Economic Robustness of the On-Shore German Wind Energy Industry under Deep Uncertainty

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Executive Summary

Germany aims to compose 65 % of its electricity mix with renewable energy by 2030. Thus, it relies on on-shore wind energy as a source. This industry has experienced a significant turmoil from 2017 to 2019 as the newly installed capacity dropped by 80 % within these two years. The public discussion sees an increase in lawsuits caused by low public acceptance as the reason for this behaviour. Action is demanded in form of a simplification of the permitting process of the wind energy projects and an increase in public support mainly by involvement of the community adjacent to the planned wind park or increased distance between projects and habitants. Even though these are noble requests, calling public acceptance as the only reason for the decrease in installed capacity does not seem plausible. Interestingly, 2017 coincides with the adoption of a new subsidization scheme which includes a bidding process. Since wind energy projects are private investment projects, their finances are key to success. The aim of this study is to gain understanding about the reasons of the slump and develop an alternative hypothesis.

A literature review summarizes the legal, political, social, and technological landscape for on-shore wind energy. A detailed synthesis of public acceptance literature is performed and understanding of the financial dependencies and influences related to wind energy projects is gained. To support the reasoning, a model is constructed which simulates the income and expenses of wind energy projects. A participation in the bidding process is simulated including a detailed calculation of interest rates, an approximation of the impact of an increasing wind turbine population and an estimation of the development of the turbine maintenance sector.

The findings of this study are threefold. First, it summarizes in detail all financial aspects of on-shore wind energy projects. As a result, it is concluded that the maximum bid is set too low and the subsidization scheme is not adapted to the financial needs of a project. As a consequence, not enough sites are built even though they could technically be available, resulting in the slump. Secondly, with the current constrains of the bidding process, the on-shore wind energy sector will remain in a slump and the 2030 goal set by the German government cannot be reached as projected technological advancements have a small effect. The slump also forces the wind energy sector into a recession. Since any scenario of technological development cannot be relied on to counteract the slump, an adjustment of the subsidization scheme is needed. The most effective way to reach the objectives is to increase the maximum bid. Thirdly, it is argued that the public acceptance would have limited to no effect on the situation.

The German government has three options. Either, (I) the maximum bid is raised or (II) reversed to the old subsidization both implying higher costs than desired or (III) other renewable energy sources have to be supported and the on-shore wind energy sector will undergo major restructuring including possible job losses.

Preface

The energy transition is the challenge of the century and consequently of my generation's lifetime. Hearing that Germany could fail at this task due to a lack of public acceptance bothered me, but looking at the historical data, things did not add up. Thus, it was chosen to be the topic of this master thesis with the aim to better understand the problem.

Since the topic is happening right now by the time of writing this thesis and is situated in Germany, most of the sources of information are in German and taken from reports and news articles. However, this thesis does not require any skill in that language.

This document can be interesting for anyone who wants a detailed insight into the financial and technological properties of on-shore wind turbines in Germany. It also presents sound arguments of the connection and causal relationship between the said properties and the slump of on-shore wind park expansion. To make the most of this thesis, readers interested in the financials should focus on the sections 2.4, 2.5, 2.6 and chapter 3. The relationships are best described by the discussion in chapter 5. Happy reading!

Elias Modrakowski
Oldenburg, August 2020

Acknowledgment

What I have learned during this master thesis is the importance of a team for the realization of such a study. Challenging your thoughts and opinion and finding the limit is something that cannot be done by a single person, yet it is what ultimately makes a policy study more robust, more insightful, and simply better. I am glad to have taken the decision to join the *Master Engineering and Policy Analysis* at the TU Delft as I have found a profession I want to pursue but also friends that do exactly what I mentioned above. So, I want to say thank you to Fatima, Ingo and Katerina who made the last 2 years a joy despite the challenges that were given to us during that time. But in the end, these make you a better person.

I also want to say thank you to Sophie for her continuous and loving support and to my parents. Thank you two the team at the *Oldenburgische Landesbank* for providing me a place to write this thesis and giving me insights it the money supply for wind energy while even though a pandemic had the world firmly under control.

Elias Modrakowski
Oldenburg, August 2020

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Abbreviations

ABM	Agent-Based Modelling
BCBS	Basel Committee on Banking Supervision
BEG	Bürgerenergiegesellschaften (Citizen Energy Corporations)
BImSchG	Bundes-Immissionsschutzgesetz (Federal Immission Control Act)
EAD	Exposure At Default
EBA	European Banking Authority
EEG	Erneuerbare Energien Gesetz (Renewable Energy Sources Act)
IRBA	Internal Ratings-Based Approach
LGD	Loss Given Default
M	Maturity
MC/TM	Maintenance Companies/Turbine Manufacturers
MLP	Multi-Layer Perceptron
NIMBY	Not In My Backyard
O&M	Operation and Maintenance
PD	Probability of Default
SCADA	Supervisory Control and Data Acquisition
SD	System Dynamics
WEP	Wind Energy Project

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Introduction

1.1. Research Context

The German "Renewable Energy Sources Act" (abbreviated to EEG, from German "Erneurbare Energien Gesetz") (*EEG 2000* 2000) took effect in the year 2000 in consequence of the Kyoto protocol (BMWi, 2019; UNFCCC, 1997). The goal of this law is to reduce economic costs of energy supply, sparing fossil energy sources and promote the development of renewable energies. In the end, the national energy supply shall consist of at least 65 % of renewable energy by 2030 and 80 % by 2050 which is in line with the Paris agreement (Bundesregierung, 2019; BMWi, 2010). It does so by prioritizing electricity from renewable energy sources on the electricity market and warrants a fixed (and normally higher) sales price per kWh to renewable energy over several years. This resulted in a high interest of private investors and in a national energy mix share of 35 % renewable energy in 2018 and wind energy supplying more than half of it (Gude, 2019, p. 573).

It is safe to say that wind energy is, and will continue to be, playing a central role in the German energy transition. Germany has experienced a continuous increase in installed total power of wind energy amounting to 53,912 MW until the end of 2019 (Deutsche WindGuard, 2020). Alarmingly, the volume of newly build onshore wind energy dropped significantly since 2017, reaching only 287 MW in the first half of 2019 compared to over 5000 MW in the year 2017 (Deutsche WindGuard, 2019a). It is the lowest building rate since 2000. While the net increase in installed power improved to 981 MW until the end of 2019, it is still on a pre-EEG-level.

The reasons for the sharp drop are diverse and is subject to debate depending on perspective and interests. The *Federation of Wind Energy* (in German: "Bundesverband WindEnergie" (BWE)) representing the wind energy sector blames the federal government, claiming it is too strict on the minimal distance of wind turbines to houses decreasing the amount of potential sites, and other requirements. Also, an increasing number of lawsuits by homeowners, communities, and organizations are stated as a reason. They delay or may even stop the planning process of

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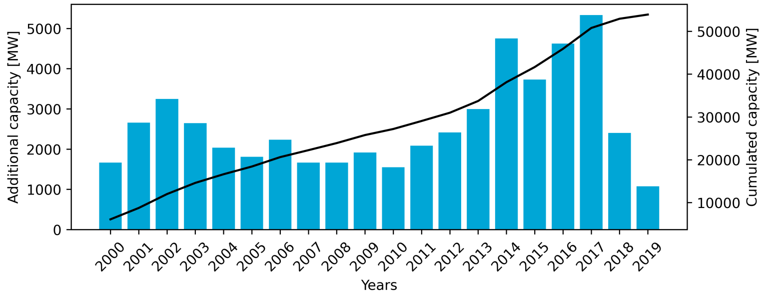

Figure 1.1: Plot of the cumulated on-shore wind energy capacity (left scale) and the yearly added capacity. Source: Bundesverband WindEnergie (2020c)

a wind park project (Bundesverband WindEnergie, 2019a). These lawsuits include environmental concerns, authorization procedures and simple "Not in my back yard" (NIMBY) complaints. Others say that the wind energy sector tries to avoid public participation to maximize profit (Zuber, 2019). It appears that different points of view collide, and no common consensus can be found to solve the problem.

Consequently, *Enercon*, one of the largest wind turbine manufacturers in Germany, recently announced to dismiss 3000 workers, which adds to the 40,000 lost jobs in the entire industry in the past two years (Bundesverband WindEnergie, 2019b). The company also plans to outsource some of its manufacturing to countries like India and China to reduce costs (Müller-Arnold, 2020). In April of 2019 the Hamburg-based turbine manufacturer *Senvion* filed for bankruptcy (Vakil, 2019). The BWE and the media call the situation "a crisis" (Bundesverband WindEnergie, 2019b; Buck, 2019; Balser and Bauchmüller, 2019).

Interestingly, while the new subsidization scheme in form of a bidding process was introduced on the 1^{st} of January 2017, the number of new wind energy project plummeted. While the highest number of wind turbines in the German renewable energy history have been commissioned in 2017, building a wind park takes time. With high certainty it can be assumed that most of these projects are subsidized with the older two-step process according to the EEG 2014. According to *EEG 17* (2016, § 22) it was allowed for wind park developers to do so, if their project passed the *Federal Immission Control Act* (BImSchG) until the 31^{st} December 2016. It seems that project developers speeded up the planning process to avoid the new system and take part in the biddings. In 2017 the participation was still high but then decreased rapidly (see Deutsche WindGuard, 2020, p. 8)).

The debate about the reason of the portrayed slump misses a discussion on the financial viability of wind energy projects with the current subsidization scheme, which may not be as negligible as believed. It is especially important as the German energy supply is private sector driven (Trend:Research and Leuphana University Lüneburg, 2013). It relies on private investment, from banks for instance, to push forward the transition from fossil to renewable energy sources. The technical uncertainty of turbine degradation, change of the environment, fluctuation in on-site wind and the competitiveness of conventional energy sources make investing in wind energy an endeavour with a small margin of error (Bomani, 2019; Kinias *et al.*, 2017). This situation might have worsened with the new bidding process. If now due to the stagnation, key corporations for the wind energy sector such as maintenance companies and turbine manufacturers have financial troubles, it would increase the risk of investment. Thus, borrowed capital becomes more expensive. This would be fatal as less investment means fewer wind park projects causing a recession of the sector, which would result in even fewer investments as the sector gets unattractive for investors. This reinforcing loop would bring the energy transition to a hold.

1.2. Research Objective and Questions

This study aims to address the reasons for a stagnation of the on-shore wind energy development from a financial point of view of these projects. The main research question is:

Under which conditions does the development of German on-shore wind energy stagnate due to financial limitations of wind energy projects caused by social, political and technical uncertainty?

In order to increase the understanding of each category they are described in the following.

Social factor All factors whose source is the public. Social acceptance and support can be reflected by (but are not limited to) lawsuits and participation in the financing as part of this category.

Political factor These are primary expressed as laws which are actively changed by politics. They define primarily the subsidies that are given to the wind energy project owner but also include requirements and restrictions during the planning phase which the wind parks must comply to.

Engineering factor As wind turbines are complex machines and their performance have a significant impact on the economy of their wind energy project, factors such as reliability are crucial for the business (Bress, 2017; Dao *et al.*, 2019; Walford, 2006). This category also includes meteorological circumstances. How these factors influence the economics is investigated.

As a guidance to answer the research question three sub-questions are answered over the course of the study.

Sub-question 1 *What social, political, and engineering factors impact the economy of a project owner at all?* — The answer to this question gives the starting point to the thesis. Using field and desk studies an overview is acquired which shapes the outcome to the following sub-questions.

Sub-question 2 *How do these influences affect the industry as a system?* — Contrary to the previous sub-question, this one looks beyond the individual wind energy project. It might be that some of the influences are the result or the cause of a systemic behaviour provoked by/provoking feedback loops in social, political, and/or economic landscape such as markets. It is important to understand the interconnectedness of the individual wind energy projects i.e. adopting a rather holistic world view.

Sub-question 3 *How should the future look like?* — Several studies have already been performed to understand what the future of energy and on-shore wind energy should look like. They are assessed in literature review to understand when the on-shore wind energy can be called "stagnated".

The aim of this thesis is not to assess the performance of renewable energy policy (e.g. Couture and Gagnon, 2010; Wiser and Pickle, 1998; Enzensberger *et al.*, 2002; Saidur, Islam, *et al.*, 2010) or investment risk evaluation studies like Gatzert and Vogl (2016) and X. Liu and Zeng (2017). It is rather a multi-disciplinary but finance-focused approach to gain understanding of the current situation in Germany and delivers an alternative hypothesis in contrast to the discussions in politics and the media. This study is unique by (1) linking the specific socio-political hurdles of wind energy projects with their finances and includes them into the bigger picture by (2) investigating the influence of uncertainties in the money supply for wind energy projects.

1.3. Thesis Outline

This thesis is divided into six chapters. While the first chapter is this introduction, chapter 2 addresses the theoretical groundwork containing a literature review of different disciplines that are relevant when answering the research question. Chapter 3 introduces a model to support the research question's answer with quantitative approach. Chapter 4 contains the simulations' results and they are discussed and set into the problem's context in chapter 5. Finally, chapter 6 summarizes the findings.

2

Theory

This chapter will lay the groundwork for this study gathering information. All sections will be explicitly or implicitly be divided into three parts: technical, social and political aspects. This follows the argumentation of Cherp *et al.* (2018) and Devine-Wright (2005) which is that the energy transition (which this topic is part of) and social acceptance of wind energy respectively are multi-disciplinary and need to be handled as such. Cherp *et al.* (2018) suggests adapting a political perspective, a socio-technical perspective, and a techno-economic perspective which are in analogy to the above mentioned three parts. The naming is just simplified.

First, section 2.1 provides an introduction to the legislative landscape. Mainly, the EEG is described. Next, section 2.2 shows the current situation of on-shore wind energy in Germany in detail. As public acceptance is key to the success of a wind energy project, section 2.3 is a literature review on that topic. In continuation the sub questions are answered. While section 2.4 describes the influences on the economy of a project owner, section 2.5 answers the question about which influences affect the industry as a system and section 2.6 describes possible future scenarios.

2.1. German Renewable Energy subsidization

EEG stands for "Erneuerbare-Energien-Gesetz" (in English "Renewable-Energy-Act") and was first introduced March, 29^{th} of 2000 (see *EEG 2000* 2000) and is a series of acts with the aim to facilitate a sustainable development of the energy supply on behalf of climate and environmental protection (*EEG 2000* 2000, § 1). Regarding on-shore wind energy, it is the central piece of legislation as it secures feed-in priority, subsidies and price stability for these projects. Since 2000, it has been updated five times (2004, 2009, 2012, 2014 and 2017) with EEG 17 being the latest version (see *EEG 17* 2016). The EEG 17 introduced a bidding procedure in order to determine the amount of subsidy in contrast to feed-in tariffs set by the government. It also sets the government's goals for the future: in the year 2025 40 to 45 % of the gross electricity usage should be covered by renewable energy, in 2035 55 to 60 % and in 2050 at least 80 % (*EEG 17* 2016, § 1). This has been increased to 65 % in 2030 with the latest coalition agreement.

Renewable energy sources that fall under the EEG must be integrated into the energy system including direct marketing (*EEG 17* 2016, § 2), what implicates every facility that is on national territory (with some exceptions) (*EEG 17* 2016, § 4). In addition, they can be subsidised. There are two ways to be subsidised: (1) via premiums and (2) via compensations (only when the installed power is smaller than 100 kW) (*EEG 17* 2016, §§ 19 and 21). As the latter option is mostly for private investors, this section will from now on focus on the premiums which are calculated using a bidding procedure.

To participate in the bidding, wind energy projects need to be approved by the authorities in two steps. Wind energy projects can only be built on designated priority areas on the regional planning level and in concentration zones on the land use planning level (TU Berlin, 2012). Local authorities can therefore steer where in their community wind energy projects can be developed. Wind energy developers need to find these areas that meet the law[1] and have enough wind to their disposal. For the second phase, projects must obey the "Bundes-Immissionsschutzgesetz" (BImSG, in English "Federal Immission Control Act"). The core of this step is an environmental impact assessment. In addition, public involvement is required by this law (see FA Wind, 2020). Project developers are required to show this permission (*EEG 17* 2016, § 36).

If a wind energy project has the permission by the authorities, they can take part in a bidding process according to *EEG 17* (2016, § 32). They must primarily submit the nominal power of the project, a security based on it of 30 €/kW and their offer which should be lower or equal a "maximum bid". The security is meant to cover contractual penalties and the offer is the price per kWh of electricity they are willing to produce at a reference site *EEG 17* (2016, § 30). The term "reference cite" will be explained later. If the sum of nominal power of all participating projects is smaller than a predefined volume (see *EEG 17* 2016, § 28), all projects will get accepted. From 2020 onwards there are two bidding rounds. The volume on the 1^{st} of February is 1000 MW; on the 1^{st} of June and 1^{st} of October it is 950 MW. In case, there are more projects than volume, the projects with the lowest offers will get accepted until the volume is reached (*EEG 17* 2016, § 32). There is a ceiling to the permitted offers: they are limited to being 8 % higher as the average of the highest accepted bid of the last three biddings (*EEG 17* 2016, § 36b).

The reference site describes a fictional site with certain meteorological properties. These are an average Rayleigh-distributed wind speed of 6.45,m/s at 100 m height, a Hellmann exponent of 0.25 and a roughness of 0.1 m (*EEG 17* 2016, Appendix 2). In case a project gets accepted, the government assures to pay the difference between market value and the bid times a correction value as given in table 2.1 (*EEG 17* 2016, §§ 20 and 36h). The government will pay this offset for the next 20 years (*EEG 17* 2016, § 25), except if the market value for electricity at

[1] Baugesetzbuch (Federal Building Code); Baunutzungsverordnung (Federal Land Utilisation Ordinance); Raumordnung (Regional planning)

the European Power Exchange is negative for six consecutive hours. In that case, it will be reduced to 0 €. The quality factor which the correction factor is a function of (see table 2.1), is the actual energy production of the wind energy project divided by the nominal energy production at the reference site. The "actual energy production" is first based on the calculated value and is later (in the 6th, 11th and 16th year) adjusted to the actual energy production (*EEG 17* 2016, § 36h). This whole procedure makes the bids comparable to each other and gives an advantage to lower-grade sites.

Table 2.1: Quality factor and correction factor to calculate the compensation according to *EEG 17* (2016, § 36h).

Quality factor / %	70	80	90	100	110	120	130	140	150
Correction factor	1.29	1.16	1.07	1.00	0.94	0.89	0.85	0.81	0.79

The *EEG 17* (2016, § 55) also describes what happens in the case of a delayed commissioning. If a developer withdraws the accepted bid, at least 5 % of the original bid is cancelled or if after 24 month the project has not yet been commissioned, a fine of 10 €/kW, 20 €/kW and 30 €/kW have to be paid at the end of the 24th, 26th and 28th month after the acceptance respectively.

As a mechanism to increase public acceptance, there is a special form of wind energy project developers called "Bürgerenergiegesellschaften" (BEG, in English "citizen energy corporations"). This is given, if the project owner is composed by at least 10 persons, not less than 51 % of the voting rights are owned by persons that live in the community in which the wind energy project is planned to be build and nobody should have more than 10 % of the voting rights (*EEG 17* 2016, § 3). The will be granted the following perks: an offer can be submitted before they have obtained a permission according to the BImSG and only have paid 50 % of the security. The permission and the remaining security must be handed in two months after an acceptance of their offer. In addition, BEGs have 48 month time to commission their project before the fines are applied.

2.2. Current situation

This section focuses on the current situation of the system. The aim is to give the reader an overview on what and where the discussion is currently at. In other words, setting the socio-political and technical context as in contrast to section 2.1 which gave the legislative setting.

2.2.1. Politics

Climate change is currently a highly politically active topic and the energy and transport sector being part of it as well. A short introduction and the political positioning towards wind energy of every German party can be found in Appendix A. It is limited to the parties that currently are in the parliament. An emergence of new parties or entering of new ones into the parliament during the next legislation is currently not anticipated (Infratest dimap, 2020) and will not be discussed in this thesis.

At federal level, the Federal Government composed by the CDU and SPD (see Appendix A.1 and A.2 respectively) represent the mixed position of both parties: "Whoever wants the exit fission energy needs to say yes to an extension of the electricity grid and wind energy plants. Merkel refers to the Federal Government's intention to accelerate and facilitate the planning [of wind energy projects] as well as improve the energy efficiency [...]. Wind energy on-shore and off-shore shall be the centre of the energy transition" (Bundesregierung, 2011, translated from German). This position has not changed since 2011 but has been substantiated as the official website states "To accelerate the expansion of wind power, the German government is to take swift steps to modify provisions of environmental and conservation law and air safety regulations that stand in the way. New regulations on the distance between wind turbines and adjacent buildings are to increase acceptance for wind power, along with new financial advantages for local authorities within which wind turbines are erected." (Bundesregierung, 2019).

