW of wind farms are stuck in licensing procedures. Administrative barriers seem very relevant then for diffusing renewable energy technologies. Although it seems likely that these types of barriers are present along the entire path of diffusion, we may assume that they intensify as a technology becomes more wide-spread. This may be because the knowledge of a renewable energy technology's impacts increases with diffusion (e.g. ecological impacts of wind turbines are much better understood today than thirty years ago) and the measures to deal with these impacts expand accordingly (e.g. species protection reports have become much more complex over time).

Lastly, the case of German onshore wind power also corroborates the idea that renewable energy technologies become increasingly dependent on 'enabling technologies' as they diffuse (Kramer and Haigh 2009). This is indicated by the shift in the political discussion from energy generation technologies, such as onshore wind power, to energy storage, conversion and transmission technologies such as hydrogen, due to their reputation of enabling the cross-sectoral use of renewable electricity. A very clear example of the need for enabling technologies are also the increasing grid bottlenecks in Northern Germany, which require the curtailment of wind farms at high costs. This has already translated into concrete restrictions for the deployment of onshore wind power as with the reduction of the tendered capacity for the grid development area in Northern Germany. Ultra-high voltage long-distance transmission lines are an example of an enabling technology, potentially allowing the excess wind-generated power from the North to be put to use in the South. Yet, these are widely opposed in Germany (Kühne and Weber 2018). This highlights how the success of onshore wind power in Germany becomes more intertwined with and dependent on the successful diffusion of other technologies over time.

A range of challenges have been mentioned, which can explain why onshore wind power is struggling in Germany: changes in the support scheme, maintaining actor diversity in the industry, securing investor confidence, increasing financial uncertainties and risks, area constraints and conflicts, clashes with conservation, political resistance, social opposition, administrative barriers and the diffusion of enabling technologies. While these challenges are found to be relevant for German onshore win power, they may also apply to other established renewable energy technologies in other contexts.

5.5. Implications of findings for German onshore wind power & the Energiewende

Let us finally consider what the findings mean collectedly for the future of onshore wind power development in Germany. While we find no evidence of a persistent decline of growth of onshore wind power in the country yet, many barriers to faster deployment do exist. Also, as the industry's expectations and underlying targets have underlined, there is a large discrepancy between the deployment that is planned, achieved and required. While the EEG's growth corridors see for average gross additions of 3.2 GW every year between 2018 and 2030, actual additions only amounted to 2.5 GW in 2018 and 1.1 GW in 2019, with 1.4 to 1.8 GW expected for 2020 (BWE 2020b). While this capacity gap between planned and realised projects should be concerning enough, there is an even larger gap to what would be required for Germany to meet its climate targets. As referred to by the interviewees, scientific assessments show that about 4.2 GW of yearly gross additions are necessary for meeting the 2030 target of a 65% share of renewables in the power mix. We find, then, that the industry's criticism is justified: While an average of 1.8 GW was realised in 2018 and 2019, respectively, 3.2 GW was planned, and 4.2 GW would have been required. Germany is behind on its own plans and off track to meet its climate targets.

While meeting these targets is not only required to stay in line with the Paris Agreement, it is also essential if the Energiewende is to preserve its good international reputation and bolster its ability to inspire other countries in their energy transitions. Worryingly, we have seen that there is already a large gap between ambitions and reality in Germany's climate mitigation efforts. Having reduced its GHG emissions by only 35.7% at the beginning of 2019 compared to 1990, it would have missed its 2020 reduction target of 40% (BMU 2020), if it had not been for the Covid-19 pandemic, and is bound to miss its 2030 reduction target of 55% (UBA 2020). This is also due to the slow progress on decarbonisation in the industry sector (-30.5% in 2018 compared to 1990) and the absence of progress in the transport sector (-0.6%) (UBA 2018). In contrast to these deficiencies, the German government has the ambition to fully decarbonise its economy by 2050, while at the same time remaining a competitive industrial nation that leads the world in climate-friendly technologies and production processes (CDU et al. 2018; BMWi 2019c). To reach these objectives, they are to be translated into concrete on-the-ground transformations of the energy system such as the electrification of transport, the wide-spread use of heat pumps in buildings and the production of green hydrogen. All of these transformations require immense amounts of renewable electricity, which will have to be generated primarily by wind and solar in Germany (Agora Energiewende 2020). As rightly pointed out by the interviewees, then, faster deployment of onshore wind power is a key prerequisite for meeting the upcoming challenges in Germany's energy transition.