The issue of not enough wind energy projects being commissioned is a well-known problem by the government and the root cause is believed to be the missing potential sites and the local acceptance. There is no official statement for this conclusion, but it is in line with the current situation painted by the parties and pro-wind lobbyists (Bundesregierung, 2019; Bundesverband WindEnergie, 2019a; Bundesverband WindEnergie, 2019b). Currently, there are two factions regarding how the local acceptance can be increased. One side states, including CDU (Appendix A.1) and FDP (Appendix A.3), that an increase in distance between settlements and the wind turbines is beneficial. The other composed of SPD (Appendix A.2), Grünen/Bündnis 90 (Appendix A.4) and die Linke (Appendix A.6) wants to increase public participation/inclusion. The right-wring party AfD is against wind energy in general and prefers a stop of wind energy project construction in the first place (Appendix A.5).

2.2.2. Society

When electricity was invented, everybody was glad to have overcome the uncertainty of the windmill age.

Dreyer (2020) – translated from German

At first glance, there is currently a paradoxical development going on in Germany. According to FA Wind (2019), 82 % of citizens think that wind energy is important or very important, 78 % living nearby a wind park are okay with them and 70 % of interviewees not living nearby a wind park would not mind a new one in their area. At the same time, a significant part of wind power (1010 MW in the second quarter of 2019) is not commissioned due to lawsuits (Quentin, 2019). Most of these lawsuits are caused by environmental protection infringements, formal errors in the permit application and health concerns what matches with the category of claimants (including combinations): 3 out of 5 claims come from environmental organisations, 36 % are private persons and 14 % are citizens' initiatives (Quentin, 2019).

In general the further south in Germany a wind park is planned to be build, the higher the chances are that they will get legally challenged as there the number of defendant cases compared to the number of planned wind turbines is as high as 42 % (Balvaria) (compare with Quentin, 2019; Hentschel, 2017). Interestingly, this share does not correlate with the population density of a federal state (see figure 2.1). The higher the population density the more likely it is to have population close to the planned wind energy site.

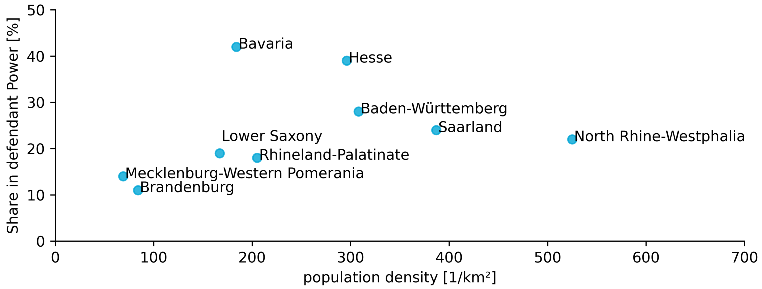

Figure 2.1: Plot of the share of defendant power to total planned power over the population density of the federal state. Sources: Quentin (2019) and Gude (2019)

While it is obvious that the environmental organisations target nature protection matters, the reasons why private persons and citizens' initiatives are more diverse. The biggest initiatives are *Vernunftkraft*[2] and *Windwahn*[3]. Windwahn (2020b) lists 1120 anti-wind energy initiatives and organizations. Their arguments can mostly be categorized in one of the following topics:

Health concerns Wind turbines produce infrasound and constant flickering from the movement and the shadow of wind turbines which contribute to health risk (e.g. Hübner, 2019). However, this is highly debated.

Environmental risks Besides being dangerous to birds getting hit by the blades they cause deforestation during construction (e.g. Windwahn, 2012).

Insecurity of energy supply Wind energy is too unsecure, and the benefits do not outweigh the risks (e.g. Verein Mensch Natur, 2020).

What has to be mentioned is the abundance of statements in news articles about exclusion of the public, lobbying and a general "we are against *them*" which has its root in insufficient involvement (Eberts, 2019; LN Online, 2020; PZ-news,

[2] www.vernunftkraft.de
[3] www.windwahn.com

2020, as a selection). There are stories where residents have not been notified of constructions on short notice (e.g. Witsch, 2019).

Zuber (2019) suggests as a reason that developers don't want to share their returns with others: "Inclusion of the public is for a lot of them [wind energy companies] still more a burden rather than a desire" (translated from German).

2

2.2.3. Engineering

Mechanical design

Since wind turbines have been first connected to the power grid in the 1980s, their layout has fundamentally changed as technological development moved on (Gasch and Twele, 2016, p. 466). They evolved from machines that generated between 30 and 450 KW and which needed a motor to spin up and two generators to hold the European grid frequency at varying wind speeds (Gasch and Twele, 2016, p. 466) to high-tech multi-MW-turbines which can be operated by remote control. All turbines face the issue of having a variable and low revolution, high torque, mechanical input from the blades and need to transform that in a constant 50 Hz alternating current. In addition, the solution to this problem needs to be compact and reliable as possible as it is situated in the nacelle of a turbine more than 100 m above ground. Turbine manufacturers can approach this in two different ways: in an integrated design or in a modular design (Gasch and Twele, 2016, p. 75). The latter is used by GE Wind[4], Vestas[5] or Goldwind[6] and consists of the rotor being connected via an axle to a gearbox which is then connected again with another axle to an "off-the-shelf" generator what allows an easy swap of the generator or the gearbox without having to dismount the rotor (Gasch and Twele, 2016, p. 77). This reduces the cost of having specialised components within the turbine but increases the system complexity as their number is higher. Alternatively, an integrated design as Enercon[7] is using, can reduce the number of pieces within the nacelle by avoiding e.g. the gearbox what makes it easier to build a more compact nacelle (reducing the cost of transport and installation) but these parts are especially designed for that turbine and cannot be easily dismounted without disassembling the entire nacelle (Gasch and Twele, 2016, p. 77).

Unexpected failures can be avoided with regular maintenance (Walford, 2006). All modern wind turbines have a Supervisory Control and Data Acquisition (SCADA) system which allows a remote check of the status of the turbine (e.g. with vibration sensors) but also visual on-site checks are done regularly. For this, wind energy project owners can close a contract with either a third-party company (like *Enova*[8], *reetec*[9] or *Deutsche WindGuard*[10]) or with the turbine manufacturer them-

[4] www.ge.com/renewableenergy
[5] www.vestas.com
[6] www.goldwindglobal.com
[7] www.enercon.de/en/home
[8] www.enovaservice.de
[9] www.reetec.eu
[10] www.windguard.com

selves (*Enercon*[11] and *Vestas*[12]) which bring the knowledge, infrastructure for the maintenance of a wind park and in some cases guarantee a minimum availability.

Situation of the wind energy generation

On the 31.12.2019, there were 29,456 turbines installed in Germany with a total capacity of 53,912 MW (Deutsche WindGuard, 2020) (see figure 1.1). 325 turbines (1078 MW of installed capacity) of these were installed in the year 2019 what is an increase in 2 % and 80 % lower than the record year of 2017 (Deutsche WindGuard, 2020).

41 % of the installed capacity is situated in the federal states with access to the sea namely Lower Saxony, Mecklenburg-Vorpommern and Schleswig-Holstein and only 15 % are in the South (Rhineland-Palastinate, Bavaria, Baden-Württemberg and Saarland) (Deutsche WindGuard, 2020). The average newly installed turbine can produce 3.3 MW, has a rotor diameter of 119 m and a nacelle height of 133 m (Deutsche WindGuard, 2020). Regarding the biddings (see section 2.1) in 2019, only in one out of six rounds the target capacity could be meet with 1845 MW being accepted instead of the aimed 3675 MW (Deutsche WindGuard, 2020).

The cost of wind energy

As every technology, wind energy has its positive and negative impacts. Saidur, Rahim, *et al.* (2011) states three advantages of wind energy in comparison to other energy producing technologies: the low impact on the habitat compared to other energy sources, the reduced of water consumption and carbon dioxide emissions. Other than coal, natural gas, oil, nuclear or hydropower, wind energy only has an impact on the site where it is located during the construction of the plant while the other produce waste, require mining or flooding of land or pollute air and water.

On the downside, they do however have an impact on the wildlife like bird strikes. There are no reliable data on this topic and the pro-wind-energy-faction relativizes the impact by comparing it to hunting, cats, windows, or vehicles (including Saidur, Rahim, *et al.* (2011)). The surrounding of wind parks does suffer from noise impact and visual impact. These aspects are intensified by the high number of plants and their decentralised arrangement.

2.3. Theory of Public Acceptance

Over the course of the last one and a half decades some important studies have been made regarding the social acceptance of wind energy in a variety of countries. In this section, they are reviewed and compared with the findings about the current social situation in Germany from section 2.2.

2.3.1. Definition

First, it has to be defined what acceptance is and what kind of acceptance is crucial currently for the success of wind energy parks. Batel *et al.* (2013) performed a

[11] www.enercon.de/en/dienstleistungsportfolio/service/
[12] www.availon.eu/en/service-vestas

literature synthesise on the difference between acceptance and support. While both imply agreement with something, acceptance takes a passive standpoint and support an active: "We can consider that while 'acceptance' seems to involve a reaction *to* something–external–and one which is mainly characterized by passivity and non-decision, *support* seems more clearly to be action-oriented [...], to imply agency *for* and engagement with something" (Batel *et al.*, 2013).

Wüstenhagen *et al.* (2007) differs between three types of acceptance:

Market acceptance The technology needs to be accepted by the producers and consumers as being a possible alternative and being usable. As this mainly relevant for innovations in the process of adoption, it has been done in the 1990s for wind energy.

Socio-political is the acceptance on the highest level of society. In this case a big portion of the German public does support wind energy (Quentin, 2019).

Community "Community acceptance refers to the specific acceptance of siting decisions and renewable energy projects by local stakeholders, particularly residents and local authorities" (Wüstenhagen *et al.*, 2007). Regarding the wind energy situation in Germany, this is one of the crucial factors.

The first and second type of acceptance are already given in the case of wind energy in Germany. A concept that needs an introduction is the "social gap" which describes "the high support for wind energy reported in surveys and the low success rate for wind farm applications" (Bell, Gray, Haggett, and Swaffield, 2013). Bell, Gray, and Haggett (2005) sees the "Democratic Deficit" as an explanation for the social gap because "particular wind power development decisions are controlled by the minority who oppose wind power". In other words, only a small number of people are required to influence the permitting process significantly. Wind energy projects can be rejected by the "community", even though the local majority accepts the proposal but stays inactive (Jones and Eiser, 2009).

2.3.2. Influences on Acceptance

There are a multitude of factors that influence community acceptance. Zaunbrecher and Ziefle (2016) gives a literature overview of the main acceptance factors based on Devine-Wright (2005) and Graham *et al.* (2009). It contains physical appearance, context and landscape (distance, visibility, etc.), environment, economic reasons, health, social reasons, decision-making & stakeholders, demographics, ethics & values, and symbolism. It shows that the reasons are extremely diverse including social, environmental, technical, and political aspects. Other authors have pointed out broader categories: Jobert *et al.* (2007) states that "local acceptance is influences by both planning rules and local factors" and Langer *et al.* (2018) gives four relevant factors: process related variables, personal characteristics, perceived side effects and technical, and geographical issues.

This abundance of factors makes it difficult to isolate the causes. As an example, when investors and facility owners are community outsiders, trust in their aims, attitude and competence becomes an issue Wüstenhagen *et al.* (2007). Comparing it to Zaunbrecher and Ziefle's (2016) categories, the simple fact that the project management is foreign can trigger economic reasons, social reasons, decision-making & stakeholder and ethics & values factors.

The distance between the households in the community and the wind park have been found to no have any major effect on the acceptance (van der Horst, 2007; Graham *et al.*, 2009).

2.3.3. Stages of Opposition

According to Wolsink (2007) there are four types of opposition: (I) the technology itself is accepted in principle but local objection based upon narrowly self-interested concern for personal utility (called NIMBYism and seen as an "individual gap" by Bell, Gray, Haggett, and Swaffield (2013)); (II) a general rejection of the proposed technology; (III) a negative general attitude which follows discussions about a specific local project; and (IV) acceptance of the technology itself but an opposition to a specific case due to perceived weaknesses with the proposal. The NIMBY idea suggests that people have positive attitudes towards something (e.g. wind power) until they are actually confronted with it, at which point they oppose it for selfish reasons (see O'Hare (1977) as found in Wolsink (2007)). Bell, Gray, Haggett, and Swaffield (2013) argues that NIMBYism contributes to just a very small percentage of resistance and that the reasons for opposition are much more complex. This is supported by the Wolsink (2007).

A feature of community acceptance is that it has a time dimension (Wüstenhagen *et al.*, 2007; Wolsink, 2007). Cowell *et al.* (2011) argues that by the time a wind energy project has been completed, the community finds ways to accept the situation and no longer resists the project. Cowell *et al.* refers to (Parkhill *et al.*, 2010) for that conclusion. While Parkhill *et al.* (2010) studied this effect in relation to nuclear power plants, it does not matter if a hazard is "real" (nuclear disaster) or debated (infrasound, etc.), if it is in the heads of the people. Therefore, the findings of (Parkhill *et al.*, 2010) can be applied.

Gaining acceptance by inclusion of the community does work (Scherhaufer *et al.*, 2018) but is bounded to all kinds of boundary conditions (see Cowell *et al.*, 2011). For example, "community"–led schemes (like the "Bürgerwindpark" in Germany) may be as controversial in the local community as developments proposed by multinational energy companies (Bell, Gray, Haggett, and Swaffield (2013) referring to G. Walker *et al.* (2010)).

2.4. Economic Influences on Projects

This section addresses the first sub-question *What social, political, and engineering factors impact the economy of a project owner at all?* It will be answered from a financial point of view and consists mainly of the income and spending such a wind energy project experiences over its life time. This question does not include the reasons why a developer chooses a site in the first place. European Wind Energy Association (2009, p. 8) states the around 75 % of the total cost of energy for a wind turbine is related to the planning and construction work. Wind energy is "capital-intensive" (European Wind Energy Association, 2009).

European Wind Energy Association (2009, p. 29) determined the key elements of basic costs of wind energy to be (I) upfront investment costs, (II) the costs of wind turbine installation, (III) the cost of capital, (IV) operation and maintenance (O&M) costs, (V) other project development and planning costs, (VI) turbine lifetime, and (VII) electricity production, the resource base and energy losses. These factors can easily be divided into two parts: pre-commission and post-commission. This is done in the following for a organization of this section.

2.4.1. Pre-Commission Influences

Deutsche WindGuard (2019b, p. 64) divides it furthermore into primary investment costs and secondary investment costs. While the previous comes from the turbine itself and its transportation and construction costs, the latter consists of planning, the foundation and infrastructure.

The specific primary investment costs per kW of nominal power varies heavily with the nominal power itself, the hub height and specific power density as it can be seen in figure 2.2. As an example, an *Enercon E-53*[13] with 800 kW of nominal power and 53 m hub height would cost around 656,000 € (820 €/kW) while an *Enercon E-160 EP5*[14] with a generator at 160 m capable of 4.6 MW costs around 5 Mio. € (1090 €/kW) according to the data (Deutsche WindGuard, 2019b, p. 71). While the specific primary costs have been reducing over the years, the movement to bigger turbines has counteracted this trend on a per turbine base (Deutsche WindGuard, 2019b, p. 74).

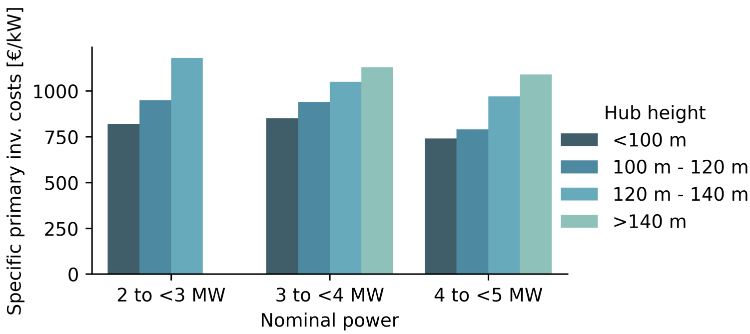

Figure 2.2: Specific primary investment costs. Source: (Deutsche WindGuard, 2019b, p. 71)

Regarding secondary investment costs the trend over the years has been mixed but tending to increase over the years from 329 €/kW between 2014 and 2016 to 406 €/kW in 2019 and 2020 (Deutsche WindGuard, 2019b, p. 77f). While the grid connection cost has decreased over the years and the foundation costs as much per kW as in 1998, the planning costs have increased in the last years signifi-

[13] www.enercon.de/produkte/ep-1/e-53/

[14] www.enercon.de/produkte/ep-5/e-160-ep5/

cantly Deutsche WindGuard (2019b, p. 80). The associated costs to the latter have doubled since 2014. The reason for this increase have been stated as to be the participation in biddings and an increment in lawsuits (Quentin, 2019, p. 11). These lawsuits are a major problem from a financial side as the average delay is about 2 years (Quentin, 2019, p. 11). During that time, labour costs need to be paid as well as legal fees. In addition, any return on capital that is already invested/gets invested is lost. If the appeals succeed, parts of the project need to be altered. In the worst case, the construction of the wind park is prohibited, and all investment is lost. Such a financial hit can be tolerated by bigger companies but not by private owners. As a consequence, lawsuits (and consequently the public acceptance) are a significant influence.

Many wind parks are project financed what means that their funding is bound to their cash-flow and not the company that tries to build it (Böttcher, 2019, p. 11). That is why they fall under the realm of specialised lending (see Appendix B). For small and medium sized projects the financing is done by banks. For bigger parks with hundreds of wind turbines other ways of financing such as private equity needs to be found. However, Germany is a densely populated and big parks are uncommon.

2.4.2. Wind Turbine Reliability

A wind turbine's reliability is crucial for the economics of wind energy as they are a main driver for the operating and maintenance costs (Bress, 2017; Dao *et al.*, 2019; Walford, 2006). It is also affecting the acceptance of the project by both the "financial and developer communities as a viable enterprise" (Walford, 2006).

There are numerous ways to define reliability. One is "The ability of a system or component to perform its required functions under stated conditions for a specified period of time" (IEEE, 1991). They are usually expressed as a probability. Wind turbine components as other electrical or mechanical devices fail over time. The probability of them failing follows a bathtub shaped probability distribution as shown in figure 2.3 (Rigdon and Basu, 2000; Tavner *et al.*, 2007). According to these authors, the probability of failure of a component can be expressed as the superposition of "Infant mortality" which decreases and "End of Life Wear-Out" which increases over time. Thus, wind turbine components are most probable to fail at the beginning and at the end of their life.

As argued in Tavner *et al.* (2007), an increase in failures at the end of a turbine's life will most likely not be encountered in reality as the will be taken out of service when such a behaviour is noticed. A counter-argument to Tavner *et al.*'s (2007) theory would be that this increase in probability of failure is either observed by maintenance or actual failure. Therefore, for modelling that increase is relevant. If it is important for this model, will be determined in chapter 3.

Unfortunately, reliability data is difficult to collect and work with as there is no "uniform method for deciding what data to collect, how to collect it, and how to record it" (Bress, 2017). Bress (2017) also mentions that comparison and quality of the results are sub-optimal as failures can appear due to all kinds of reasons that might not be stated in the databases and because of the rapid evolving technologies,

Figure 2.3: Schematic failure probability over time (adapted from Tavner *et al.* (2007))

most of the results will be outdated by the time they are "reliable". The possibility to extrapolate the data to newer technology-based machines is questionable (Walford, 2006). In addition, not all information that is needed is available as it is up to the operators to publish it (Bress, 2017). It is unattractive to them to do so because it is bad advertising for both the operator and the manufacturer. Similar disadvantages were found recently by Dao *et al.* (2019) which compared 14 reliability data sources. Studies such as Kusiak and Li (2011) and Reder *et al.* (2016) try to minimize these drawbacks.

Reliability of wind turbines is usually broken down in its sub-systems (as in Tavner *et al.*, 2007; Tazi *et al.*, 2017; Dao *et al.*, 2019) which are the ones as listed in section 2.2.3. Scholars commonly agree that gearboxes and rotor-blades are the most critical sub-systems in a wind turbine while electrical sub-systems are the ones with the highest failure rate (Tazi *et al.*, 2017; Dao *et al.*, 2019; Tavner *et al.*, 2007; Spinato *et al.*, 2009, and more). These studies can also show dropping failure rates over time what reproduces the bathtub model as mentioned above (Tavner *et al.*, 2007). Wear is the main and most common cause of failure for wind turbines (Tazi *et al.*, 2017).

Counter-intuitively, wind turbines without a gearbox are not necessarily more reliable (Tavner *et al.*, 2007; Spinato *et al.*, 2009). Even though their missing one of the most critical components, it is possible to build them modularly (Gasch and Twele, 2016, p. 75ff) what makes swapping faulty components much faster and cost efficient. Direct-drive (gearless) variants are integrated and a generator failure means the decomposition of almost the entire turbine. In addition, geared wind turbines can use more standardized components (high-speed generators, etc.) what allows saving cost as they are off-the-shelf components (Polinder *et al.*, 2006). Nevertheless, electrical related failures have a lower downtime than mechanical failures (Spinato *et al.*, 2009; Tavner *et al.*, 2007; Dao *et al.*, 2019). Concluding, from academic studies it is not possible to determine the most reliable turbine concepts. It makes sense as all concepts are successfully used on the market.

2.4.3. Post-Commission Influences

Lawsuits after a wind park's construction and commission are unlikely, yet Quentin (2019, p. 9) has found that 30 % of defendant wind energy projects are already commissioned in Q2 of 2019.

Regarding the recurring expenses, According to European Wind Energy Association (2009, p. 45) O&M costs consists mainly by insurance, regular maintenance, repairs, spare parts, and administration. This has changed since 2009 since nowadays most wind energy project owners have signed a full-service contract which include all repairs and spare parts in case needed (Bundesverband WindEnergie, 2020a). Full-service contracts even provide compensations in case of downtimes above a certain threshold eliminating the concerns of reliability described in the previous section altogether for the project owner. Thus, in a more recent study, maintenance and repairs are included into one parameter and adds savings for decommissioning (Quentin, 2019, p. 11). Of course, both the foreign and equity capital must be paid back regularly as well. The average cost for this type of O&M has reduced significantly over the last years. While in the years 2014 to 2016 operators had to pay for maintenance 18 €/kW and 29 €/kW in the first and second decade of operation respectively, it reduced to 13 €/kW and 21 €/kW (Quentin, 2019, p. 83). The author justifies this decrease with the increase cost pressure due to the bidding process. But also, it is most likely that maintenance work does not scale linearly with the increasing average turbine power.

The decommissioning has become an ever more important topic as the first turbines commissioned under the EEG in 2000 finish their subsidization period in 2020. Especially the turbine blades which are built from composite or carbon fibre reinforced materials are difficult to process and the current capacities in Germany are insufficient (Umweltbundesamt, 2019; Knight, 2020). Recycling one rotor blade costs around 3000 € which is a reason why it has become ever more popular to sell the turbines abroad (Beutler, 2020). Since it is expected that the wind turbine waste will increase significantly over the next years and decades (P. Liu and Barlow, 2017), the costs of decommission can be expected to be a major cost factor in the future.

Regarding the income, the primary uncertainty of the cash-flow is the variability of wind. Watson (2014) estimates a variation in energy output between years of 15 %. A not neglectable reduction in electric yield compared to the theoretical output comes from array losses/park effects, rotor blade soiling losses, grid losses and machine downtime (European Wind Energy Association, 2009, p. 55). Turbines in a wind park cast "wind shadows" and other turbines that are positioned behind them. The downtime is covered in increasing occurrences by the maintenance contract which provides a maximum downtime agreement.

2.5. Inter-Sectoral Influences

While in the previous section 2.4 factors that influence a wind energy project directly, the following one discusses elements that are of a broader scale and cannot be triggered by a single project but through the organisation of multiple but the outcomes do affect every single project individually. The following aspects are not exhaustive but have been found to be the most relevant for this study.

2.5.1. Financial Fitness of Maintenance Companies

Turbine manufacturers and maintenance companies form a central part of the wind energy sector. It is safe to say that every wind park is maintained professionally. Otherwise extended downtimes are more likely which is not acceptable for an investment that solely relies on income generated when being operational.

Turbine builders and maintenance companies depend on a big number of WEPs in their portfolio to remain in business. Service contracts for wind parks have been shown to be more profitable compared to the construction. *Vestas* made 1.743 billion € of revenue in Q1 2020 with an EBIT margin of -6.6 % while the service offer made 474 million € of revenue but with a 26.2 % EBIT margin effectively making more profit (Vestas Wind Systems A/S, 2020a). This negative margin is caused by "lower average project margins where logistical challenges and supply chain bottlenecks, commissioning of delayed projects from 2019, and the COVID-19 situation increased cost levels" (Vestas Wind Systems A/S, 2020a). The wind energy sector has shifted from a turbine market to a service market where "margins for services are reportedly above 20 % while margins for turbine supply are below 10 % [...]. However, the latest data shows this gap is narrowing" (New Energy Update, 2019). There are also differences between the manufacturers' EBITDA margin as found by Lacal-Arántegui (2019). In 2016, *Enercon*, *Nordex*, *Siemens* and *Senvion* profit margin as lower than 10 % while *Vestas*, *Goldwind*, *Gamesa* and *Suzlon* achieved between 16 % and 19 % (Lacal-Arántegui, 2019). In general, higher profit margin indicate that a company is more capable to reduce prices to stay competitive and to cover their fix costs even with a smaller portfolio.

As stated in the introduction of this study, some these companies have already started to reduce their costs by laying off workers and sell portion of their assets for restructuring purposes. The question which has evolved from the high dependence of wind energy projects on their maintenance companies is, in the case the contractor goes bankrupt, what would be the response of the wind project owner? The answer is twofold. If it is "just" a third-party company, they would most likely switch to the next one. If it is the manufacturer of the wind turbine which also would supplies spare parts, the situation is more difficult. Some wind turbines are built using off-the-shelf components, but others are more specialized.

In the case of the insolvency of *Senvion* in 2019 (Vakil, 2019), the company was not able to sell their business at once. However, *Siemens Gamesa* bought the European maintenance service for on-shore wind turbine and intellectual property (Siemens Gamesa, 2020). This indicates that it is possible that with the bankruptcy of one company its assets will likely be transferred to another company. It is unknown if this is the case, when multiple companies file for insolvency in a short amount of time.

2.5.2. Available Sites

It is safe to say that where one wind park is, there is no space for another one. While in the 90s the majority of new wind turbines were installed in the north of Germany, their share has stagnated in the last decade at around 40 % while more and more wind turbines are installed in what is considered the south (Deutsche WindGuard, 2018). In 2019, most of the newly commissioned turbines are located inland in the East and not as traditionally seen at the coast of Germany (Deutsche WindGuard, 2020). This is an indicator that developers of wind energy projects are required to search for new sites inland as the number of sites that are legally available for wind energy use is limited in the first place (13.8 % in 2013 (Lütkehus *et al.*, 2013)). The lifetime of a wind turbine is around two decades. It takes time until coastal sites are free again for re-powering. This lack of technically available sites can be worsened by increasing the distance between the turbines and neighbouring households. Lütkehus *et al.* (2013) showed that an increase of this distance from 600 m to 1000 m would decrease the number of available sites by 60 % and 1200 m by 75 %.

Unfortunately, the further away from the coast, the lower the average wind speed and the surface roughness which results in higher turbulences. This results in higher electricity production costs as the yield is low due to the said wind regime but the investment and running costs remain the same compared to coastal regions. The consequence is that the more wind energy is installed on-shore, the worse the condition for the new wind turbines.

2.6. Possible Future Scenario

The German government aims for a share of 65 % of renewable energy from the total electricity consumption (Deutscher Bundestag, 2019, p. 31). The total demand is expected by the government to stay comparable to the "current" one (in this case 2018) due to an increase in efficiency while the consumption for heat and transportation increases as well (Deutscher Bundestag, 2019, p. 26). In 2019, the total electricity consumption in Germany was 569.2 TWh while 101.2 TWh came solely from on-shore wind (bdew, 2020). Deutscher Bundestag's (2019) prediction is debated. Bundesverband Erneurbare Energie (2020) expects 740 TWh to be consumed which is an increase of 30 % and is explained by the "heat pumps, electromobility, and PtX (Power-to-Gas, Power-to-Liquids)". Agora Energiewende and Wattsight (2020) estimates 600 TWh. Interestingly, the network development follows scenarios where the electricity consumption is between 639 TWh and 687 TWh by 2035 (Bundesnetzagentur, 2020)

The question whether the goals of 2030 can be achieved with the current slump in wind energy development has only been reviewed by one study, namely Agora Energiewende and Wattsight (2020). It suggests that due to the development collapse of wind energy, the goal for 2030 cannot be reached unless counter-measures including the promotion of other technologies are implemented.

3

Model

3.1. Motivation and Modelling choice

Chapter 2 showcased in detail the current situation in Germany and summarized different academic domains the research question deals with. However, this study demands a quantitative approach to answer this question. Computer based models are a tool for such a task and have the benefit of being able to simulate thousands of alternative futures.

The aim is to develop a model that can reproduce the core interactions to ultimately show under which conditions the slump appears. Because the system itself consists of only a few actors with limited interactions, the focus can lie on a high degree of detail which can facilitate a more robust interpretation of the results. As this model tries to combine political factors into a socio-technical environment, either a System Dynamics (SD) approach or an Agent-based modelling (ABM) approach could be applied. These are discussed in the following and previous to an introduction of the "deep uncertainty"-approach in section 3.1.4. The remainder of this chapter will address the conceptual outline of the model (section 3.2), a detailed specification in section 3.3, the calibration in section 3.4, a technical implementation of the model in section 3.5 and finally a discussion on the validation of the model in section 3.6.

3.1.1. System Dynamics

SD was developed by Forrester in the 1950s and is used widely ever since (Forrester, 2007). It is a top-down approach to synthesise real world interactions as causal relations, producing feedbacks, stocks, flows and time delays. As stated in Forrester (1990), SD is based (among other) upon "the wealth of information about structure and decision-making processes that exists primarily in people's heads". In other words, it requires a deep understanding of different parts of the system in order to break down and distil sometimes complex interactions into simple formulas. However, this knowledge does not require to contain the understanding of the bigger picture and the "interactions between interactions". This is the strength of SD as "system dynamics models provide a means of understanding the causes of industry behaviour" (Lyneis, 2000). SD models provide even for highly dynamic systems a quantitative tool that can run many scenarios in a short amount of time, because they consist of differential equations (Forrester, 1997) which can quickly be solved by computers nowadays.

The downside of SD (see Featherston and Doolan, 2012) is the limited level of detail until the complexity of the model itself gets out of hand. This comes from its top-down nature. It is mostly noticeable when the level of detail required is on individual level as System dynamics handles every entity flowing through the system as homogenous. This trade-off between pluralism and complexity has been addressed by scholars such as Osgood (2009).

3.1.2. Agent-Based Modelling

The general idea of this bottom-up approach is to model the system by creating autonomous decision-making entities (agents) with a simple set of decision rules to interact with their environment, which also includes other agents (Bonabeau, 2002; Parker *et al.*, 2003). This approach gives the possibility to model "spatially distributed systems of heterogeneous autonomous actors with bounded information and computing capacity" (Epstein, 1999). Due to the interaction between the agents, macroscopic emerging properties of the system that are not explicitly designed by the modeller arise (Epstein and Axtell, 1996; Epstein, 1999). The result is ABM's capability to be modelled as close to the real system as it can get (Bonabeau, 2002). Thanks to this, numerous authors see great potential for this formalism in social science modelling markets, organisations, and societies etc. due to being capable of modelling responses and adaptions of a population to an environment (Epstein, 1999; Bonabeau, 2002; Tesfatsion, 2006).

It must be noticed that ABM also has downsides. The fact that ABM allows that just a small number of assumptions regarding behaviour and initial states is needed, makes their correctness more so important. The calibration, verification and validation of agent-based models is inherently difficult due to their nature (Galán *et al.*, 2009; Parker *et al.*, 2003). As they work on a low level of aggregation by definition (Bonabeau, 2002), studies using ABM need to spend a significant amount of time dis-aggregating statistical data to obtain information about each agent which is a source of error (see e.g. Zhang *et al.*, 2016; Fontaine and Rounsevell, 2009). Especially Zhang *et al.* (2016) point out the problem of getting access to entity-accurate data. They used synthetic data and from statistics to solve it. This comes close enough to reality but can be a source of error by changing the behaviour of the agents significantly. Continuing, the decision rules can contain flaws. As Fontaine and Rounsevell rightfully points out in a study about future residential demand, the study will be undertaken "with the assumption of continuation of baseline behavioural trends" (Fontaine and Rounsevell, 2009). In other words, it is necessary to assume that the decision pattern of the agents will not change of the modelled time-span. This is a strong assumption due to the variability in opinion in fast-pace cultures. In addition, agents can either have several different answers to one decision from which one is randomly selected (they might be having equivalent outcome for the agent but produce different collateral effects) or they just act irrational (Bonabeau, 2002). This however should not be a problem this model faces as later shown.

3.1.3. Choice

It appears that while the calibration and data gathering for an ABM model is more difficult, the more detailed results on project level will be beneficial at the end. The above-mentioned downsides of ABM are manageable when considered during the development of the model and analysis of the results. The fact that System dynamics aggregates and generalizes all interactions to a combination of stocks, flows and feedbacks would not be ideal for the richness of detail that is needed. The implementation of e.g. yearly biddings would not be a straight forward. In other words, it is not self-evident to construct an SD-model that has the required level of detail on a project by project basis as required to answer the research question. Thus, the Agent-based modelling (ABM) approach is used.

3

3.1.4. Deep Uncertainty

"Uncertainty can be defined as *limited knowledge* about future, past, or current events" (W. E. Walker *et al.*, 2013). This uncertainty is ultimately that reason why studies are done. The goal is to improve the knowledge so that uncertainty is reduced. Surely, uncertainty can be insufficient information about the value of a parameter. But if uncertainties "are not just parametric, but also relate to functional relations, model hypotheses and aspects, model structures, mental and formal models, world views, modelling paradigms, the effects of policies on modelled systems, and the lack of consensus on the valuation of model outcomes [...] then traditional modelling and model-based policy-making tends to fail" (Hamarat *et al.*, 2013). This kind of uncertainty is "deep uncertainty". It is an alternative approach where the question that is tried to answer is not "What will the future look like?" but rather "How do plausible futures look like?" (see Maier *et al.*, 2016). The difference is the abandonment of the claim to pinpoint the future with some probability. This opens the possibilities to designing robust policies which do not rely on exact information or relations/structures that all stakeholders agree on (see J. H. Kwakkel and Pruyt, 2013; J. H. Kwakkel, Haasnoot, *et al.*, 2016). They are rather constructed in such a way that they can deal with any possible scenario, independent of their likelihood.

This study will adopt this approach since key parameters to describe the future of wind energy in Germany are missing and/or are debated. However, whenever it is possible to use exact numbers, distributions, or processes/interactions, it is done. Taking deep uncertainty into account reflects in the way a model's inputs are sampled. Instead of applying a specific distribution, they are uniformly drawn from the uncertainty space to cover it as even as possible. Further details are described in chapter 4.

3.2. Concept

3.2.1. Narrative and Actors

As already stated previously in the introduction to this study, the goal is the understand the economics of wind energy projects (WEPs) and therefore the financial details for every wind energy project will be assessed. This includes every step from assessing the site to the decommissioning after 20 years. Which steps are required by the EEG have already been outlined in section 2.1. Nevertheless, the narrative the model is developed around is the following.

To build a new wind parks, developers search nationally for adequate sites and will select the best one available to their knowledge. They then assess the wind regime and decide what configuration of wind turbines (number, brand, size, etc.). In continuation, they collect offers for a maintenance contract and after having all their potential income calculated and costs sorted out, the developers might ask a bank to finance the investment. In the meantime, all the required permissions have to be gathered. During these steps public opposition is common e.g. juridical actions against the project. However, when all these problems are cleared, the developers move forward and participate in the bidding process that is required by law (see section 2.1). If that succeeds, they can commission the power plant and pay off their liabilities every year with the produced revenue from electricity.

This happens hundreds of times simultaneously across all Germany resulting in ideally thousands of Megawatts of power being commissioned each year. These turbines could not exist for two decades or more if they are not maintained properly. These companies are both turbine manufacturers and companies that only focus on repairing turbines. They heavily rely, as every business, on enough income to pay both their fix and variable costs.

Banks look closely at the finances of the WEPs include them in their rating which dictate the interests on the loans they are willing to give out. While most of the lawsuits are settled before loans are granted and the local wind speed has become a manageable uncertainty, they should have a close look on the performance of the maintenance contractor as they are key to both the income and cost of a wind energy project. Other aspects like the reliability of project developers is not considered.

Public acceptance for wind energy is existent on a national level and therefore only relevant for this study on a local level. Therefore, there is no need for it to be modelled separately from the wind energy projects (WEP). Section 2.3 showed clearly that local acceptance is a complex matter. Thus, a detailed, numerical representation of this topic would be out this study's scope.

Consequently, the model will consist of three types of actors, namely maintenance companies/turbine manufacturers (MC/TM), banks and wind energy projects / local community (from now on only wind energy projects (WEP)). The latter will be modelled in combination as each wind park only interacts with its local community and therefore can be seen as one “entity”. The German government will not be an actor but rather be represented by the environment which influences the system via external factors. The actors are visualized by the rounded off boxes in figure 3.1.

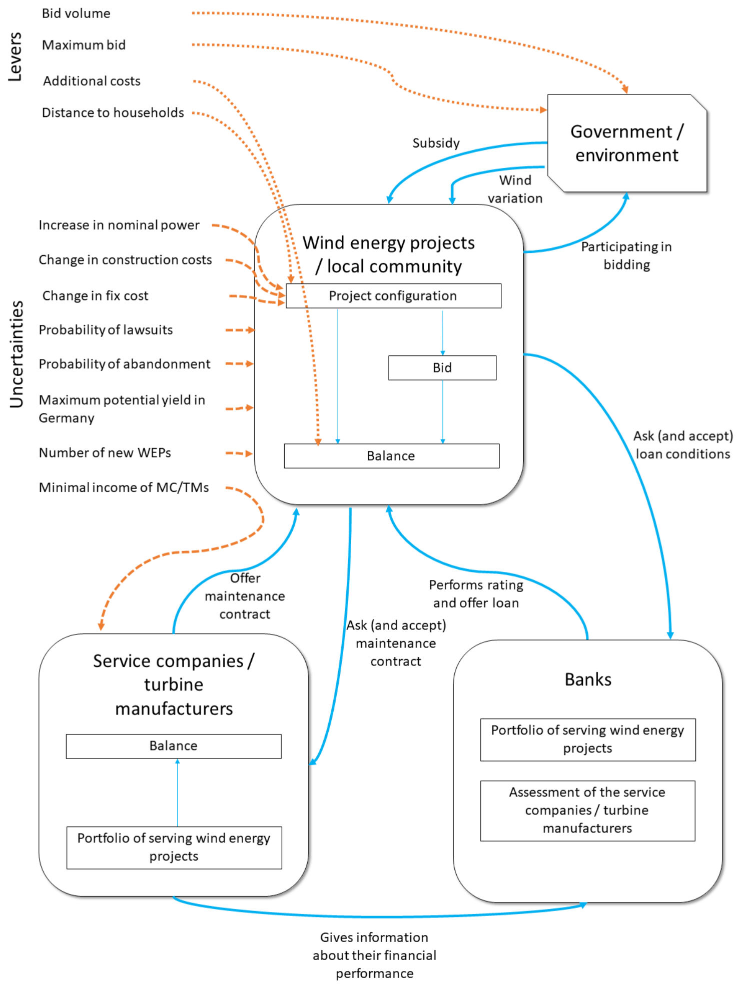

Figure 3.1: Schematic of the interactions within the system. Rounded boxes are the actors, blue arrows show interactions and orange arrows external influences like uncertainties and levers.

3.2.2. Interactions

Like in the real system, the actors within the model interact with each other. These are represented by the blue arrows in figure 3.1 and are explained in more detail in the following section 3.3. Figure 3.2 shows the steps a WEP goes through during its lifetime and figure 3.3 outlines the steps model will go through every year i.e. every time step. All the interactions can also be found in figure 3.1 represented by the arrows.

As it can be seen in figure 3.3, a year starts with setting up the environment for the new year, especially the wind conditions of that year. In continuation, banks assess the financial status of the MC/TMs which becomes important during the loan offering. Next, the existing WEPs first check whether their maintenance company is still providing their service and then assess their financial situation. Internally, wind energy projects maintain a financial balance that is updated every time step using the income and costs.