However, current growth of onshore wind power is not only insufficient for meeting the climate targets, it is also endangering the German wind energy industry: Over 40,000 jobs have been lost in the industry in recent years (BMWi 2019b; Zeit Online 2019). Moreover, large developers and manufactures are shifting their business activity towards foreign markets as domestic sales plummet. More localised actors, such as companies working in assembly, installation, maintenance and repair cannot easily make that shift to foreign markets (Böhmer et al. 2019). Small developers are also limited in this respect and are thus forced to sell their projects, get bought up entirely or even go bankrupt. These worrying developments bring back the memories of the doom of the German solar industry, which was a global leader with 150,000 employees only in 2011 and then gradually paled into insignificance (Wehrmann 2018). Of course, with the difference being that this time, the industry is not endangered by cheaper Chinese manufacturers, but by a failing domestic market. Of course, this collapse of the German wind energy industry is regarded as a crisis by the interviewees, which work within or with the industry.

More than that, however, it stands in stark contrast to the government's intention of becoming world-leading in green technologies. This is because the German wind energy industry is already there: It offers a future-oriented product that is essential for climate mitigation, includes very large manufacturers such as Nordex and Enercon, and still employs over 100,000 people. It makes sense then for Germany to try to sustain and foster this seminal industry.

Evidently, then, faster growth of onshore wind power is needed in Germany. But while our model predicts that growth will pick up again in the future, it also shows that growth is likely to be insufficient at 2.5 to 3 GW. At the same time, our analysis has shown that many barriers to deployment persist, while others have emerged and will emerge over time. First of all, there is the general constraint by the EEG's growth corridors, which limit deployment at an average of 3.2 GW per year in the 2020s. Second of all, the majority of projects, which were contracted in 2017 and should have technically been built in the early 2020s, cannot be expected to come online due to a lack of profitability or the failure to secure a permit. Third of all, undersubscription represents a lack in deployment with an approximate time delay of 15 months. As we have seen, 8 out of the total of 11 auctions have been undersubscribed since 2018. This will drastically constrain capacity growth from 2020 onwards. At the same time, we know that undersubscription is not the issue itself. Instead, it is mainly caused by a lack of newly permitted projects free of lawsuits. Further, the area constraints and area conflicts that lie behind these barriers are likely to intensify: Depending on which of Germany's states will choose to opt-in to the 1000m distance regulation, the designated areas for wind farms could shrink by up to 40% (Bons et al. 2019). Fourth and finally, the expiring feed-in tariffs for installed wind farms and the barriers to repowering make it likely that a lot of existing capacity will be removed in the 2020s. Therefore, while undersubscription constrains the future added capacity, the expiring feed-in tariffs increase the future removed capacity – meaning that it will be increasingly harder to secure the required net added capacity to meet the climate targets and sustain the industry.

However, while we can try to anticipate certain growth trends, the exact impact of the different identified barriers cannot be known with certainty. This has to with the fact that barriers trigger and reinforce each other so that their joint impact on deployment is larger than if barriers were in isolation from each other. Let us consider three examples. First of all, while the barriers of missing permits and lawsuits have led to undersubscribed auctions, they also had another effect. The high premium rates associated with undersubscribed auctions have created an incentive for not building transition projects, so that these can be taken to the auction in 2019. In turn, this means that the undersubscribed auctions, and therefore the issues with licensing and lawsuits, have not only directly affected future growth but also indirectly diminished present growth. The second example is about the relation between long-lasting licensing procedures and the speed of technological innovation. When a project has finally been permitted after long procedural delays, its turbine type is likely to be outdated due to the rapid pace of innovation. As building outdated turbines runs counter to developers' economic interests, the delays in procedures incentivise re-planning. In turn, this means that sluggish procedures do not only lead to undersubscribed auctions by delaying the permits necessary for participation but also by increasing the number of permits that is re-planned and thus not immediately taken to the auction. Finally, a third of these examples can be found in Bavaria: the state's stringent distance policy has forced wind farms to be developed in greater proximity to conservation-sensitive areas. In that way, the distance policy does not only directly reduce the available area for wind farm development, it also indirectly increases the conflicts of wind farm developers with conservation groups and species protection authorities. While there may be many more of these examples, these three illustrate very well how different barriers interact in complex and unforeseeable ways, making the full scale of their impact very hard to predict. Given the multitude of barriers identified through this study, it may be, then, that their joint impact on future growth is even greater than expected.

Taken all these considerations together, we find that current deployment rates of onshore wind power in Germany are insufficient in every respect. Whether for the success of the Energiewende or the sustenance of the wind energy industry, much faster growth of onshore wind power at about 4.2 GW is needed. However, our model suggests that future annual deployment is unlikely to exceed 3 GW. Further, we find that there is a range of barriers to deployment, which threatens to curb future growth. At the same time, the interactions between barriers, and specifically their nature of triggering and reinforcing each other, may mean that their actual consequences for deployment will be even more severe. These considerations take us back to our conclusion that German onshore wind power is not in crisis. It will be recalled that a crisis was defined as a situation, where capacity growth is in steady and persistent decline. This definition will need to be changed: Whether German onshore wind power is in crisis should not be evaluated based on whether growth is declining, but whether it is fast enough to keep up with the requirements of climate mitigation and the needs of the German wind energy-industry. Growth of onshore wind power in Germany may be advancing at a linear pace, but this is insufficient for meeting these goals. Due to the insufficient growth and the multitude of barriers that are likely to impede growth from rising to sufficient levels in the future, we can conclude that German onshore wind power is indeed in crisis.

6. Conclusion

6.1. Synthesis of findings & theoretical significance

This thesis has investigated the recent slowdown in capacity growth of onshore wind power in Germany in 2018 and 2019. Specifically, it has looked at German onshore wind power's long-term growth trajectory, the wind energy industry's expectations for growth and the underlying barriers to deployment in the country. The first research question aimed to find out whether the recent slowdown actually represents the kind of crisis that it is portrayed as in the public discourse, understood as the beginning of a steady and persistent decline in capacity growth. By viewing German onshore wind power through the lens of technology diffusion theory and testing different growth models, its growth was found to have peaked and stopped accelerating. At the same time, the evidence suggests that the technology's growth is not yet in decline but nearly linear, which is expected at the middle stage of the growth phase of renewable energy technologies. The technology thus seems to still be a long way from market saturation. Indeed, the model suggests that growth can be expected to a rise again in the future, in line with the long-term growth rate of 2.5 to 3 GW. As there is no evidence of a persistent decline in growth yet, it was at first concluded that the 2018/2019 slowdown does not represent a crisis.

The second research question sought to understand the origins of the wide-spread narrative of German onshore wind power being in crisis. On the basis of interviews and content analysis, this was achieved by comparing actual growth with the wind energy industry's growth expectations, as well as examining their underlying assumptions, targets and points of reference. The results show that growth expectations are grounded in experiences of much faster growth in the past, but also build on the geophysical conditions for deployment and the technological and economic potential of the German wind energy industry. The recent struggles of the industry are another factor explaining the large gap between expectations and actual growth. Further, the expectations take into account assumptions of the role of onshore wind power in the future Energiewende and normative scenarios for meeting Germany's climate targets. In sum, there seems to exist agreement around the notion that much faster expansion was common in the past, would be possible in the present and is required for the future. This seems to create the perception of the 2018/2019 slowdown as a crisis.

Finally, the third research question set out to explain why growth falls short of expectations. This required drawing a comprehensive picture of the dynamics of onshore wind power development in Germany, with a focus on the underlying barriers to deployment, their interactions and development over time, as well as their concrete impact on capacity growth. Based on interview, content and data analysis, several barriers were identified that kept deployment below expectations in 2018 and 2019. First of all, the switch of the support scheme from feed-in tariffs to auctions pulled forward a lot of new installations. This had to do with the industry's apprehension of the auctions and the digressing feed-in tariffs for transition projects. As a result, projects that would have only been built in 2018 and even 2019 were shifted to 2017, causing an imbalance in the statistics on annual deployment. Although this pull-forward effect did not affect long-term growth, it did create a sudden drop in deployment rates after 2017 and thus helped fostering the perception of a decline. Second, the fact that 97% of projects contracted in 2017 were granted 54-month implementation deadlines meant that these projects would not be built in 2018 and 2019. To a lesser degree, these projects would also not be built because they failed to receive their permit or turned out unprofitable as a result of underbidding. Combined, this explains why only 8% of contracted capacity from 2017 has been realised. The third reason has to do with the transition projects, which, if permitted before 2017 and realised before 2019, would still get feed-in tariffs. 900 MW of these transition projects had not been built until 2019 as these were either blocked by lawsuits or re-planned for a more profitable contract. Fourth and finally, delays in implementation have become more common, stretching deployment over a longer time period – meaning that certain projects that would have come online in 2018 and 2019, only did so afterwards.