After that, new WEPs are created as shown in the left part of figure 3.2 (Time step 0). WEPs obtain a load capacity which results in an expected yield by applying equation 3.1. A load capacity determines how much of the in theory possible yield is actually produced. A more detailed explanation can be found in section 3.3.2. This represents the P50-yield, the yield that is expected to be reached with a probability of 50 % and coincides with the mean of a normal distribution and in reality is estimated by experts in yield assessment and is used for the rating and cost estimation. The actual load capacity is somewhere around that value follows a normal distribution. Something that needs to be addressed is the lack of space for additional wind energy in the densely populated Germany. While an extensive geographical information model is out of scope of for this thesis, this aspect must be included. While it is known that the distance of the WEPs to settlements is not important, in this study it will be assumed to be the economic viability which hinders more projects to be developed. Project developers are keen to populate the spaces with wind parks where the income to cost ratio is highest first. An indicator is that the north of Germany where the wind speed is higher and more consistent coincides with where most of the wind parks are situated. Consequently, a central assumption will be that the more WEPs are built, the worse the wind regime of the following one. This is modelled by a reduction of the load capacity. The implementation of this assumption is described in section 3.3.2.

The next step after setting the basic parameters of the WEP is that they randomly get delayed due to lawsuits and decide whether they will continue. While in reality a lawsuit appears at any point in time during the planning process of the project, the model will handle this at the beginning to avoid unnecessary calculations. In continuation, they randomly select a maintenance company from the list of MC/TMs and request a contract. This selection is based on the brand of the turbines that are planned to be installed and the market share of the companies. At that point, the WEP has enough information about the income and costs that they request a loan from the bank. A bank performs a rating based on the information they have and offer the wind energy project a credit given an interest rate according to their probability of default. If the bank does not deny a loan due to too bad financial conditions, the WEP moves forward and bids for a subsidy.

If all new WEP have performed these steps, the bidding process is performed according to section 2.1. The WEPs that get accepted are build. At the end of the time step, the MC/TMs assess their financial status.

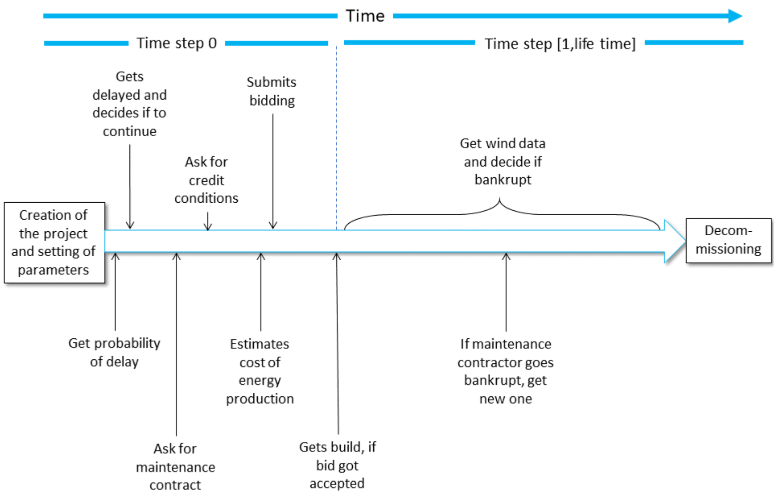

Figure 3.2: Timeline of the lifetime of one wind energy project.

3.2.3. Inputs and Outputs

Any model can be structured with the XLRM framework which distinguishes between policy levers i.e inputs ("L"), exogenous uncertainties ("X"), measures ("M") i.e. outputs and relationship ("R") which represent the interactions within the model (Lempert *et al.*, 2003). Figure 3.4 shows the XLRM-representation of this model.

The policy levers are the thresholds of the bidding process which are the compensation per kWh of electricity called the maximum bid and the maximum volume (see section 2.1). In addition, it is possible to impose additional costs on the WEPs and set the maximum and the minimum distance to households. This makes it possible to simulate policy propositions such as the effects of financial participation of the adjacent communities as proposed by the Green party, SPD and die Linke (see section 2.2) and the increase of said distance proposed by the CDU (see section A.1). Both policy options are believed to increase the public acceptance.

The uncertainties are introduced either due to a lack of precise data or actual uncertainties in the real system. The latter is mainly the technological development in terms of increase in nominal power of the turbines and the increase or decrease of construction and fix costs. Data that is unknown is the percentage of minimal income to the 2017 base case (see section 3.3.4), the probability of a lawsuit and

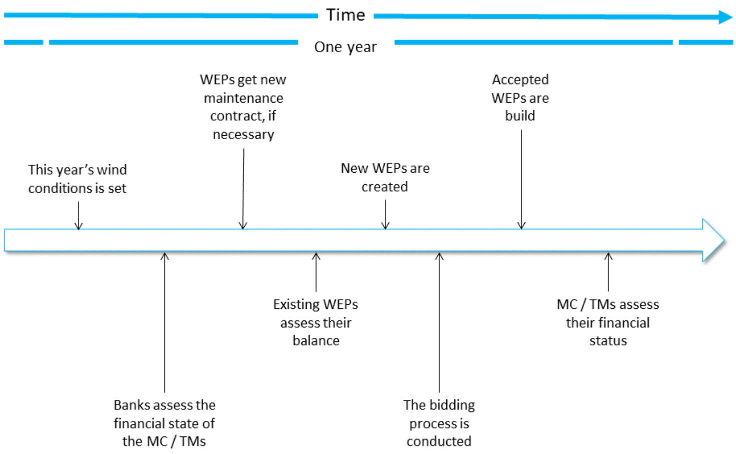

Figure 3.3: Timeline of one step representing one year.

the probability of the WEP's abandonment due to the said lawsuit. In addition, it is unknown what the maximum potential yield in Germany is and how many new sites are assessed each year.

The central output of the model is the yearly yield of all WEPs. It is used as a measure whether the energy transition goals are met or not. Alongside, the number of bankrupt MC/TMs and the number of newly build projects is logged.

3.2.4. Bankruptcy Prediction Models

The bankruptcy prediction models are procedures which help to primarily estimate the probability of a default typically within a year. Based on this value an interest rate is selected. Usually, the higher the probability of default, the riskier the loan, the more equity must be set aside, the higher the interest rate. The European law differentiates between different tiers of risk assessment models where the simplest ones assume a risk factor while the highest tier includes the exposure at default (EAD), loss given a default (LGD) and the remaining credit run time (M). This is summarized in detail in Appendix B.

Nevertheless, how these values are calculated can differ widely. Bemmann (2007, p. 6) provides a categorization of different approaches. If informal methods are excluded, they can be divided into inductive, empirical-statistical or structured models. Inductive models use "Scoring" which categorizes the default risk based in different input parameters (Yap *et al.*, 2011). Empirical-statistical models can range from basic statistical regression to applying artificial intelligence (see Fritz and Hosemann, 2000). Finally, "structured models" as called by Bemmann (2007, p. 15)

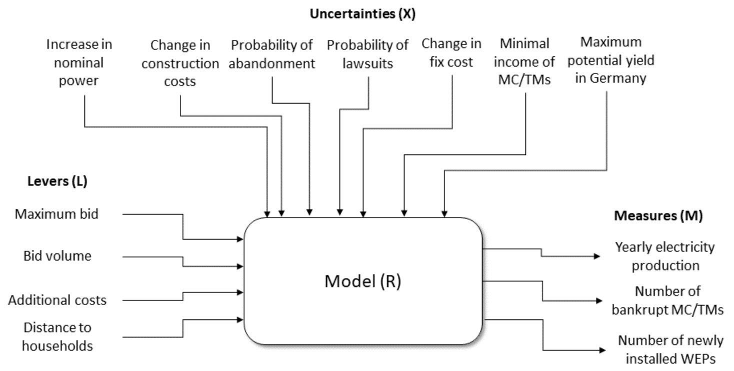

Figure 3.4: The XLRM-representation of the model.

contain complicated and sophisticated models such as the *Merton-model* (Merton, 1974), and other deterministic approaches.

3.3. Model Details

3.3.1. Metadata

Agent-based models perform their actions in discrete time steps. Each of these steps represent one year. The first year corresponds to 2020 and each simulation will go until 2030 which is the next milestone during the energy transition. It could be argued that 2050 would be a better choice to see, if the current policy would be able to achieve the final goal set by the government. However, the EEG has changed six times since 2000 and therefore the systemic uncertainty regarding the subsidization scheme is high. Thus, simulation runs until 2050 would not generate meaningful results.

Regarding the number of agents that are generated per simulation, the following is done. The maintenance companies/manufacturers are created according to the actual number of relevant stakeholders which are 6 manufacturers and 5 maintenance companies (see section 3.3.4). According to Deutsche Bundesbank (2020), there have been 1717 credit institutions in Germany as of 2019. Even though, it would be possible to generate that number of bank agents, there is no benefit to that because there are no interactions between banks or WEPs are assumed to not compare banks or similar. Thus, the number of banks per simulation is limited to one. The number of WEPs is an uncertainty and thus is discussed in section 3.4.

3.3.2. Wind parks

Setup

This section explains the details of a WEP's setup. It contains which turbine brand will be used, the number of turbines, the load capacity, the nominal power of each turbine, the fix costs per year of the project as well as the initial investment costs.

Turbine brand The German wind turbine market is composed by only a handful of manufacturers. In 2018 the market share of newly installed wind turbines by installed power was as follows: *Enercon* 54 %, *Vestas* 24 %, *Nordex* 9 %, *Senvion* 6 %, *Siemens Gamesa* 4 %, *Fuhrländer* 1 %, and miscellaneous 1 % (Mackensen *et al.*, 2019, p. 45). As the company *Fuhrländer* went bankrupt in 2012 and the market share can be neglect, it is not considered in this study as well as the miscellaneous. The market share of all wind turbines is used instead of the one of newly installed wind turbines, because the latter might be prone to random fluctuations in the number of commissions during that year. However, trends like that one manufacturer could have become more popular in recent years and the market share of another one is solely based on old turbines that will be decommissioned soon, are neglected by using this approach. This must be considered during the interpretation of the results. During simulation's a newly initialized WEP will choose one turbine manufacturer based on the above-mentioned weights but will not consider manufacturers that have gone bankrupt during the simulation run.

Nominal Power The nominal power, i.e. the maximum power a wind turbine can produce is a key parameter in the wind energy industry. According to Deutsche WindGuard (2020), in 2019 the average nominal power was 3317 kW. The actual nominal power per wind turbine for each WEP is drawn from a normal distribution which is limited to 900 kW on the lower side and 4800 on the upper side (also given by Deutsche WindGuard, 2020). These values will shift over the years due to the technological development which can be seen in figure 3.13 and will be discussed further in section 3.5.3. The difference between the first quartile and the third is 600 kW (Deutsche WindGuard, 2020) what corresponds to 445 kW of standard deviation.

Number of turbines The number of turbines per WEP will be drawn based on the distribution from newly commissioned projects in 2018 according to Mackensen *et al.* (2019, p. 44). The source gives the probability of for tuples of 1-2, 3-4, 5-6, 7-8 and more than 9 turbines per project. It is assumed that within each tuple the numbers are equi-distributed. Since there is no information on what "more than 9" means, this number will be used as the maximum. The resulting probability distribution can be seen in figure 3.5.

Initial investment costs In the literature, initial investment costs are usually separated into main and additional investment costs. Deutsche WindGuard (2019b, p. 71) gives a detailed statistic on the main initial investment costs per kW installed capacity. The main investment costs consist of the turbine itself while the additional costs include the foundation, infrastructure planning costs and to forth. As Deutsche WindGuard (2019b, p. 71) gives the main costs for different nacelle heights (see figure 2.2), a parameter which is not considered in this study, the average nacelle height of 133 m in 2019 of newly installed turbines (Deutsche WindGuard, 2020) is assumed. This results in the following main investment prices per kW of installed power:

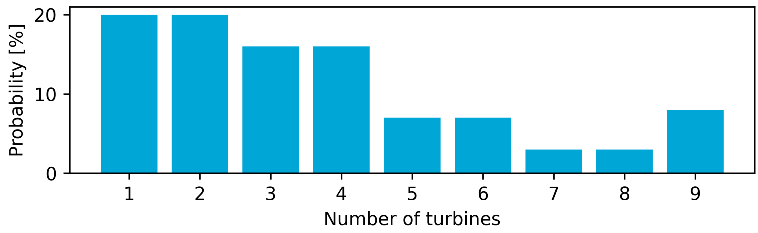

Figure 3.5: Probability of the number of turbines in each WEP based on Mackensen *et al.* (2019, p. 44).

3

- 2 to <3 MW turbines: 1180€/kW
- 3 to <4 MW turbines: 1050 €/kW
- 4 to <5 MW turbines: 970 €/kW

Deutsche WindGuard (2019b, p. 78) also provides the additional investment costs which are 406 €/kW on average in 2019. This must be added to the above-mentioned turbine costs. The study also confirms that there are no significant differences between regions in terms of initial costs.

These initial investment costs are not financed entirely by loans. For wind projects 20 % to 30 % come from equity which is required by most banks (Mbistrova, 2018, p. 7). Thus, a percentage within that range will be deducted total construction costs to equal the requested loan.

Average load capacity This parameter determines how much of the in theory possible energy yield is actually harvested. As a consequence, it is an indicator on how much wind there is on site. The load capacity η combined with a reduction factor r (introduced later), the power per turbine P and their number n gives the annual yield E as in function 3.1 which will then facilitates to estimate the income of the project.

$$E = \eta \cdot r \cdot n \cdot P \cdot 8760 \left[\frac{h}{a}\right] \tag{3.1}$$

Mackensen *et al.* (2019, p. 7) states for 2018 an average of 1801 full load hours and a 10-year average of 1637 full load hours. Data from Kaltschmitt *et al.* (2013, p. 819) also estimates wind energy turbines to run between 1400 to 5000 full load hours. Full load hours is a yield equivalent giving the number of hours which it would take to generate the yield with the turbines continuously on maximum capacity. If this number is divided by the 8760 hours of a year, the load capacity is obtain. The newly installed turbines in that year are estimated to deliver a long-term average of 2788 full load hours (Mackensen *et al.*, 2019). For the 2016 and 2017 newly installed turbines this number is 2721 and 2738 hours respectively (Rohrig, Durstewitz, Berkhout, *et al.*, 2017; Rohrig, Durstewitz, Behem, *et al.*, 2018). There is a big gap in performance between the existent and new turbines. Gasch and Twele (2016, p. 152f) explains this phenomenon with the fact that the early EEG benefited wind turbines that had a high yield while the newer iterations of the bill reward a constant yield under any circumstance. If all wind turbines are focussed on high yields, during strong wind periods there would be an oversupply of electric energy what results in an electricity price of 0 ct/kWh or even negative like in 2017 (see Reed, 2017). Therefore, the trend has gone to install turbines which can achieve their nominal power at lower wind speeds via larger sweep areas (see section 2.2.3). Therefore, the load capacity is not an efficiency equivalent which can be increased due to technological development over time but rather a design choice/financial decision made by the project developers. Thus, when the average load capacity of a WEP is mentioned in this study, the highest possible load capacity that can be achieved on that site is meant.

For new WEPs during the simulation runs, an average 2788 full load hours as in 2018 (see Mackensen *et al.*, 2019) could be used what corresponds to a load capacity of 0.318. An issue that is noteworthy is that the average full load hours of the above-mentioned studies only consider successful installed wind turbines. This is further discussed in section 3.4.

They scatter around this value following a normal distribution with a minimum of 0.16 (equivalent to 1400 full load hours) and a maximum of 0.57 (equivalent to 5000 full load hours) (see Kaltschmitt *et al.*, 2013, p. 819). This range needs to be introduced to reduce the generation of unrealistic projects. Regarding the standard deviation of this distribution there is no explicit data on this topic. However, the *Fraunhofer institution* provides a data pool consisting of 738 on-shore turbines from 2002 to 2018 with a 600 full load hours difference between the first and third quartile of load capacity (Mackensen *et al.*, 2019, p. 85). If the spread of the load capacity has not changed over the years, this results in a standard deviation of 445 full load hours or 5 % load capacity.

Regarding the reduction factor r in formula 3.1, Lütkehus *et al.* (2013) provide an assessment of the potential space available for wind energy in Germany. Using a geographic information system, Lütkehus *et al.* estimate an area of 49361 km^2. When populated with with wind turbines of 3.2 MW and 3.5 MW this corresponds to a 2897.87 TWh of potential yield. The value multiplied with a reduction coefficient[1] is used in this thesis as the maximum amount of wind energy that will be harvested.

A sensitivity analysis in Lütkehus *et al.* (2013, p. 39) showed how the maximum potential yield decreases with an required amount of minimum load capacity (see figure 3.6). In order to simulate a decrease in efficiency, the following is done: In figure 3.6, instead of varying the minimum full load hours to assess the total possible yield, the underlying function can be reversed to show the reduction in full load hours given the total yield in Germany as the latter is known in the model. This can be done as the marginal, next wind park is the next best one with fewer full load hours. This is the central assumption of section 3.2: project developers always choose the next best site for a new WEP whose wind regime quality is lower

[1] As the actual maximum of potential yield in Germany is unknown, it falls under the topic of deep uncertainty (see section 3.5.3).

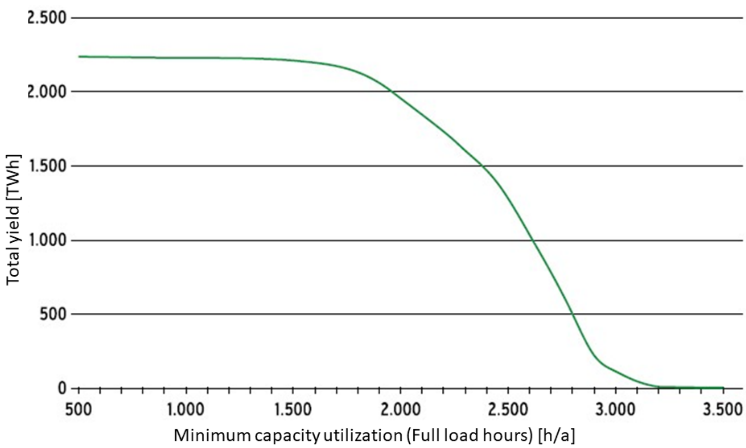

Figure 3.6: Sensitivity analysis of the maximum theoretical yield in Germany as a function of minimum required full load hours. Source: Lütkehus *et al.* (2013, p. 39)

Table 3.1: Influence of the distance to households on the potential area. Source: Lütkehus *et al.* (2013, p. 38)

Distance to households	600 m	800 m	1000 m	1200 m	2000 m
Share of the potential area	100 %	66.3 %	40.9 %	24.8 %	2.8 %

because all the better sites are already populated.

Figure 3.7 shows the reduction percentage of load capacity r in function of the percentage of already commissioned yield. The ordinate is normalized in such a way, that the 100 % mark coincides with the dotted, black line which represents the current yield of on-shore wind energy as in 2019 (106 TWh (Deutsche WindGuard, 2020)). The coordinate is normalized in such a way that 100 % coincide with the 2897 TWh of estimated maximum yield in Germany by Lütkehus *et al.* (2013) time the maximum yield uncertainty factor and the distance-to-households-lever (for both factors see section 3.2.3). The latter is given in metres and must be converted to a percentage of area. This is done using again a sensitivity analysis in Lütkehus *et al.* (2013, p. 38). This study's results are given in table 3.1 and are linearly interpolated for the use in the model.

Fix costs Fix costs are composed by terrain lease, business management, insurance, saving for demolition costs and miscellaneous. They do not include the maintenance costs in this case which are described in section 3.3.4. They will

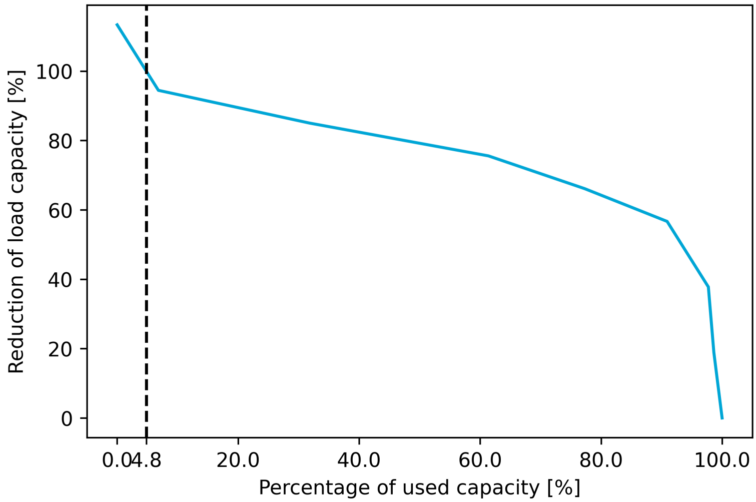

Figure 3.7: Load reduction factor r based on the already available yield. The dotted, black line representing the current yield of on-shore wind energy as in 2019 coincides with the 100 % mark. Based on a sensitivity analysis of Lütkehus *et al.* (2013, p. 39).

be estimated to be fixed values and passed on the installed power ranging from 26 €/kW a to 31 €/kW a in the first decade of operation to 30 €/kW a to 38 €/kW a in the second decade Deutsche WindGuard (2019b, p. 84). These ranges are assumed to be uniformly distributed.