While these findings can explain the growth dynamics for onshore wind power in Germany, they are also relevant on a more general level. This is because the 2018/2019 slowdown improves our understanding of the growth constraints that renewable energy technologies such as onshore wind power run into after they have established themselves on the market. These constraints have been understudied, with most existing research focusing on the early growth stages of renewables. Since onshore wind power is highly developed in Germany, the recent slowdown provided for a good empirical case of a mature renewable energy technology struggling in its advanced stages of growth. Describing this case thus empirically substantiated and further advanced an understudied part of technology diffusion theory. Beyond this, however, our analysis enriched the theory by laying out several challenges that renewables such as onshore wind power may face in their later growth stages. These include area constraints and area conflicts, resistance of the political regime, conflicts with conservation, diminishing social acceptability of the technology, changes to the design of the support scheme, administrative barriers to deployment, maintaining the diversity of actors in the socio-technical network, ensuring investor confidence in the development process and an increasing dependence on enabling technologies. While some of these challenges have been outlined before (Markard 2018; Kramer and Haigh 2009), many are new and thus expand technology diffusion theory. That is, they add to the scientific knowledge on the limitations to the growth of mature renewable energy technologies. Combined, these findings also provide a straightforward answer to the question of why onshore wind power is struggling in Germany while thriving both in Europe and globally: The technology finds itself in a more advanced stage of growth in Germany and is facing unique challenges, which other countries are also likely to face in the future.

Interestingly, the identified challenges also allow conclusions about the interconnection between onshore wind power and the social, economic and political context of the society, in which it is deployed. That is, onshore wind power cannot be merely regarded as an isolated technology serving the energy needs of a society, from which it is otherwise detached and unaffected. Instead, the technology is deeply embedded within the society's structure and shaped by its interactions with the regulatory and administrative make-up, the land use conflicts and the value system of the society. As onshore wind power is used to thrive within planned energy transitions, it is highly vulnerable to regulatory changes. The switch from feed-in tariffs to auctions in Germany highlighted the extent of this vulnerability, with growth slowing down immediately afterwards. Importantly, this slowdown happened even while the majority of the wind farms built in 2018 – at least 73% – were transition projects. When looking at realised wind farms from auctions alone, the slowdown would be much more severe. Quite clearly, then, the switch of the support scheme has caused growth to plummet – and even at a larger scale than the data suggest at first sight. This vulnerability of onshore wind power to changes in the regulatory context endangers its diffusion across changes of governments. This is because the political support for an energy transition based on onshore wind power varies between different parties. In Germany, this can be observed very clearly – with an ideological gulf between supporters (The Greens, SPD) and sceptics (CDU, FDP) of wind power in politics. As was seen with the increasing emphasis on reducing costs and managing deployment under CDU leadership, as well as the associated regulatory changes such as the abolishment of feed-in tariffs, changes in the political regime matter for onshore wind power. In the recent push for Germany-wide distance regulations by the CDU, we see how partisan ideology can put obstacles in the way of onshore wind power development and effectively slow down an energy transition. Obstacles are also found in the administrative procedures that the technology is subjected to, however. The German case clearly shows how bureaucratic barriers and sluggish and inflexible procedures increase the complexity, costs and time effort for realising new wind farms and thus slow down growth. Evidently, then, onshore wind power is immediately affected by its regulatory environment and strongly dependent on ongoing political support. More than that, however, the technology is also subject to a country's area constraints and the resulting land use conflicts. As any other infrastructural project, the technology stands in direct conflict about the claimed area with other interest groups. In Germany, most of these conflicts seem to arise due to nature conservation, flight safety, monument protection and military concerns. Especially paralysing have been the conflicts with conservation groups, pointing to onshore wind power's predicament that it is regarded as part of the problem and not the solution by many conservationists. However, area conflicts can also emerge out of social resistance. Due to their salient and frequent visual appearance, onshore wind farms are very different from other energy supply plants. They shape entire landscapes and become an integrated element of local communities, and are thus prone to clash with people's preferences and values. This can spark fierce resistance, as is seen with the rise of citizens' initiatives against wind power in Germany. In all these different ways, we find, then, that onshore wind power constitutes an integrated part of the broader social, economic and political context of the society, which it powers. The technology is frequently challenged by the interactions between itself and this context and – as seen in Germany – it can even be obstructed and paralysed by these interactions.

6.2. Practical implications and policy recommendations

After interpreting the joint findings of this study, German onshore wind power was indeed considered to be in crisis. This revision had to do with a change to the crisis definition, so that it refers to a situation, where growth falls short of what is required for meeting the climate targets and sustaining the wind energy industry – which both applies to Germany. And while the past slowdown is concerning enough, the future does not look much brighter: Our model suggests that future capacity additions are unlikely to rise above 3 GW per year – too little when compared to the 4.2 GW needed to meet the 2030 climate targets. Further, there are a variety of barriers to deployment, which exist already or are expected to emerge over time, and will most likely constrain growth in the future: Undersubscribed auctions, unrealised projects from 2017's auctions and the expiring feed-in tariffs of installed wind farms. Policy-makers in Germany should thus be alarmed about the current state of onshore wind power and the consequences for the Energiewende. As higher growth of onshore wind power is needed to meet the climate targets and allow for the transformations necessary for the Germany's energy transition, the barriers need to be dealt with. While a comprehensive policy proposal cannot be offered here, a few recommendations for policy-makers and decision-makers shall be made.

First of all, as an overlying aspect on the energy policy agenda, the German government should bring in line the target values for onshore wind power expansion with scientific estimates for the required additions to meet the 65% target. Concretely, this means lifting the 2030 target for the installed capacity of onshore wind power from currently 67-71 GW to about 82 GW. Accordingly, the EEG's growth corridors need to be expanded, allowing for annual gross additions of 4.2 GW until 2030. While increasing the tendered capacity is an important step that provides investor confidence in the onshore wind power sector, it does not resolve the issues underlying the undersubscribed auctions. If planning and licensing barriers persist, developers will continue to lack the projects necessary for bidding. Resolving this will require designating enough areas for wind farms so that the tendered capacity can be built. For example, we could imagine a proportional requirement for a minimum of designated areas for wind farm development in Germany's states. This requirement could be linked to a timeline, specifying a deadline for when development plans have to be released.

At the same time, however, the available area should not be shrunk through universal distance policies that are unlikely to foster public acceptance. Instead, in order to address acceptability issues, the government should emphasise the overwhelming support for onshore wind power in the German population, stress the technology's essential role for the country's future energy system and try to pacify the minority of opponents. The latter may be achieved through more inclusive participation norms and the support of energy cooperatives outside of the auction scheme. However, we have seen that there are more pressing barriers to deployment than a lack of public acceptance. These regard the area conflicts that onshore wind power is drawn into over issues such as conservation, flight safety, monument protection and military concerns. A solution may be to legally grant wind farms a preferential status over other infrastructural projects due their essential role for climate action and the energy system. For flight safety issues, in particular, more conflicts could be avoided by decreasing the assessment radius for flight safety infrastructure to international standards. For conservation conflicts and the underlying 'green-green dilemma', an attempt may be to adjust the species protection law so that wind farms are acknowledged for their value to climate mitigation and nature conservation and thus prioritised over other infrastructures. While the energy transition of course needs to be in line with the goals of conservation, the former also needs to be acknowledged as prerequisite for the latter: Nature cannot be conserved without climate change mitigation. Granting legal exceptions for wind farms could allow the involved authorities and courts to weigh the long-term value of a large wind farm against the death of a single individual from a protected species.

While resolving conflicts during planning and licensing is important, avoiding procedural delays is essential too. This requires staffing and equipping the involved authorities accordingly so that their capabilities allow for swift procedural action. In certain cases, the bureaucratic framework will need to be reformed, so that, for example, development plans that are challenged can easily be adjusted and changed afterwards. Getting rid of these barriers can increase the number of projects that are planned and permitted successfully, so that enough exist to claim the tendered capacity. Further, dealing with lawsuits is important for dealing with undersubscription and allowing for timely implementation. While resolving the conflicts with conservation would help a lot in terms of lawsuits, we might also imagine a more general solution: A regulated timeline for legal objections against new wind farms with a final deadline, after which no new lawsuits may be filed. After a project has successfully passed such a process of legal vindication, it would be granted the legal security to proceed to the auction and be built without new legal challenges arising.