Initial asset This parameter is an initial value for the balance which is a necessary starting point for both the actual balance of the WEP as well as for the banks' rating. This value however is abstract and cannot be find in any literature as it basically represents the liquidity of the project owner and how much she/he is willing to spend extra on the project. As the model does not consider post-commissioning delays, it is assumed that they are only willing to pay one year of fixed costs which then corresponds to the initial asset.

Additional calculations The actual load capacity and therefore the actual energy yield will be drawn from a distribution as the uncertainty of a energy yield prediction is simulated. Kwon (2010) showed that the classical Measure-Correlate-Predict method that is used for that matter can have an uncertainty of around 11 % which is the result of meteorological variation. This value is used as the standard deviation to draw the actual yield from a normal distribution.

The *EEG 17* (2016) intends to support low wind speed sites by applying a correction factor to the bid of a WEP (see section 2.1 and table 2.1). This requires a reference yield which is given by the WEP's configuration but with the global average capacity factor of 0.318. The idea behind this decision is that the reference yield or reference site should represent the average and is calibrated as such.

Based on the probability of a lawsuit and a consequent abandonment a WEP continues with a commissioning or gets already dismissed.

Commissioning

The commissioning is described by the left half of the timeline of figure 3.2 i.e. Time step 0. It consists of selecting a maintenance company, get an offer from a bank and perform a bidding.

Choosing a Manufacturer or service company for maintenance It is assumed that project developers have no particular reason why they choose one turbine manufacturer over another but conform to the market share. The same holds for whether they opt for a third-party maintenance company or sign a maintenance contract directly with the turbine manufacturer. The survey Bundesverband WindEnergie (2020a) which examined the service quality in 2019 will be the main source of information. The market shares can be seen in table 3.2. From 5386 turbines that have been taken into account in this study, 4230 have service contracts with the manufacturer and 1156 with a service company resulting in 78.54 % and 21.46 % respectively. Table 3.2 shows the percentage of how many of the contracts have been signed with each company for each type of contract (manufacturer or service company contract) which are taken from Bundesverband WindEnergie (2020a). In addition, the actual market share is added to the table by combining the two percentages. It must be mentioned that *Availon* is part of *Vestas* and therefore its market share is given to *Vestas*.

Table 3.2: Market share of servicing of service companies and wind turbine manufacturers in Germany in 2018. *Vestas* market share is adjusted from originally 18.5 % to 21.9 % because *Availon* (originally 3.4 % market share) is added. Source: Bundesverband WindEnergie (2020a)

Manufacturer service contract	Share / %	Market share / %	Service company contract	Share / %	Market share / %
Total share	78.54		Total share	21.46	
Enercon	54.4	42.7	Availon	11.3	—
GE-Wind Energy	5.6	4.4	Deutsche Windtechnik	47.1	10.1
Nordex	7.7	6.0	Enertrag Service	14.0	3.0
Senvion	6.6	5.1	Enova Service	7.6	1.6
Siemens Gamesa	1.8	1.4	PSM	16.9	3.6
Vestas	23.9	(adj.) 21.1	WindMax	4.1	0.88

However, not every wind turbine brand (see section 3.3.2) can be serviced by any service provider. *Enercon* will not sign a service contract for an *Nordex* turbine. The exception is *Vestas*. The company offers their "Multibrand service" which contains maintenance plans for *GE*, *Siemens Gamesa*, *Senvion*, *Nordex*, and *Suzion*

(Vestas Wind Systems A/S, 2020b). *Availon*, the subsidiary enterprise of *Vestas* is incorporated as is forms part of *Vestas'* service. The matrix 3.3 shows which service company can maintain which brand of turbine.

During the simulations, a WEP picks one of the companies that support its turbine brand. The decision is weighted according to the market shares. For example, a WEP with *Enercon* turbines can choose between *Enercon*, *Enertrag Service* and *Enova Service* (see table 3.3). According to table 3.2, they have a market share of 42.7 %, 3.0 % and 1.6 % respectively, which results in a probability of 90.27 %, 6.34 % and 3.38 %. The underlying assumption is that a variation in brand types serviced by a companies only originates from the market share of the turbine brand itself.

Table 3.3: Table of the supported turbine brands by each service companies and wind turbine manufacturers. Sources: Vestas Wind Systems A/S (2020b), Deutsche Windtechnik (2020), Enertrag (2020), Enova Service (2020), and psm-service (2020). *Enercon*, *GE-Wind Energy*, *Nordex* and *Senvion* offer maintenance contract but do not state that it is not only for their turbines.

	Vestas	Enercon	Nordex	Senvion	Siemens	GE
Enercon		X				
GE-Wind Energy						X
Nordex			X			
Senvion				X		
Siemens Gamesa					X	
Vestas	X		X	X	X	X
Deutsche Windtechnik					X	
Enertrag Service	X	X	X	X	X	X
Enova Service		X				
PSM			X	X		X

Estimating prices and obtaining a loan A price of electricity demanded by the WEP is estimated as following. It is assumed that the price p is set to such a level (given by equation 3.2)that all expenses including the amortization for the first year (the construction cost divided by the run time rt assuming a steady repayment) and an interest rate of 2.5 % (equal to the median of table 3.7) can be paid while the project's actual load capacity η is at minimum the mean minus one standard deviation σ. E is the revenue of one year.

$$p = (0.25 + \frac{1}{rt}) \cdot C_{construction} + C_{fixed} + C_{maintenance} - E - \frac{E * \sigma}{\eta} \tag{3.2}$$

In continuation, a WEP consults its bank by giving the necessary information. This includes the estimated price per kWh and other parameters explained in section

3.3.3. The answer is a list of rates that have to be paid each year. If the interest rate is of the worst class (see table 3.6), the project is dismissed. Based on this, the price per kWh is adjusted again as above but this time with the rates given by the bank.

Bidding Then, the WEP takes part in the bidding by dividing the estimated price by the correction factor (see table 2.1) and submitting the result. When all WEP have submitted their bids, the bidding is performed as described by the EEG17 by first sorting them by bid and excluding all too high bids. The bid volume is then filled up with the remaining WEPs starting with the lowest bid until the volume is filled. These WEPs are then ordered to be build. If a WEP is not build it takes part in the bidding process two additional times until it gives up and is dismissed.

Building The building consists of telling the selected maintenance company and bank that it is build and setting its status accordingly.

Step

If a WEP is up and running, it checks whether the maintenance company is not bankrupt. Otherwise a new one is found as explained above. In continuation, it calculates its balance by obtaining the year's wind index v_i (i^{th} year) and the net income $I_{net\,i}$ according to equation 3.3 where R_i is the payment to the bank, C_{fixed} is the fix costs, and the remaining resembles the maintenance costs which are based on the last year's yield.

$$I_{net\,i} = v_i \cdot E_{avg} - R_i - C_{fixed} - C_{maintenance} \cdot v_{i-1} \cdot E_{avg} \tag{3.3}$$

The result is then added to the balance of the previous year and capped to the reserve requirement given by the bank. A WEP has always a self-induced minimum reserve requirement of 10 % of the current year's costs. If the balance is negative, a WEP is assumed to be bankrupted. Interconnection between the bankruptcy of WEP due to an insolvency of a potential parent company does not need to be considered. The reasons is the projects' financial nature. The funding is tied to the cash flow of the project and not the company. (Böttcher, 2019, p. 11). Thus, in case of an insolvency the parent company is legally unaffected.

A WEP decommissions after 20 years.

Model Initialization

During the initialization of the model wind parks are loaded in according to historical data from Bundesverband WindEnergie (2020c) which provides the number of turbine installations and sum of their nominal power per year. From there the average nominal power per turbines can be derived. The number of turbines in each WEP is still derived from the distribution in figure 3.5. Since the oldest WEPs in the systems should have at least one year of their 20-year lifetime left, WEPs are generated for each of the past 19 years. according to the setup procedure explained above with that average power until the historical amount of yield and number of turbines is met. Initializing the model in that way impacts the performance of the model significantly but not the results as it can be seen in figure 3.8. For 10 different setup instances, 500 scenarios which are identical across setups were simulated in order to show a sensitivity of the outcome to the setup over the uncertainty space. It can be seen that variations is minor. The relative standard deviation of the 10 averages is 0.41 %. Thus, 5027 pre-generated WEPs are loaded into the model instead as a performance gain outweighs the variability. Table 3.4 shows the statistical similarity of the used setup WEP and the actual historical data extracted from Bundesverband WindEnergie (2020c).

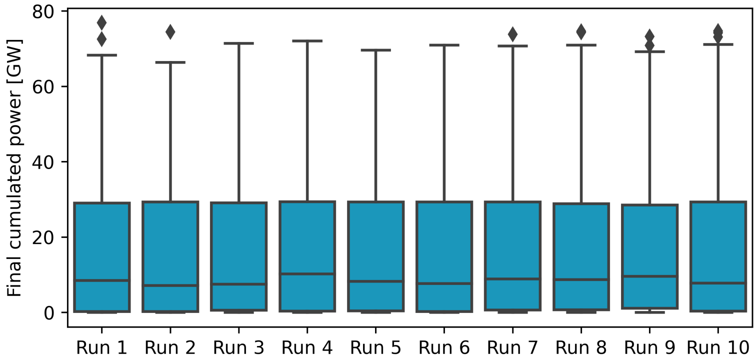

Figure 3.8: Boxplot of the distribution of the final cumulated power for 10 different setup instances.

3.3.3. Banks

Banks with their rating and supply of liquidity form a central piece in the development of wind energy projects. An extensive internet research concluded that not a single internal procedure and or any information regarding credit or rating matters is disclosed by any bank. However, the KfW (in German acronym for *Kreditanstalt für Wiederaufbau*) is a German state-owned development bank and offers a great amount of transparency regarding its loan conditions including all necessary information for this study. They are explicitly stated below. Thus, the KfW is selected as the reference bank of this model.

Setup

The Bank model does not require major setup calculations but include the following points.

Required reserve aim This parameter gives how much liquidity reserve the bank requires from the WEP. It gets drawn from a triangular distribution with minimum 10 %, mode 50 % and maximum 100 % of the current year's amortization of the WEP in question and represents its maximum balance.

Table 3.4: Statistics of the Setup. P corresponds to the nominal power. Source for actual data: Bundesverband WindEnergie (2020c)

	Simulated			Actual	
Year	Avg. P / kW	Added turbine count	Total added P / MW	Total added P / MW	Added turbine count
2000	1113.21	1495	1664.46	1665.00	1495
2001	1275.02	2080	2653.89	2659.00	2079
2002	1389.40	2337	3246.71	3247.00	2328
2003	1553.15	1690	2634.22	2645.00	1703
2004	1696.65	1198	2034.70	2037.00	1201
2005	1713.17	1045	1796.74	1808.00	1049
2006	1858.46	1196	2232.92	2233.13	1208
2007	1868.86	891	1664.00	1667.00	883
2008	1925.69	859	1662.20	1665.00	866
2009	2019.36	945	1915.48	1917.00	952
2010	2040.14	751	1539.21	1551.00	754
2011	2320.02	900	2079.63	2085.00	895
2012	2412.86	998	2414.30	2415.60	998
2013	2588.84	1157	2990.78	2998.41	1154
2014	2685.82	1761	4740.80	4750.26	1766
2015	2727.47	1369	3729.17	3730.95	1368
2016	2843.23	1622	4618.83	4625.00	1624
2017	2966.08	1792	5317.80	5333.53	1792
2018	3226.36	741	2399.06	2402.00	743
2019	3340.36	315	1061.95	1078.00	325

Initial interest An interest rate needs to be assumed from the bank prior to the rating in order to simulate the cash-flow during that process and get the actual interest rate as a consequence. As it can be seen in table 3.7 the actual interest rate ranges between 1.20 % and 7.81 %. Thus, for the sake of simplicity this parameter is set to 2.5 % which is the median of the interest rates from table 3.7.

Maintenance company risk multipliers There is no direct connection with the manufacturers/service company but for the ranking the banks will get the official financial status (okay or critical) of the company what will be included into the wind parks rating. If the maintenance company has the status "okay" nothing will be altered (multiplier of 1). If the status is "critical" the maintenance costs are assumed to be double to account for a possible bankruptcy what could imply higher expenses (see section 2.4.2).

Table 3.5: Input values with their corresponding min and max for the rating.

	Minimum Value	Maximum Value
Nominal power	1000 kW	10^5 kW
Initial asset	0 €	10^6 €
P50 Load capacity	0.16	0.57
Std load capacity	0.02	0.10
Construction cost	600 €/ kW	1200 €/ kW
Average fix costs	1 € / kW	50 € / kW
Initial interest	1 %	8 %
Maintenance costs	0.008 € / kWh	0.060 € / kWh
Compensation	0.01 € / kWh	0.30 € / kWh
Required reserve aim	10 %	100 %
Repayment-free years	0 a	3 a

Rating

The rating is the central task of the bank in this study. Projects that are likely to fail during their lifetime will receive a bad rating and are unlikely to get realized. As the bank is asked by a WEP for a loan during their commissioning, they also obtain the necessary input values which can be seen in table 3.5. The detailed explanation of the rating model is given in Appendix C.

A problem that appeared during construction of this model was that the rating model was not fast enough to run enough experiments for a robust interpretation of the data in a reasonable amount of time. Thus, it is replaced by a trained *Multi-Layer Perceptron* (MLP) which is a supervised feed-forward artificial neural network. In summary, it consists of three parts: an input layer where each of the input parameters represents one node, a number of hidden layers of a certain size, and an output layer which in this case would have one node, namely the probability of default (PD). Nodes contain one single value and are connected to all nodes of the adjacent layers. For further information on this type of machine-learning algorithm, there is extensive literature such as Hastie *et al.* (2009).

In order to train the neural network, a training set was generated by running the above-mentioned rating model 500,000 times with inputs ranging between the minimum and maximum values given in table 3.5. 75 % of these inputs-output combinations were used to train the network while the rest is used to test and verify the result as seen in figure 3.10.

Some optimisation techniques have been applied during the process in order to maximise the quality of the neural network. Firstly, neural networks converge faster when their input values are close to zero (LeCun *et al.*, 2012). Thus, the inputs are normalized between the minimum and maximum which then correspond to 0 and 1. Secondly, the performance of this machine learning algorithm is sensitive to its dimensions namely the width and number of hidden layers. This and the L2 penalty parameter is optimized by running the neural network training with full factorial sampling and selecting the best test sample correlating neural network. The number and the size of hidden layers ranged between 5 and 70 with 5 step increments. The penalty parameter was drawn from the list of 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7}, 10^{-8} and 10^{-9}. Figure 3.9 visualises the results and a neural network with a size of 65 layers and 65 nodes per layer with a penalty parameter of 10^{-8} showed to have the highest correlation of determination $R^2 = 0.998$. Figure 3.9 also shows that further improvement with higher numbers of nodes and layers cannot be expected.

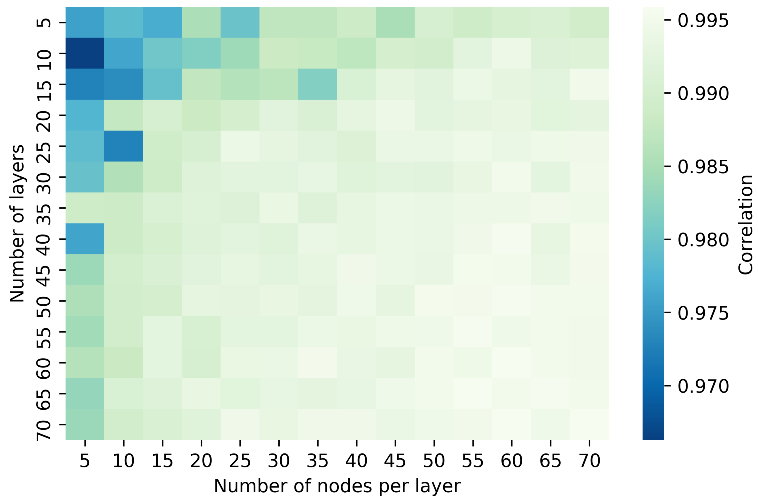

Figure 3.9: Visualization of the highest correlation between the training set and the corresponding output from the neural network in function of the size and number of nodes.

Conversion of Probability of Default to Rate of Interest

In the previous section the rating has been explained which results in a probability of default (PD). The KfW offer matrices in Kreditbank für Wiederaufbau (2014) and Kreditbank für Wiederaufbau (2020) which help to translate a PD into an interest rate. In general, PDs are first converted into rating classes and every rating class corresponds to one interest rate. In order to make projects comparable, the project probability of default needs to be normalized to the 1-year probability of default given the formula 3.4 where the PD is the project PD, p_d is the 1-year PD and rt is the credit run time.

$$p_d = 1 - \sqrt[rt]{1 - PD} \tag{3.4}$$

Then they classify the creditworthiness according to the 7 classes which are shown in table 3.6 (Kreditbank für Wiederaufbau, 2014).

The KfW offers a variety of products for different occasions ranging from company loans for innovation or climate protection, as seed capital for start-ups or even to private citizens for renovation and so forth. Regarding renewable energies,

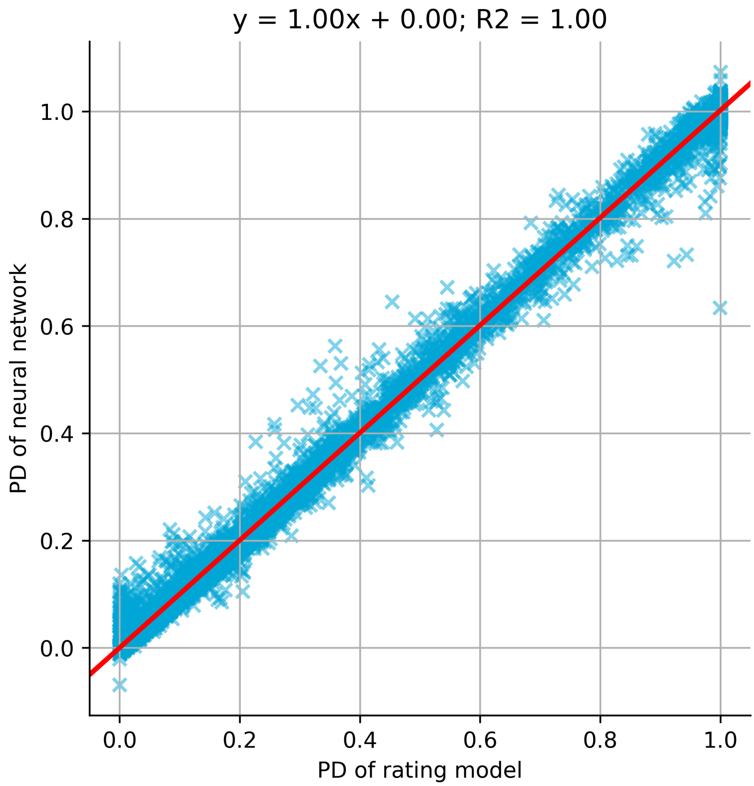

Figure 3.10: Validation of the neural network using the testing set including a linear regression.

Table 3.6: Credit rating class with the corresponding PD margin. Source: Kreditbank für Wiederaufbau (2014). The "Remainder" class is added for the sake of completeness.

	1-year probability of default	
Rating class	Lower bound (exclusive) / %	Upper bound (inclusive) / %
1	0.0	0.1
2	0.1	0.4
3	0.4	1.2
4	1.2	1.8
5	1.8	2.8
6	2.8	5.5
7	5.5	10.0
Remainder	10.0	100.0

the KfW offers 8 products[2] while only one is suitable for financing on-shore wind energy: Product 270. The Standard program with 15 years of run time, 3 years without amortization and 15 years of binding interest of this credit offering maps for each price class A to I the effective rate of interest as given in table 3.7.

Table 3.7: Credit price classes with the corresponding interest rates Kreditbank für Wiederaufbau (2020). ERI standing for "Effective Rate of Interest"

Price class	A	B	C	D	E	F	G	H	I
ERI / %	1.20	1.60	1.90	2.41	3.02	3.74	4.26	5.40	7.81

The two tables 3.6 and 3.7 are mapped together via a matrix that depends on the loss given default (LGD) (see Kreditbank für Wiederaufbau, 2020). It is assumed here that with wind energy project it is possible to recuperate more than 70% of the exposure at default what maps the two mentioned tables together as given in table 3.8. The resulting interest rate is then offered to the requesting WEP.