Beyond all these issues, it is also important to catch up on the lost projects from 2017's auctions. One solution could be to assess the share of projects that are not built by their implementation deadlines and to transfer this capacity back into the future tendered capacity. This would mean that every contract that is not realised is tendered again at a future auction. Lastly, there needs to be a solution for installed wind farms that lose their feed-in tariffs in the next decade. Certain planning and licensing exceptions will have to be thought of to allow the existing wind farms to be repowered with modern turbines. Until repowering is possible, governmental subsidies will to ensure the continued economic profitability of the installed capacity.

6.3. Limitations and future outlook

Finally, some limitations of this thesis and suggestions for future research shall be mentioned. One of this study's limitations is its method of data collection. As the dynamics of onshore wind power development in Germany are highly complex, a quantitative assessment of the effect of each barrier on growth was not feasible. This meant that, especially when there was no quantitative data available, this study's inferences about the impact of different barriers was heavily based on the interviews. While the interviewees bring in valuable personal experience, they are also subject to biases. Especially developers may bring in a more narrow perspective that is shaped by their everyday work experience in their home state. This is why it was considered important to also interview experts that could provide a broader perspective. Still, the possibility of biases distorting the analysis cannot be ruled out entirely.

The complexity of weighing the impacts of different barriers against one another also means that there remains some uncertainty. In terms of the undersubscribed auctions, for example, it is not entirely clear which barrier is obstructing participation most. While missing permits and lawsuits seem to be the primary causes, re-planning was brought up consistently as well. Future research may provide some clarity about the reasons behind non-participation by conducting a comprehensive survey of project developers in Germany. Another example, where it is difficult to ascertain the strength of each barrier's impact on deployment, has to do with 2017's auctions. For these contracted projects, it cannot be known with certainty whether missing permits or a lack of profitability prevented realisation. It could be that for many of these projects, due to a lack of profitability, permit applications were no longer pursued at some point. But it could also be that, even though developers were willing to implement these projects, they failed to be granted the permit. Distinguishing between these two factors may be interesting for future research.

Another important limitation was missing data. For example, there is no official data source tracking the number of permit applications for new wind farms over time. Determining whether this number has dropped in recent years was thus not possible. While many interviewees have suggested that there seems to have been a decline due to planning difficulties and a temporary drop due to the switch of the support scheme, these statements cannot be verified. Future research may want to survey German developers about their permitting activity in recent years. This is relevant because trends in the number of applications are essential for understanding the barriers behind missing permits. If the number of applications has never declined, we know that only licensing barriers are responsible for the lack of permits. If it has declined, we know that planning barriers are influential too. Another interesting question that could not be answered by existing data is to what extent citizens' initiatives against wind power and other wind energy critics disguise as conservationists in lawsuits. While the official data indicates that these critics are only responsible for a minority of lawsuits, several interviewees pointed to the common practice of critics leveraging on species protection law to further their own interests. Future research should look into this in order to clearly distinguish between the challenges of conservation and social acceptability in Germany.

Also, it should be mentioned that the consequences of the COVID-19 pandemic and the associated economic crisis could not be factored into the analysis of future barriers to onshore wind power in Germany. While the exact effects of this crisis cannot be estimated at this point, we may assume that the economic difficulties following the pandemic will be relevant challenge to the growth of onshore wind power in the immediate future.

Furthermore, while this study has primarily focused on specific barriers to deployment of onshore wind power in Germany, it has also described certain general challenges that lie behind these barriers such as area constraints and political resistance. It was beyond the scope of this study, however, to properly distinguish between the impact of different challenges. Consequently, there remains uncertainty as to which challenges are most important in explaining the struggles of onshore wind power in Germany. Are new wind farms mainly obstructed by a lack of area and the conflicts surrounding the available area? Or is it the increasing political resistance, which has translated into inaction – meaning that not enough area has been made available and that administrative barriers to deployment have accumulated over time? These questions clearly go beyond an investigation of concrete barriers to deployment such as lawsuits, procedural delays or flight safety restrictions. Instead, they could be addressed in future research as to attempt to carve out the underlying, more general challenges for German onshore wind power and distinguish between their relevance and impact.