External Influences

Banks are not affected by meteorological or technical factors. It is unlikely that the bank's playing field changes from the political intend to support wind energy in particular as there are easier ways to subsidize wind energy. Other reasons would be more substantial and difficult to foresee within the scope of this study.

3.3.4. Maintenance Companies

Maintenance companies have a rather passive function in this model. Their main task is to keep track of their finances, provide the WEPs with information on the cost of maintenance and being able to receive payments.

[2] www.kfw.de/inlandsfoerderung/Unternehmen/Energie-Umwelt/Erneuerbare-Energien-Umwelt/

Table 3.8: Credit rating class with the corresponding PD margin and effective rate of interest (based on Kreditbank für Wiederaufbau (2014)). LB and UB stands for "Lower Bound" and "Upper Bound" respectively. The "Rest" class is added for the sake of completeness.

Rating class	LB 1-year PD (excl.) / %	UB 1-year PD (incl.) / %	ERI / %
1	0.0	0.1	1.20
2	0.1	0.4	1.20
3	0.4	1.2	1.60
4	1.2	1.8	1.90
5	1.8	2.8	2.41
6	2.8	5.5	2.41
7	5.5	10.0	5.40
Remainder	10.0	100.0	—

Minimum Required Income

To assess the economic situation of turbine manufacturers and maintenance companies, it seems reasonable at first to implement the same of financial balancing method as for WEPs (see section 3.3.2). However, the finance of an actual company is far more complex than the one of a wind turbine project. Companies are able to raise external funding, increase their liquidity by selling different kinds of assets and reduce their cost by slowing down research and innovation or laying off workers (the latter has been done by *Enercon* in 2019 (Bundesverband WindEnergie, 2019b)). In addition, most companies whose shares are not publicly traded, do not publish their financial reports and are not willing to communicate detailed information about their economic situation.

Consequently, the following is implemented in this model to approximate a balance: A company becomes insolvent if their income is lower than a certain percentage of the income of a reference year. This year is 2017 because it resembles the best year for wind energy in Germany due to the highest number of wind turbines are installed in that year as well as being in operation (see figure 1.1).

Income Margin

The wind energy sector has shifted from a turbine market to a service market where "margins for services are reportedly above 20 % while margins for turbine supply are below 10 % [...] However, the latest data shows this gap is narrowing" (New Energy Update, 2019). This can be affirmed by the example of the Danish manufacturer *Vestas* which declared an EBIT margin from 2019 Q1 to 2020 Q1 of 20.8 % to 28.4 % for service and turbine supply ranging from -6.6 %[3] to 11.1 % (Vestas Wind Systems A/S, 2020a). Thus, both the income from maintenance and construction are important and must be considered.

As mentioned above, it is already known how much the owners of WEPs pay for maintenance and construction. Due to a lack of more specific information,

[3]This negative margin is caused by "lower average project margins where logistical challenges and supply chain bottlenecks, commissioning of delayed projects from 2019, and the COVID-19 situation increased cost levels." (Vestas Wind Systems A/S, 2020a)

Table 3.9: Total revenue for each company in 2017 calculated from the setup data based (see section 3.3.2).

	Reference income from service / Mio. €	Reference income from construction / Mio. €
Enercon	437.49	2343.76
GE-Wind Energy	11.44	381.829
Nordex	19.45	511.238
Senvion	21.37	535.893
Siemens Gamesa	4.40	213.326
Vestas	284.84	1186.93
Deutsche Windtechnik	166.22	0
Enertrag Service	235.01	0
Enova	2.13	0
PSM	38.46	0

the revenue per commissioned WEP is then assumed to be the construction costs times a percentage per company drawn from an uniform distribution between 5 % and 10 % representing the margin. In analogy, the yearly income from service is between 20 % and 30 % of the payment.

For the reference turnover from 2017 the WEP setup is used (see section 3.3.2) and can be seen in table 3.9. Validating these numbers is difficult as most companies either do not show their exact number or do not provide them disaggregated enough to have a figure for on-shore wind energy in Germany.

Maintenance Costs

When receiving an application from a wind farm, an offer for service contract is returned. Finding exact figures is difficult since they are mostly disclosed since it is a private sector. However, according to Svoboda (2013) the yearly maintenance costs are about 1.5 % of the initial investment costs for on-shore wind turbines. Deutsche WindGuard (2013, p. 33) suggests about 10.5 €/MWh for maintenance and repairs. The two sources are comparable when combined with the fact that on average around 1500 full-load hours' worth of energy have been harvested in Germany in 2013 (the year of both studies) (Fraunhofer IWES, 2020) and 1180 €/kW (Deutsche WindGuard, 2015). As technology moves on and it will be expected that the turbines' construction costs decrease while their power increases (see chapter 3.5.3) A triangular distribution is used in this model to draw the maintenance costs with 0.8 ct/kWh, 1.05 ct/kWh and 1.3 ct/kWh of annual yield as the minimum, mode and maximum, respectively.

External Influences

It is assumed that the manufacturers do not experience any external influences.

3.4. Calibration

The number of WEPs that are necessary for the project is highly uncertain. For a deeper understanding of the problem and calibration of the model, figure 3.12 and 3.11 shows the bid prices of 1000 WEPs in the first year of simulation. All uncertainties are set in such a way that they represent the situation of 2019. The percentage of abandonment due to a lawsuit is set to 20 %. The dotted vertical line indicates the current maximum accepted bid of 6.2 ct/kWh. The first insight that this visualisation delivers is the fact that the bid prices can be approximated with a normal distribution. Secondly, the higher the average load capacity, the higher the average load capacity, the lower the bidding prices and the narrower the spread.

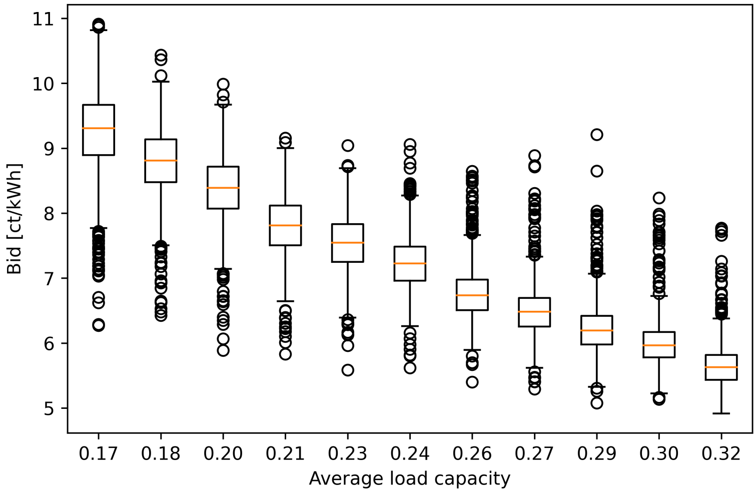

Figure 3.11: Boxplot representing the distribution of bids in function of the average load capacity

In section 3.3.2, Mackensen *et al.* (2019) was cited for the fact that newly installed turbines are estimated to deliver a long-term average of 2788 full load hours. This is the equivalent to an average load capacity of 0.318. However, figure 3.12 shows that this cannot be the case as too many wind turbines would participate in the bidding, which is not the case as seen in the last two years (see Deutsche WindGuard, 2020). The reason is that Mackensen *et al.*'s (2019) findings only consider the wind turbines on the left side of the 6.2 ct/kWh-bid-mark. Thus, it cannot be considered as the global average load capacity that can be used in the model.

In order to calibrate the model correctly, the number of initial WEPs and the global average load capacity have to be set in such a way that the tail below the dotted line of figure 3.12 sums up to around 88 WEPs commissioned in 2019 (see initiation of the model in section 3.3.2). If the number of WEPs is chosen too high, the model's performance suffers. If it is set too low, the model is not capable to describe a situation correctly in which more WEPs can be accepted due to better conditions. The combination of 1000 new WEPs per time step and a global load capacity 0.265 (see lower left of figure 3.12) is used for this model as it approximates the number of WEPs that would get accepted compared to 88 WEPs for 2019 and the average load capacity of accepted WEPs (0.322 compared to the actual 0.318 (Mackensen *et al.*, 2019)). However, this decision must be taken into account during further discussion as it is made under the premise of an increase in available sites, if the maximum bid is increased.

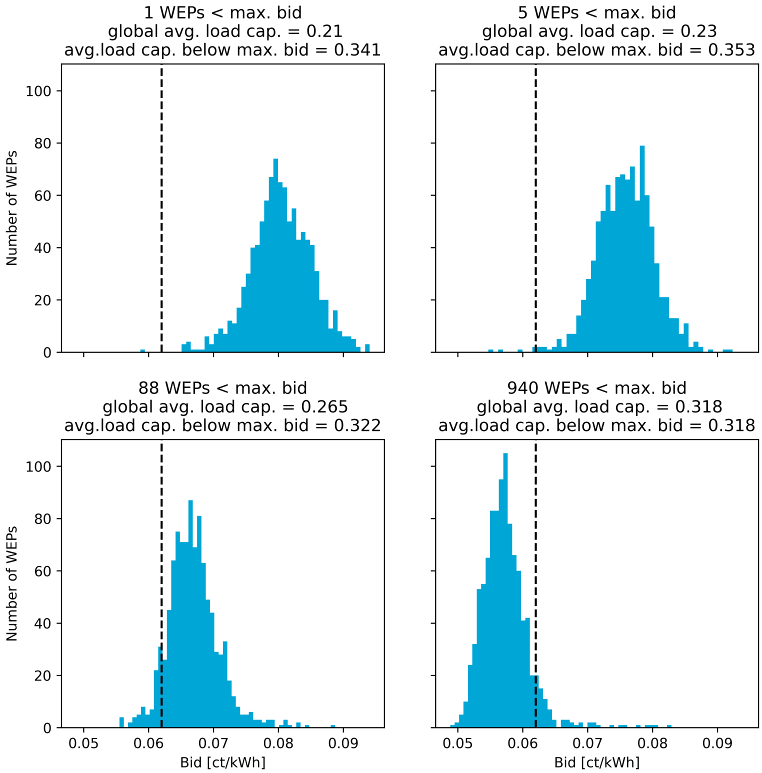

Figure 3.12: Distribution of bid prices in function of the global average load capacity

3.5. Experiment design

3.5.1. Outline

Since the aim of this study is to better understand under which condition a slump happens, the experiments should explore the uncertainty and lever space which is mapped via the model to outputs that can then be categorize.

3.5.2. Levers

In the following section the ranges of the levers which were introduced in section 3.2.3 are explained.

Maximum Bid

According to *EEG 17* (2016, § 36b), the maximum compensation should be 8 % higher than the highest accepted bid from the last 3 bidding rounds. However, in 2019 the maximum compensation at every bidding round was fixed to 6.2 ct/kWh (Deutsche WindGuard, 2020) and remains the same for 2020 (Plazzo, 2019). In the previous EEG 14, the first and second subsidy stages were set to 8.9 ct/kWh and 4.95 /kWh for reference. The maximum compensation in this model ranges between 4 ct/kWh and 10 ct/kWh to accommodate all eventualities.

Bidding Volume

The law states that from 2020 on, in February 1000 MW and in June and October 950 MW of power can be installed and is increased or decreased by the difference between the desired volume and the actually accepted one in the previous year (*EEG 17* 2016, § 28). For reasons of simplicity the bidding volume will range between 800 MW and 4000 MW per year.

Additional Costs

As mentioned in section 2.2, the German parties SPD, Grünen/Bündnis 90 and die Linken want to increase public acceptance using participation and inclusion of the local public. One suggestion is that the developer pay the community their WEP is situated in a "fee" of 10,000 € per turbine per year. This suggestion is implemented, and the additional costs will range from 0 € to 20,000 € per turbine to account for all eventualities.

Distance to Households

The alternative proposition which is suggested by the CDU (see section 2.2), is a higher distance between households and the closest wind turbine from the current 600 m to 1000 m. The range that is implemented in this project is based on Lütkehus *et al.* (2013, p. 38). A sensitivity analysis of the available space in function of the distance to households was performed and ranges from 600 m to 2000 m. A range between 600 m and 1300 m is explored in this study. This limitation is discussed in Appendix D.

3.5.3. Uncertainties

In analogy to the previous section 3.5.2, this one will explain the ranges for the uncertainties given in section 3.2.3.

Technological Development - Nominal Power

Thanks to innovation on almost every part of a wind turbine, the nominal power of installed wind turbines has increased every year since 1997 as it can be seen in figure 3.13 (Deutsche WindGuard, 2019b). An almost consistent increase of around

100 kW per year can be observed. However, it is uncertain if this trend will continue. A reduction seems unlikely but technical and juridical limitations can slow down the development or even bring it to a halt. Thus, the normal distribution of the nominal power as given in section 3.3.2 will shift each year in the range between 0 kW and 200 kW.

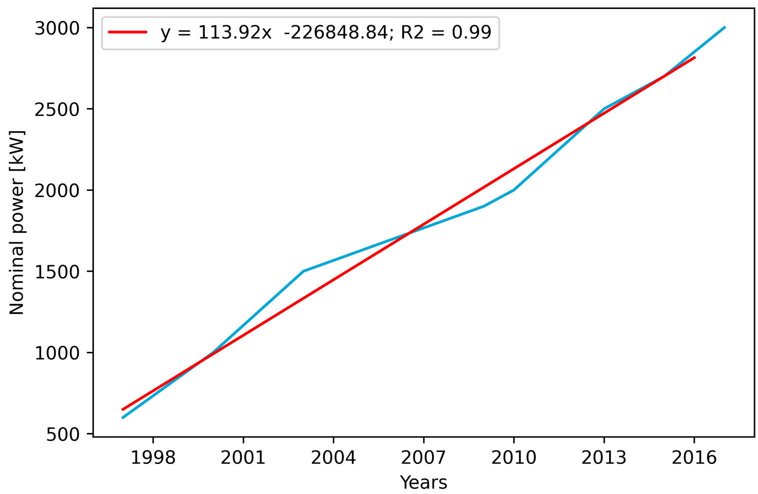

Figure 3.13: Development of the nominal power P_t per newly installed turbine over the years including linear regression. Source: Deutsche WindGuard (2019b)

Technological Development - Fix Costs

According to Deutsche WindGuard (2019b, p. 85) fix costs seem to have decreased per kW of installed capacity over the years in every aspect besides leases which have outweighed the rests. Thus, the average fix cost per kW (excl. maintenance costs) increased from 27 € in 2014 to 2016 to 28 € in 2019 to 2020 (Deutsche WindGuard, 2019b, p. 83 - 84). This is change is marginal. Thus, all what can be assumed is that the trend of the fix costs is unknown but will be marginal. As a consequence, the uncertainty will range from -0.5 €/kW a to +0.5 €/kW a corresponding -5 to 5 €/kW over a course of 10 years.

Technological Development - Construction Costs

Construction costs have grown in the last years mainly due to an increase in planning complexity, increasing the share of the total additional investment costs from 19 % in 2014 to 2016 to 29 % in 2019 and 2020 (62 €/kw to 117 €/kW respectively) (Deutsche WindGuard, 2019b, p. 77). However, all other sources of costs have not changed significantly over the years and variations that are given by this study are mainly due to the variation in the samples (high variance as the authors explain). In this study a variation of $\pm$10 €/kW a is assumed (corresponding to 100 €/kW in 10 years).

Minimum Income of Maintenance Companies

As this uncertainty is deeply unknown and could vary widely based on the ability of the company to adapt, the percentage in relation to the 2017 base case (see section 3.3.4) can range from 5 % to 90 %. 0 % is unreasonable as otherwise they could continue to exist even without any income and 100 % is avoided as they would have been bankrupt by now already.

Probability of Lawsuits and Abandonment

Currently about 20 % of all approved WEP face a lawsuit (Quentin, 2019, p. 20). Whether this percentage will fall or rise in the next years is unknown. Thus, this study will assume a rise or fall of 10 % per year at maximum. The rate of abandonment due to the lawsuits is uncertain. Therefore, a range of 0 % to 90 % is assumed.

Maximum Potential Yield

While the results of Lütkehus *et al.* (2013) is used to model the reduction in site quality, the actual maximum potential yield cannot be adopted directly. These almost 2897.87 TWh/a have been calculated using a single type of wind turbine plus not every potential site can be made available as there could be are many reasons for not installing a wind turbine on these areas. Thus, this value is reduced by a factor which ranges between 25 % and 100 %. This range is set due to reasons discussed in Appendix D.

Number of Generated Wind Parks

The number of WEPs that are assessed every year is difficult to estimate as statistics about not realized projects are not available. In 2014, a survey found out that one out of 5 to 10 projects that are initiated are commissioned (Rohrig, Berkhout, *et al.*, 2015, p. 92). For 467 WEPs installed in that year according to the model setup that will be used (see section 3.3.2), this corresponds anywhere between 2335 and 4670 WEPs. However, these number are not representative anymore since it became more difficult to find a site, more lawsuits are filed and a bidding process has been implemented since then. The difficulty in the estimation of this parameter lies in order in which these projects are developed. This normally, the financial viability is assessed before permissions are requested, this model assumes that permissions are granted and then assesses the financial status. If developers see that there is no chance to have financially viable project with the current cap on subsidy they are abandoned and not pushed forward. For the WEPs' setup procedure (see section 3.3.2), 88 WEPs are initiated and "build". If the 20 % of lawsuits is assumed and between 0 % to 90 % abandonment rate, this results in 88 to 105 of new WEPs necessary to simulate the yield of 2019. This drop of two orders of magnitude between 2014 and 2019 cannot be explained neither by the above mentioned three changes over the time. This will be discussed further in section 3.4.

3.5.4. Technicalities

The model is written in Python 3.7 and using the Mesa library[4] version 0.8.7 as the framework for the ABM which already provides a scheduler and a data collection function. As the software implementation of neural network, the "MLPRegressor" of the renowned Python library *Scikit-learn*[5] version 0.20.3 is used. The EMA workbench version2.0.8 (J. H. Kwakkel, 2017) is used for the sampling and running the simulations. It provides an easy way to connect the model and includes state of the art samplers which allow an even exploration of the uncertainty space. The range of the dimensions from which the samples are drawn are given in the following sections 3.5.2 and 3.5.3. The number of runs is given in chapter 4.

3.6. Validation

3.6.1. Definition and Validation Process

What the validation of a model is, is a contested a matter in the literature. While most scholars agree that validation is the process of confirming that a model is consistent with the intended application of the model, there are two opposing understanding what "the intend" of a model is (Barlas and Carpenter, 1990). On one side, authors such as Schlesinger (1979), Moss *et al.* (1997), Galán *et al.* (2009), Sargent (2010), and Bharathy and Silverman (2013) see the purpose of a model to represent the reality as good es possible. Especially Sargent (2010) provides numerous techniques to compare models with the corresponding real system what then confirms its validity.

On the other side, the purpose of a model is often seen as an assistant tool to make an argument. To quote Oreskes *et al.* (1994): "Validation does not necessarily denote an establishment of truth (although truth is not precluded). Rather, it denotes the establishment of legitimacy, typically given in terms of contracts, arguments, and methods". Here the idea is that the model is valid, if it can create confidence and can convince the critical reader from the point the author wants to make and should help to understand the system (Van Dam and Nikolic, 2012). Barlas and Carpenter (1990) described this approach as "inherently a social, judgmental, qualitative process: models cannot be proved valid but can be judged to be so".

Even though, the two "types" of validation seem to differ their quantitative versus qualitative nature, they both aim for the same result: to increase confidence in the model either by critical reasoning or by simple data/behaviour comparison. These two approaches are applied in the following sections in context of this model where they seem most feasible. In other words, were a comparison with the system that it should mimic is possible, this will be done. Otherwise its validity is discussed in a qualitative matter. In the following, the possibility of historic replay, face validation through expert consultation, literature validation and model replication are discussed which are methods found in both Van Dam and Nikolic (2012) and Sargent (2010). In addition, the validity of the key assumptions made during

[4] mesa.readthedocs.io
[5] scikit-learn.org

3

the model construction are argued.

To discuss the validity of the model, it is important to understand the intended application of the model as already mentioned. The aim of this study is to investigate the reasons behind the stagnation of the wind energy sector from a financial point of view. Since the major change of the EEG 17 is the introduced bidding system its influence on the commissioning of wind parks is of high interest. Thus, the model's purpose is to replicate the financial side of WEPs and the bidding process. This thesis' attention is primarily on that part and therefore it is modelled in great detail. The inclusion of the public acceptance as an input parameter was as important as the modelling of the MC/TMs since they both help to link this study to the current debate and see the implications of the stagnation, respectively. However, modelling them in detail would be out of scope of this thesis due to their complex nature. The assumption that had to be made here are the weaknesses of the model. The result is that the model is invalid for qualitative purposes. The numbers given in chapter 4 about the future state of wind energy in Germany are not robust enough for further use but rather give an indication of the trends and weights. A precise forecast is not the purpose of this model neither is it intended.