Further, another agenda for future research could lie in testing the extent to which the challenges for German onshore wind power can be extrapolated to other transition contexts. Does onshore wind power have to face the same or similar challenges as it is moving through its advanced growth stages in other countries? May the lessons-learned from Germany's case be helpful in safeguarding wind energy transitions elsewhere? For example, we can imagine that the initial mistakes in the German auction scheme can serve as important lessons for policy-makers in other countries, which are switching to auctions. At the same time, it may be that the challenges for German onshore wind power only have limited application to other countries. Instead, they may vary with the social, economic and political context of the society, in which wind power is deployed. For example, it is reasonable to assume that onshore wind power thrives better in countries with a much less dense population and thus fewer area conflicts than Germany. Future research will need to look into this application of growth challenges to onshore wind power across different countries and contexts. Relatedly, there is also uncertainty about the extent to which the identified challenges apply to other renewable energy technologies than onshore wind power. For example, while it is plausible that cost efficiency is a universal concern for all renewables, the issue of diminishing social acceptability may be more relevant to onshore wind power than, for example, solar, due to its much larger impact on the landscape. Thus, a final recommendation is that future research investigates how growth challenges vary across different renewable energy technologies that are in their later stages of diffusion.

Despite these limitations, this thesis has been able to provide relevant insights both for onshore wind power in Germany and diffusing renewable energy technologies, in general. Firstly, German onshore wind power was identified as a technology moving through an advanced stage of growth. Secondly, the wind energy industry's growth expectations were analysed, explained and found to be largely justified. Current growth of onshore wind power in Germany is not only insufficient for the industry but also for the country's climate mitigation ambitions. Thirdly, a comprehensive account of the dynamics of onshore wind power development in Germany was offered, explaining the reasons behind the 2018/2019 slowdown in growth. Key barriers to deployment were identified and concrete starting points for reigniting the technology's growth in the country were laid out. The case of onshore wind power in Germany very well illustrates the limitations to the continued diffusion of renewables in their later stages of growth. It further demonstrates how the underlying growth challenges may vary across different stages of diffusion.

Overcoming these challenges will be essential for established renewable energy technologies if they are to continue to diffuse.

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Quentin, Jürgen. Advisor on Energy Economics and Policy, Fachagentur Windenergie and Land. Telephone interview, 25 March 2020.

Alex, Peter. Head of Investor and Public Relations, EnergieKontor. Telephone interview, 4 December 2019.

Müller, Eric. Head of Project Management and Planning, VSB Energy. Telephone interview, 9 April 2020.

Schmedding, Sabine. Energy Policy Expert, VDMA Power Systems. Former: Political Advisor, German Wind Energy Association (BWE). Telephone interview, 30 March 2020.

Schütte, Daniel. Head of Project Development, Energiequelle. Telephone interview, 1 April 2020.

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Berger, Lukas. Public Relations Manager, Company X. Telephone interview, 7 April 2020.

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8. Glossary

Contracted project
A wind farm that has received its contract from the auction and can go into implementation.

Decline
Understood as a long-term, persistent and steady decrease in growth.

Development plan
Either a regional or a municipal plan, which specifies the designated areas for onshore wind farm development. Serves as the planning basis for new wind farms.

Distance regulation
A legal requirement for a minimum distance from a wind turbine to a settlement.

Energy cooperative
An association of citizens that owns a renewable energy plant such as a wind farm.

Gross added capacity
The total capacity of newly installed wind farms for a given year.

Net added capacity
The total capacity of newly installed wind farms, subtracted by the capacity of removed wind farms for a given year.

Slowdown
Understood as a temporary decrease in growth

Transition projects
With the switch from feed-in tariffs to auctions, the regulator allowed for transition projects. These could still benefit from feed-in tariffs if they were permitted before 2017 and in operation before 2019.

Uncontracted projects
Wind farms that have not yet received their contract from the auction.

Underbidding
The practice of bidding at very low and maybe even unprofitable prices at the auction.

Undersubscription
Refers to the auctions: If auctions are undersubscribed, the tendered capacity is not claimed by the bid capacity. That means that the auction offers more contracts than bids are submitted for.

Unpermitted projects
Wind farms that have not yet been granted their permit, as required by the Federal Immission Protection Law (BImSchG).

Unrealised projects
Wind farms that are not yet in operation.