3.6.2. Historic Replay

During a historic replay it is tried to recreate the past using the model. A validation with that outcome is not possible in this case. The only year that have used the same subsidisation scheme as the model is 2019 since 2017 and 2018 formed a transition period from the previous law and dynamics originating from it might not be captured with the model. A validation on one data points does not have any informative value. As Van Dam and Nikolic (2012, p. 127) puts it: "Validation cannot simply compare computed behaviour to 'real' system behaviour if there is no 'real' system available for comparison or if the model is exploring possible future states."

3.6.3. Validation through Experts

The consultation of experts can be done to validate the subsystems of the model but also, the outcome of the entire model can be discussed in that part. Both maintenance companies and wind energy project developers have been reached out to. The aim was to verify key assumptions and information and get feedback for the finding of the project. Appendix E shows in detail which stakeholders have been contacted and what question have been asked. Unfortunately, by the time of writing non has answered the E-Mail. Consequently, a validation through experts could not be performed.

Regarding the rating, a similar version to bank's rating has been validated through experts of the bank *Oldenburgische Landesbank*. The differences lie in the depth of the inputs, but similar results could be obtained for several cases.

3.6.4. Validation through Literature

Regarding literature validation, in chapter 5 the results will be compared to other studies. Since the outcome of this thesis is an alternative to the current explanation of the phenomenon that is currently happening, the number of comparable literatures is small.

3.6.5. Validation of Key Assumptions

The model was built in such a way that it uses as much available data as possible in both simple data and the algorithms and interactions. Fortunately, most of the processes such as the bidding or income and cost calculation are well documented in the law (*EEG 17* 2016) or the standard literature (Gasch and Twele, 2016). However, during the construction of the model assumptions had to be made as there was a lack of access to certain information or simply it was out of scope of this thesis which make them the weak points The most crucial assumptions are (I) the modelling of limited space via the reduction factor r, (II) the economics of turbine manufacturers and maintenance companies, (III) public acceptance/lawsuits, and (IV) the assessment of credit-worthiness. These aspects are discussed in the following.

Modelling of Limited Space

A wind park cannot be constructed anywhere. Positioning next to an airport or in the centre of a city is prohibited but they also cannot be positioned where another wind park is. Due to shading effect with other wind parks they cannot even be build right next to them. Therefore, one of the main concerns of the pro-wind-energy party is the limitation of viable sites. Thus, it needs to be considered.

It is also a valid assumption that wind energy project developers try to maximise their profit by focus their resources on better sites than on worse. Their interest in optimizing their income-cost-ratio results in the optimization of the load capacity which is confirmed by Gasch and Twele (2016, p. 152f). The load capacity tends to be higher in places with a high quality wind regime like near the coast as there are costs that do not scale with the yield or the nominal power which than have to be made up for with selling more electricity. It would be possible to build wind turbines with a large rotor diameter and an extremely small generator which reaches nominal power already at very low wind speeds resulting in a load capacity of nearly one. The consequence would be that fix costs such as the construction of infrastructure needs to be paid with less yield. This would increase the cost of electricity significantly. Oppositely, lower wind speeds mean lower load capacity needs even though the WEP developers try to optimise it as much as possible. While a more sophisticated submodel using geoinformations, weather data, catalogue of wind turbine models which simulates the blocking of available sites would have been a more precise option, the reduction of load capacity would still have been the outcome anyway.

The difference between the two approaches would have been how the reduction would play out with an increasing (or decreasing) population of wind parks. For this the curve from Lütkehus *et al.* (2013) as adapted and the process of implementation in the model is extensively described is section 3.3.2. The scale and *exact* shape of this curve is open for discussion as it was generated using one wind turbine type plus the actual viability or legality of the site was not considered in detail. "Legal" in the context of compliance with not being situated in a protected landscape, too close to households, etc. These projects could still be appealed due to other reasons in reality. The scale is subject to deep uncertainty as the "maximum yield factor". In addition, Appendix D shows that in most cases, the shape and especially the final drop originated by a high number of wind parks (see figure 3.7) does not have a major impact in most cases. In most cases the reduction is (almost) linear. As it can be seen in figure D.2, the reduction is only noticeable with high numbers of wind park, min. distance and a low max yield factor. This does not mean however, that small percentages cannot not make a difference. The impact will be further discussed with a sensitivity analysis in section 4.1.

Economics of Turbine Manufacturers and Maintenance Companies

Due to their strong connection to the well-being or simple existence of wind turbines, they are an essential part of the system and needed to be included in the model as a consequence. The problem that arises is the complexity of modelling companies and especially multi-national ones. Whether their financial health is good or bad depend on a variety of factor. Therefore, it was decided that modelling the economics of these companies is not an option. This is the reason why the uncertainty "percentage of minimal income to the 2017 base case" was introduced and the income was simulated based on their market share and consequent portfolio. Reaching this minimal income cannot be linked with an automatic insolvency of the company in question. It can rather be seen as an indicator that by the time this point is reached some major restructuring had to be gone underway in that company. While a bankruptcy by one of the smaller companies with (as an example) 10 % of the income compared to 2017 is likely to happen, for companies like *Vestas* is would mean a restructuring (maybe selling) of their German division. In addition, it must be stressed that the EBIT margins change drastically over time and might not be representative for the actual company. Thus, the outcome of the manufacturers should and is considered in the result and discussion chapter as a rough indicator of the healthiness of the wind energy sector and not as a quantitative output of the model.

Public Acceptance

Public acceptance and especially in the case of wind energy is extremely complex. The literature review on public acceptance in section 2.3 showed that due to the social gap data on public acceptance in certain areas is next to useless. Thus, modelling this section was not an option. Thus, public acceptance became an uncertainty lever in this study. Similar to the minimal income for turbine manufacturers and maintenance companies, it is required to interpret the results regarding public acceptance in an qualitative way since its impact and origin is more complex than just than a share of WEPs being delayed or abandoned.

However, taking public acceptance into account only via an input parameter is not a problem for the usefulness of the model since its primary aim is to help to understand the finances of wind energy projects and not the causes which are extensively studied by other authors.

Assessment of Credit-Worthiness

As already stated in section 3.3.3, it is difficult to obtain inside information regarding ratings as it is a company secret. Fortunately, the KfW provided precise information on how a project's probability of default is translated into an interest rate. However, if the PD is correct is open to discussion. The approach, which is described in Appendix C, requires as little calibration as possible and due to the validation of similar model by experts from the *Oldenburgische Landesbank* (see section 3.6.3) the confidence in the validity is high.

4
Results

Since the aim of this study is to increase the understanding of the system and show under which conditions the wind energy development stagnates, three experiments are performed and the results are showcased in this chapter. First, a sensitivity analysis on all input parameter is done. This indicates which factors are the most influential and which do not change the outcome significantly. Second, it is interesting to see what the upcoming years would look like, if the EEG keeps unchanged. At last, also the levers are adjusted to see what is possible and if the current scheme is capable of reaching the primary goal. The following sections are structured in such a way that the first paragraph outlines the experiment design while the remaining explain the findings.

4.1. Sensitivity analysis

The aim of a sensitivity analysis (SA) is to "quantify the relative importance of input variables or factors in determining the value of an assigned out variable" (Saltelli, 2020). In other words, the result of a sensitivity analysis is to assess which input parameter is the most effective on influencing the model's output. For this purpose, the variance-based SA by Sobol (2001) is used. Since the result of a Sobol SA depend on the sample size and converge with a sufficiently high number. Therefore, studies such as Sarrazin *et al.* (2016) and Jaxa-Rozen and J. Kwakkel (2018) show in detail how this number can be estimated by optimizing the sample size to fulfil the convergence criteria. However, these techniques are resource intensive and not suitable for the run time of this model. Thus, in this case 60,000 samples of the parameter space are used which is assumed to be high enough. The result can be seen in figure 4.1 and is compared to the SA of a portions of this dataset. It showed that after 30,000 samples the variation is minimal. In figure 4.1, two indices are shown for each input parameter. S_1 is the first order index and measures the contribution to the output variance by that input alone. S_T represents in analogy the contribution to the output variance by the interaction with all other input parameters.

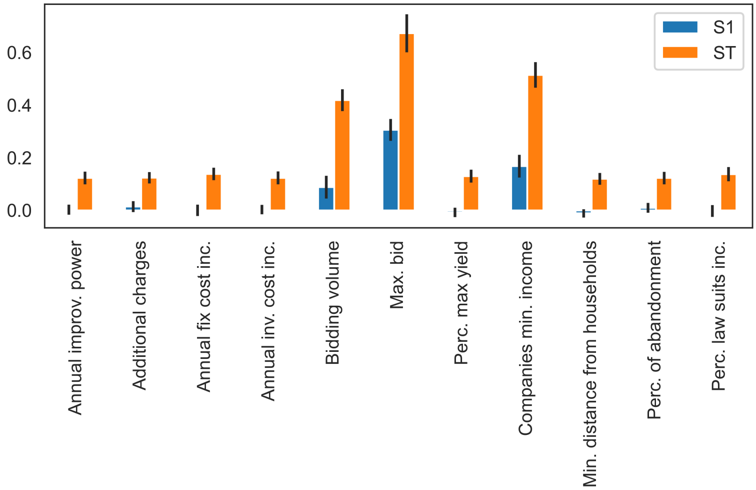

Figure 4.1: Sobol sensitivity analysis on all input parameters.

The results show that the policy levers defining the bidding process have the most influence on the annual yield expected in 2030. The system is especially sensitive to the maximum bid. A high S_1 index can be interpreted as by only increasing the maximum bid, a change in the yield can be achieved. A low S_1 index but a high S_T index for the bidding volume can be explained by the fact that this restriction is only noticeable when enough WEPs are able to take part. This is however dependent on other factors. Interestingly, additional charges and the min. distance from households as implemented in the model do not influence financial situation of wind energy projects significantly.

The most influential uncertainty is the minimum income from maintenance companies and turbine manufacturers which is validated by the findings in with the base case in section 4.2. All other uncertainties have a similarly limited influence and cannot change the outcome on their own since the cap induced by the bidding process is so dominant. What is interesting is the low influence of the lawsuits and abandonments which are thought of to be critical are part of it.

4.2. Baseline Behaviour

This section discusses the base case: *What would happen if the current system is not changed and would remain the same?* Currently, the maximum compensation is set to 6.2 ct/kWh and (Deutsche WindGuard, 2020) and 1900 MW of annual bidding volume. Addition fees or a decrease in projects is not part of the policy yet. Thus, they are set to the defaults of 0 €/a and 600 m, respectively. To sample the parameter space, a Latin Hypercube Sample of 1000 different scenarios is used and each is repeated 10 times. The latter has been done to reduce the variability due to random variations within the model. Naturally, the higher the number of repetitions, the smaller the said variability. The 10 repetitions are the result of a trade-off between resources and accuracy. Figure 4.2 shows the results as the yearly yield over the years. The aim for 2030 is a 65 % share of electricity from renewable sources (Deutscher Bundestag, 2019, p. 31). The German government estimates the electricity demand close but below the current level which in the case of 2019 was 569.2 TWh/a (bdew, 2020). Therefore, 140 TWh to 145 TWh of electricity from on-shore wind energy per year is necessary (Deutscher Bundestag, 2019, p. 30).

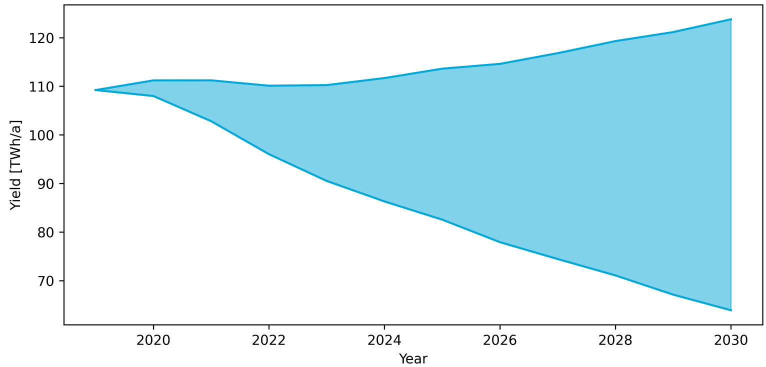

Figure 4.2: Yearly yield over the years for each scenario with the current policy.

The 140 TWh of annual yield by 2030 cannot be achieved in any scenario given the constrains. However, there are two major courses wind energy can have. Either it will decrease in the next 10 years about 40 to 50 TWh/a or there is an increase of maximum 10 TWh/a. Interestingly, this course will be decided after 2021 where the paths diverge significantly. This coincides with the first wave of wind turbine instalments 20 years ago in the year 2000 (see figure 1.1). This is an indicator that the financial health of maintenance companies is important for meeting the energy transition goal for 2030.

To further understand under which conditions the wind energy sector can at least hold its current state of development of 101.2 TWh/a (bdew, 2020), a Patient Rule Induction Method (PRIM) is used to find the ranges in the uncertainty space where these scenarios are most likely to happen. Bryant and Lempert (2010) gives a great introduction to this methodology. In essence, it is an iterative algorithm that "peels away" parts of the uncertainty space were the wanted output is not generated (in this case more than 101.2 TWh of annual yield). The result can be seen as the red rectangles in figure 4.3. The density threshold that a box has to meet is 50 %. If an uncertainty is not listed, its influence on achieving the desired outcome is minimal. Figure 4.3 shows a strong dependence of the health of the maintenance companies. They must be able to continue working with at least 16 % of their income from 2017.

This is also validated by a mapping of average number of bankruptcies per Scenario over the achieved yield as seen in figure 4.4. The main take-away is that

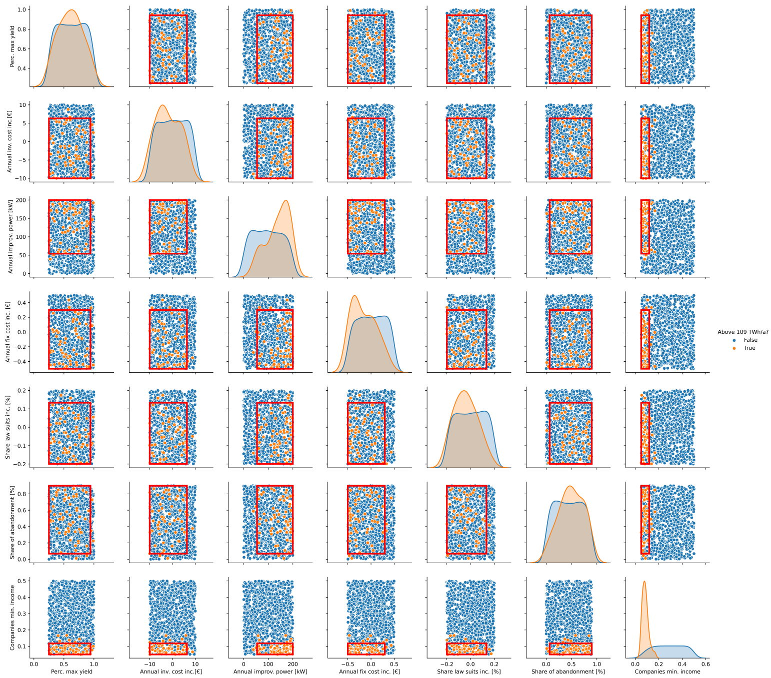

Figure 4.3: PRIM performed on the uncertainties of the base case.

most companies will file for insolvency or need to undergo main revision of their enterprise. Conclusively, the open exploration of scenarios with the current policy shows two key remarks. First, a positive development of on-shore wind energy with the current system can only happen when the sector is able to adapt but the 2030 goal cannot be achieved. And secondly, a thinning out of the wind energy sector is unavoidable. That means that the companies in the wind energy sector need be able to adapt to a drastic lack of income.

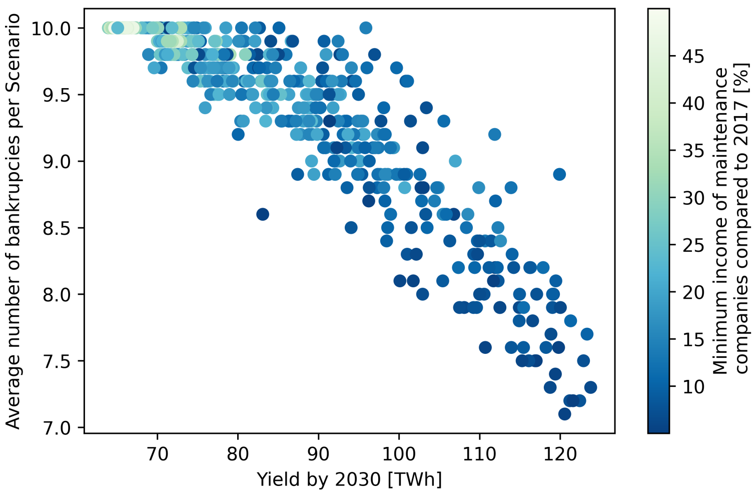

Figure 4.4: Average number of insolvent maintenance companies in function of the yield and minimum income of maintenance companies compared to 2017.

4.3. Alternative Futures

Similar to the previous section 4.2, this section discusses possible future scenarios and their outcome but will include a change in policy as well. The sensitivity in section 4.1 showed that the policy levers have the greatest impact on the system. The number of Latin Hypercube samples of the parameter space is increased to 10,000 scenarios since four more degrees of freedom are added. Each scenario is repeated 10 times again which then are averaged. The total wind energy yield over the years can be seen in figure 4.5.

In contrast to figure 4.2, the goal of the Government of 140 TWh to 145 TWh per year can be achieved by 2030. The lowest outcome remains the same as with the base case. To further understand under which conditions this happens the PRIM is applied in this case as well but with a threshold of 140 TWh for annual yield in 2030. The dimensions that can be reduced can be seen in figure 4.6. Again, the density threshold that a box has to meet is 50 %.

As expected, the three main influences are the bidding price, bidding volume and the resilience of companies. But also, the percentage of abandonments and

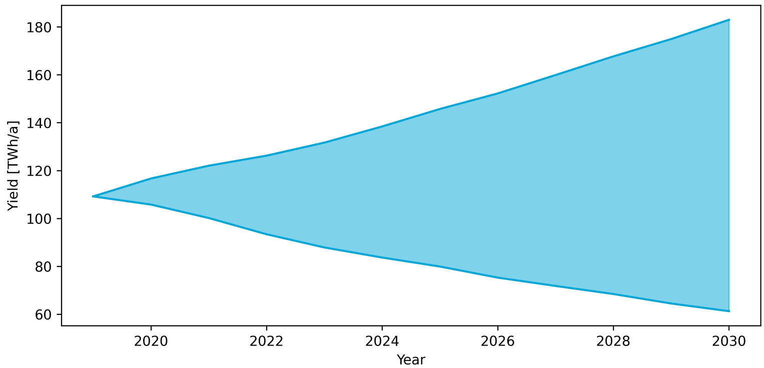

Figure 4.5: Yearly yield over the years for each scenario with varying policy.

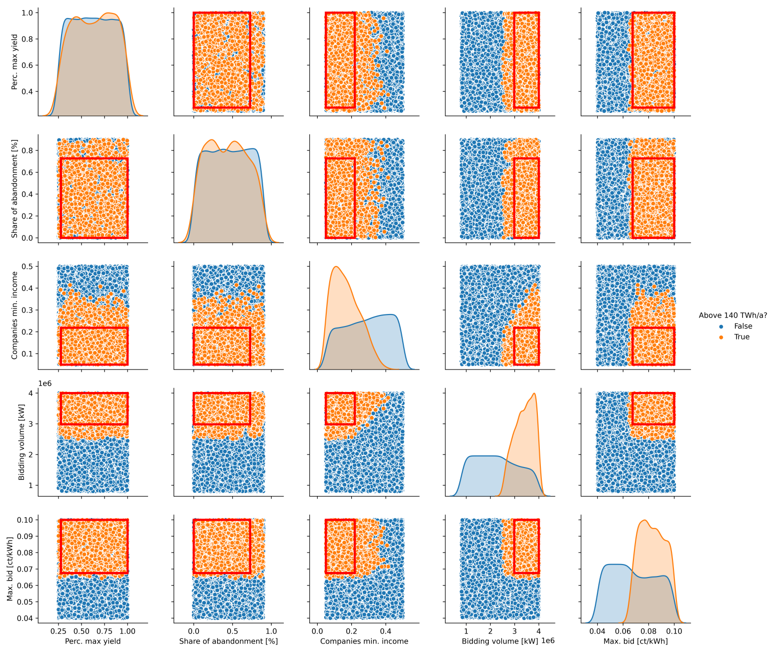

Figure 4.6: PRIM performed on all policy levers.

percentage of maximum yield. The latter comes natural as with lower percentages of max yield, the reduction factor r gets extremely low as it can be seen in figure D.2 in Appendix D. What stands out are the “sharp” edge between surpassing the threshold and not for the maximum bid and the dependence of the outcome on the combination of minimum income of companies and the bidding volume.