9. Appendix

Table 8 – Data on capacity and turbine growth in Germany

The table shows growth data for onshore wind power in Germany, both on capacity and turbine basis. Added capacity/turbines mean what is actually added, net added capacity/turbines specify the added capacity/turbines minus the removed capacity/turbines. There are inconsistencies across (not within) these data points since the method of counting new installations varies between sources. While one source counts a new installation once it has been built, the other counts it once it has been commissioned (which comes with a time delay). All data from: (BWE 2020a; BWE 2002; Quentin 2020d)

Year	Installed capacity	Installed turbines	Net added capacity	Added capacity	Added turbines	Added capacity/ added plants
1990	55	488	-	-	-	-
1991	106	769	51	-	-	-
1992	174	1028	68	183	1211	0.15
1993	326	1636	152	151	586	0.26
1994	618	2470	292	309	820	0.38
1995	1121	3540	503	505	1070	0.47
1996	1549	4346	428	428	806	0.53
1997	2089	5195	540	534	849	0.63
1998	2877	6205	788	794	1010	0.79
1999	4435	7881	1558	1568	1676	0.94
2000	6095	9359	1660	1665	1495	1.11
2001	8754	11438	2659	2659	2079	1.28
2002	12001	13759	3247	3247	2328	1.39
2003	14609	15387	2608	2645	1703	1.55
2004	16629	16543	2020	2037	1201	1.70
2005	18428	17574	1799	1808	1049	1.72
2006	20622	18685	2194	2233	1208	1.85
2007	22247	19460	1625	1667	883	1.89
2008	23903	20301	1656	1665	866	1.92
2009	25777	21164	1874	1857	940	1.98
2010	27190	21607	1413	1443	721	2.00
2011	29060	22297	1870	1977	889	2.22
2012	30989	23030	1929	2335	982	2.38
2013	33730	23645	2741	2997	1153	2.60
2014	38116	24867	4386	4639	1702	2.73
2015	41652	25980	3536	3804	1396	2.72
2016	45911	27270	4259	4440	1560	2.85
2017	50777	28675	4866	5498	1852	2.97
2018	52931	29213	2154	2464	762	3.23
2019	53912	29456	981	1078	325	3.40

Table 9 – Auction data for German onshore wind power

This table shows all relevant data trends for each of the auctions held for onshore wind power since 2017. Sources: (Quentin 2017a,b; Quentin 2018b-f; Quentin 2019c-g; Quentin 2020b,d)

		May 17	**Aug 17**	**Nov 17**	**Feb 18**	**May 18**	**Aug 18**	**Oct 18**	**Feb 19**	**May 19**	**Aug 19**	**Sep 19**	**Oct 19**	**Dec 19**	**Feb 20**
Permissible maximum price (ct/kWh)		7.00	7.00	7.00	6.30	6.30	6.30	6.30	6.20	6.20	6.20	6.20	6.20	6.20	6.20
Average bid price (ct/kWh)		5.82	4.64	4.02	4.90	5.48	6.11	6.17	6.04	6.12	6.20	6.20	6.20	6.11	6.18
Average premium price (ct/kWh)		5.71	4.28	3.82	4.73	5.73	6.16	6.26	6.11	6.13	6.20	6.19	6.20	6.11	6.18
Tendered capacity (MW)		800	1,000	1,000	700	670	670	670	700	650	650	500	675	500	900
Bid capacity (MW)	With permit	681	548	338	989	604	709	388	499	295	239	188	204	686	527
	Without permit	1,456	2,379	2,253	-	-	-	-	-	-	-	-	-	-	-
	Total	2,137	2,927	2,591	989	604	709	388	499	295	239	188	204	686	527
Permissible bid capacity (MW)		990	1,225	1,362	1,697	1,384	1,288	921	1,840	1,780	1,525	1,300	1,320	1,750	1,640
Contracted capacity (MW)	With permit	64	59	7	709	604	666	363	476	270	208	179	204	509	523
	Without permit	742	954	993	-	-	-	-	-	-	-	-	-	-	-
	Total	807	1,013	1,000	709	604	666	363	476	270	208	179	204	509	523
Contracted capacity for energy cooperatives (MW)		776	958	993	155	113	43	58	92	12	0	5	5	60	5
Non-participating capacity (MW)		-	-	-	708	780	579	533	1,341	1,485	1,286	1,112	1,116	1,064	1,113
Realised capacity (MW)		148	72	7	435	302	227	113	116	46	2	0	0	0	0