5 Discussion

Until now, this study has gathered information from literature and a model has been developed to get insights in order to build up a foundation for this chapter. Chapter 5 aims to answer the research question and its sub-questions.

5.1. Findings and Discussion

What social, political and engineering factors impact the economy of a project owner at all?

The first sub-question regarding the impact of factor on a single project can be divided into social influences, technical/engineering factors and political/economic aspects. An academic literature and newspaper review showed that wind energy developers are confronted with a difficult situation. In general, most of the population nationally and locally near the project site, accepts the construction of wind turbine. However, only few people are enough to delay or stop a project. Therefore, it is not the public acceptance of the average resident that has to be raised, but rather that of the biggest opponents of the project. The root causes of opposition are diverse and might not be reflected by the pleaded reason. An integration of the community into the decision process or distribution of monetary profits can help. However, if these strongest opponents are fundamentally against wind energy as a technology or they are NIMBYs, it is unlikely that inclusion would have an effect. This does not mean that public participation should not be sought, but rather that legal opposition to a wind energy project is close to unavoidable. It has been found that legal opposition contributes economic stress to the project, since it is a significant cost factor in addition to the primary construction cost. Furthermore, it appears before the commission when revenue is generated. As a consequence, it reduces the number of actors capable of withstanding this stress and developing a wind energy project and the number of possible wind energy projects.

Wind turbines are extremely predictable in cost for the project owners. During operation, they do not depend on resources whose price is market driven and thanks to the technological advancements in the last 20 years, wind turbines became efficient and reliable. The residual risk is usually covered by insurances and maintenance contracts. Thus, the only uncertainty impacting the economy of a project owner from an engineering perspective is the wind.

This makes the revenue from selling the wind parks ever so important. The sensitivity analysis in section 4.1 showed that the bidding volume and the maximum bid are the most influential parameters. Thus, the German government has the most effective tools to their disposal for shaping German on-shore wind energy. The impact on the finance of additional costs mandated by the government is minimal. The reason is that WEPs that are financially strong enough to take part in the bidding process can withstand the additional stress from royalties to communities as proposed by some political parties in Germany. The other proposal is the increment of distance of planned wind energy projects to surrounding residences. While at first sight the sensitivity analysis indicates a small impact on the yield, it must do with the model implementation. As this factor reduces the maximum capacity, it just makes it harder for project developers to find sites suiting the restriction and be economically viable rather than outright reducing the number. In other words, if the maximum bid is increased enough, it could counteract the negative impacts of that policy. However, studies showed that such a strategy does not have any effect on the acceptance. Since the load reduction factor r is only sensitive in the extremes (see figure 3.7 and Appendix D) where the maximum is small, it does not have a significant effect on the model.

How do these influences affect the industry as a system?

WEPs are dependent on the wind energy industry due to construction and maintenance. Companies depend on a certain portfolio size in order to operate. It is clear that the wind energy sector will go through a big financial turmoil and needs to live with less revenue due to the slump. However, the results of this study shows that achieving the yield goals of 2030 comes with a working wind energy sector. Whether one is caused by the other or vice versa cannot be determined. Nevertheless, it is save to say that a construction and maintenance infrastructures is required to further develop wind energy. With an ongoing slump they are likely to disappear and introducing new one would require time.

If the assumption "Project developers always choose the next best site for a new WEP" holds, it can be expected that with an increasing number of wind energy projects, wind parks will be constructed more and more towards the south of Germany where the wind conditions become worse. As a consequence, with equal construction costs, less yield can be harvested. A cost reduction is needed in order to make up the lower income.

How should the future look like?

The technological development will not change any of that. Some of these insights have been found in other studies as well. The goal of 2030 of at least 140 TWh/a from on-shore wind energy cannot be achieved with the subsidization scheme. It is not enough to counteract the decommissioning of older wind turbines from 2000 and beyond.

With the EEG 17 as it is now, the goal of 2030 cannot be reached (Agora Energiewende and Wattsight, 2020) which is also a common perception in the wind energy sector (Weinhold, 2019; Bundesverband WindEnergie, 2020b). The financial situation of the wind energy sector will be difficult (Bundesverband WindEnergie, 2019b).

Under which conditions does the development of German on-shore wind energy stagnate due to financial limitations of wind energy projects caused by social, political and technical uncertainty?

Technological limitations could not be found as a problem as the reason for a stagnation. The technical development has been steady in the past years with no significant changes. Also, it cannot be expected that reasonable changes in cost and efficiency are capable to improve the situation of German on-shore wind energy.

The public acceptance plays a secondary role and its improvement cannot counteract the slump. While it is implemented into the model as dismissing a percentage of WEPs, the abandonment is in reality a combination of cost overrun and actual losing the lawsuit. The later happens in the minority of cases. Normally however, it does not outright stop WEPs, rather it only delays them, resulting in higher costs. It mainly contributes to the slump by increasing costs and occupying resources.

5

While the finance of wind energy projects is influenced by various uncertainties as given above, this study shows that the system as a whole is primarily in a slump due to the bidding process, a political factor. It is the predominant restriction for wind parks to either be commissioned or not. The threshold set by the policy makers is out of reach of the capabilities of the sector. The selected maximum bid price is set too low and cuts off the majority of sites. This leaves developers with only a handful of potential wind energy projects left. These projects are now challenged by an increase in lawsuits. The influence of the bidding process might have fallen under the radar since the problem of public acceptance is more immediate. However, this study showed that with a minor increase of the maximum bid, a significant growth of economically viable sites is possible. It has to be mentioned that the actual shape and number of total potential WEPs per year are deeply uncertain and also might adjust dynamically (if many WEPs are commissioned it attracts more developers resulting in even more projects), the sensitivity of a change in maximum bid depends on where this threshold is on the curve. As figure 3.12 showed, the distribution of bid prices from all potential WEPs are shaped similar to a normal distribution. This is an indicator that there might be enough capacity to reach the energy transition's goals, but it is simply too expensive and cannot take part in the bidding as they will not get accepted anyway. But the maximum bid is not only too low, the scheme itself might not be optimal as shown in the following.

Misalignment costs and subsidy

The reasons why two-step subsidization of the EEG 14 or even the transition to the EEG 17 is thought to be superior to the one-step premium might be rooted in the nature of project investment. The research shows the weight of capital costs. Since these projects are heavily upfront investment dependent, the majority is financed by loans which must be paid back with interests. In addition, as they rely on one income stream only, which is uncertain by nature (namely the wind), wind park owners are required to build up a reserve for years where income is lower and/or costs are higher than expected. These two financial stresses happen in the first 10 to 15 years of production. Capital costs form a substantial part of the composition of running costs. Interestingly, there is a misalignment between the current subsidization scheme and the normal credit conditions. Wind park owners were subsidized with the past EEG 14 at a higher rate in the first years. The length of this period was dependent on the site's quality. This follows the typical cost schedule. However, the new EEG 17 subsidization is independent of time. Thus, wind energy projects are highly profitable in the last years but not in the beginning of their lifetime where reserves need to be built. This phenomenon is shown in figure 5.1. While the diagram is highly schematic, it shows a problem with the current policy. Since it cannot be assumed that all project developers are capable of bridging the first years, there could be a significant number of projects that cannot be realised, even though the net profit after 20 years is positive. A competitive system cannot work if the stakes for wind energy projects are so high in the first years as it takes 7 years to develop a wind park. Projects are only developed if the owners can make sure that they can pay their liabilities at any point in time.

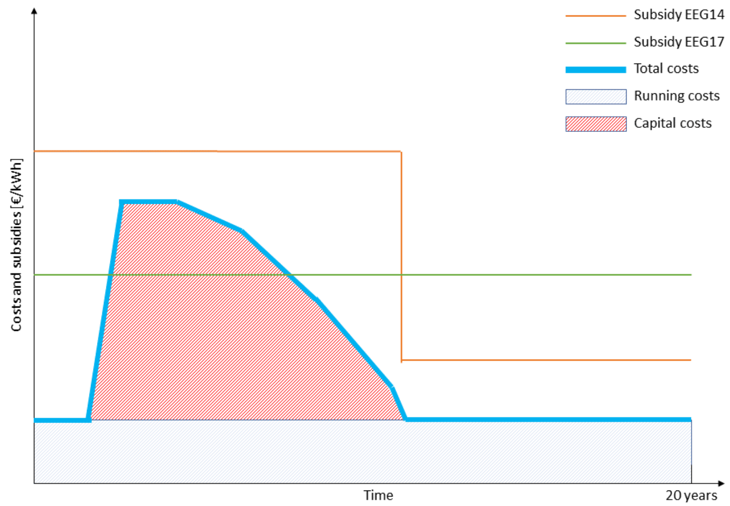

Figure 5.1: Schematic representation of the subsidy scheme of the EEG 14 and EEG 17 and costs per kWh of electricity.

5.2. Model Limitations

The modelling decision was made to use a model with great depth but limited in scope. This means that while the financial side of on-shore wind energy in Germany is modelled in detail, other aspects such as feedback in the social part have been neglected. It is possible that the effect of public participation, etc. has further effects that are not considered.

In continuation, the outcomes are categorized as a "stagnation" by the expected required yield for on-shore wind energy by 2030. Nevertheless, it does not consider dynamics that are generated by the slump itself within the renewable energy sector. For example, a drop in on-shore wind energy development could lead to another technology to have a stronger growth. This is neglected as the goal is fixed.

The biggest limitation of this model however is the fact that the number and quality of potential wind energy sites is highly uncertain. Section 3.4 partly manages this uncertainty by adjusting the average load capacity but the outcomes of the sensitivity of the maximum bid might depend on this.

5.3. Policy Implications

The German wind energy sector is currently in a turnaround. Previous EEG have been designed to quickly increase the share of renewable energy in the German electricity supply. An industrial sector had formed around this fast pace. To cover the demand 160,200 persons were employed in 2016 (Bundesverband WindEnergie, 2020c). The wind energy sector is simply not there yet to deliver enough wind energy projects which are so competitive and financially resistant, especially due to the last years of intensive subsidization which is not a good incentive for efficiency. Since this industrial sector needs to adapt to the new requirements, a recession of some sort will happen and can be seen right now. This does not necessarily mean that the affected companies lay off workers for the purpose of scaling down but that they will need to focus more on the international market in order to be financially sustainable. This could also involve moving the manufacturing off-shore resulting in the termination of contracts in Germany.

There is a simple solution: increasing the maximum bid threshold for on-shore wind energy. This would increase the number of WEPs that take part in the bidding, resulting in more commissions and more revenue for the wind energy sector and achieving the goal for 2030. This would be the most effective way. Increasing the public acceptance might not be as effective in the long run to achieve objectives due to a simple reason. In section 2.3 it was shown that wind energy experiences a democratic deficit (see Bell, Gray, and Haggett, 2005). If these studies are applicable for the current situation in Germany, the majority of inhabitants close to the planned wind turbines are already in favour. It takes only a few persons to file these lawsuits. It was found that the distance to households has no effect on the acceptance of these few people (van der Horst, 2007; Graham *et al.*, 2009) as well as royalties given to the community, both propositions by politicians. The previous would only have negative effects on the availability of potential sites, while the second is more complicated. Financial inclusion of the community at first sight is good idea since it appears to have little impact on the financials of WEPs (as found in this study) and would satisfy the opposition that concerns the mismatch between costs and benefits. This refers to the community having the costs by living with wind turbines in their vicinity while the benefits (revenue) goes largely to companies situated somewhere else in Germany. However, it could be understood as bribery by the small minority of people that are fundamentally against wind energy (see Windwahn, 2020a). Due to the said democratic deficit it takes only few voices for a prosecution. Quentin (2019) showed that these 61 % of lawsuits are filed by NGOs (which most likely are not even situated in the vicinity) of the WEP and 72 % are due to nature protection concerns (which are not solved by grassroot participation). Following this line of thought, the effect of royalties is minimal. However, this does not mean that there are no benefits to it. It can incentivise local governments to open space for wind energy in the regional planning and close the discrepancy between the said costs and benefits which has ethical benefits. A third proposition is a simplification of the permission procedure that is requested by wind energy sector. This would reduce the time of delay, but it has to be taken care of not simply bypass the concerns of the opposition. This could increase their antipathy. In addition, even if by some means the public acceptance could be increased, the number of lawsuits would not approximate to 0 %. If Quentin's (2019) 20 % of WEPs with permissions are defendant taken as a reference, a 20 % increase in commissioned wind power would not help to achieve the goal. However, the actual number of WEPs that cannot be realized due to increased costs, forced adjustments in the plans which made them financially unviable or simple abandonment of the projects, is uncertain and could vary significantly.

Unfortunately, increasing the maximum bid is not that trivial. The goal of the bidding process introduced with the *EEG 17* (2016) was to make the wind energy sector more competitive by only accepting the most economical wind parks. Since the bids of possible wind parks is shaped like a normal distribution this corresponds to the outliers of this distribution. The German electricity price is one of the highest in the world with 30.85 ct/kWh for domestic use in 2019. Around 20 % of it (6.8 ct/kWh) are part of the EEG surcharge. It is used to finance the EEG subsidy and adapts based on the amount paid out to renewable energy projects in the previous year. In 2021, an increase to 8.6 ct/kWh can be expected as low gas prices and a low demand due to the COVID-19 pandemic have lowered electricity market prices significantly and at the same time the weather was exceptionally good for renewable energy driving up the amount of energy that has to be subsidized (Hein *et al.*, 2020).

It is known that the EEG has become more expensive as anticipated and therefore costs are reduced by forcing the industry into a more competitive nature. Naturally, the supply decreases with a lower price. The intention of the bidding model was to find the line where the price of electricity is lowest and the necessary commissions to reach the goals of 2030 are still achieved, using free market mechanics. Unfortunately, this line is higher than expected by the German government.

If an increase of the maximum bid is not viable, alternatives must be found to secure the objectives for 2030. Agora Energiewende and Wattsight (2020) suggests more investment into solar energy and off-shore wind energy. In May 2020, the cap on solar energy was lifted which limited the subsidized installation volume to 52 GW (Reuters, 2020). A focus on off-shore wind energy intensifies logistical problem that are inherent of Germany's demographic properties. In this case, most of the production would occur in the North while most of the population and industry is situated in the mid to south of the country. This puts extreme strain on the power grid and caused the introduction of the “network expansion area” which limits the construction of on-shore wind energy on land in the coastal areas (Bundesnetzagentur, 2017).

6

Conclusion

While the *EEG 17* (2016, § 1) states that the development of renewable energy should be constant, cost effective and grid compatible, all three have not been the case in the last years at any point. As the current iteration of the EEG tries to tackle the second and third statement, problems with the "constant development" arises. At the current speed of expansion in German on-shore wind energy, the goals for 2030 of 65 % electricity supply by renewable energy cannot be achieved (Agora Energiewende and Wattsight, 2020, and this study). Even a reduction in wind power can be expected since the first wave of wind turbines from 2000 will decommission.

The general consent is that the slump can be resolved with increased public acceptance and easier permission procedures. The discussion revolves around that idea. However, a rapid decrease of public support seems not plausible as the root cause of the market turmoil after 2017 since the expansion dropped form 5 GW in 2017 to 1 GW in 2019 (Deutsche WindGuard, 2020). Thus, this study proposed the hypothesis that the bidding procedure is the main problem and in particular the bid ceiling that was implemented.

The aim of this study is to investigate the conditions under which the on-shore wind energy development in Germany stagnates. It shows that the primary reasons is the bidding process. First, the current maximum bid is set too low for the majority of potential wind energy projects. Second, the constant subsidization over 20 years of the EEG17 does not fit the average development of running and capital costs over the years were the financial stress due to capital cost and reserve building is high at the beginning but low in the later years.

In addition, this study argues that the effect of reductions of lawsuits is argued to be limited. It only solves secondary problems, namely delays and reduction in costs and resources, which intensify the issue by reducing the number of available sites that are already scarce due to the financial limitations. A continuation of the current system will result in a major change of the companies within the German wind energy sector as it is used to heavy subsidization of the past years. With the current trend in technological advancement and cost reduction this problem will not be solved.

Thus, the German government has three options. Either, the maximum bid is raised or reversed to the old subsidization both implying higher costs than desired or other renewable energy sources have to be supported and the on-shore wind energy sector will undergo major restructuring including possible job losses. Maybe the on-shore wind energy in Germany is at the end of its career.

6.1. Future Research

Future research in this area relative to this study can be organized in three sections. First, this research was centred on the micro financial situation of wind energy projects. Thus, approaching the problem statement on a higher level with less detail but a broader scope opens several possibilities. On the one hand, other renewable energy sources could be included. Consequently, the interaction between the rise, stagnation and fall of different technologies could be investigated. A result could be to see the total cost of the energy transition for different levels of market share of renewable energy. On the other hand, the supply chain for maintenance services and turbine manufacturing could be modelled in greater detail.

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A

Political Parties

An introduction and a political position regarding wind energy of each of the parties currently in the parliament is stated here. Their positions are mainly cited from the official websites or from sources close to the parties to reduce the political view bias of the reference's author. They are not listed in any particular order.

A.1. CDU

The *Christlich Demokratische Union* (CDU) is a christian-democratic, center-con servative and economic-liberal party (see the CDU's principles (CDU, 2020b)). It currently forms part of the government together with the SPD and achieved 26.8 % during the elections in 2017 (Der Bundeswahlleiter, 2017).

On their website the party supplies a positioning paper regarding energy (CDU, 2020a). In there, their main position is that energy supply must be clean, secure and affordable. Climate protection and the energy transition can be done best using the social market economy and not with prohibitions and continuous subsidies (CDU, 2020a). The resulting innovations could then be exported what would strengthen the economy (CDU, 2020a). Recently, CDU suggested a fixed distance between the wind turbines and settlements of 1000 m (Witsch, 2020; dpa, 2019).

Regarding wind energy, the CDU trusts the free market to develop innovations which make the energy transition a success. They want to use the minimal number of guidelines.

A.2. SPD

The *Social Democratic Party* is center-left and supports a social economy, more social justice and a ecological and worker friendly restructuring of industrial society (Decker, 2018c). It currently forms part of the government together with the CDU and achieved 20.5 % during the elections in 2017 (Der Bundeswahlleiter, 2017).

This party's position is against conventional source of energy and pro renewable energies (SPD, 2020). Matthias Miersch, an environmental politician of the SPD, suggests a financial compensation for homeowners payed by the project developers that live next to wind turbines to increase their acceptance (Zeit Online, 2020).

The SPD supports wind energy and would like to make deeper interventions than the CDU.

A.3. FDP

The *Freie Demokratische Partei* (FDP) is a party from the political centre that stands for liberalism, economic liberalism but has a restrictive opinion about European politics (Decker, 2018a). The party achieved 10.7 % during the elections in 2017 and is the second biggest opposition party (Der Bundeswahlleiter, 2017).

Following the idea of economic liberalism, the FDP are in favour of modern energy technologies but do not support the subsidies given to wind project owners. "It doesn't make sense, to expand an energy source at high speeds and subsidies, if the produced electricity cannot be used." (Christian Lindner, translated from German as cited in Portal Liberal (2017)). Ideally the market should regulate itself in that matter (Portal Liberal, 2017). To increase public acceptance, they support a distance to residential areas of at least 10 times the height of a wind turbine (FDP, 2020).

A.4. Grünen/Bündnis 90

"Die Grünen/Bündnis 90" is a green party following green politics[1], social liberalism and Pro-Europeanism (Decker, 2018b). The party achieved 8.9 % during the elections in 2017 (Der Bundeswahlleiter, 2017).

As their core ideology is pro-environmental. They strongly believe is wind energy and want to directly involve the people into the energy transition (Grüne/Bündnis 90, 2020). Even though wind parks form a dilemma between local nature protection and global climate protection they opt for the later which is reassured by their alienation of the stopping of a forest clearance for a Tesla production site (Kersting *et al.*, 2020).

This party is strongly for an energy transition driven by wind energy and local communities. Their political approach is more radical than the one from the current government (CDU and SPD).

A.5. AfD

The "Alternative für Deutschland" (in German "Alternative for Germany") (AfD) is a right-wring, nationalistic and anti-Europe party founded in 2013 (Arzheimer, 2015). The party achieved 12.6 % during the elections in 2017 (Der Bundeswahlleiter, 2017).

The party follows a strict anti-wind energy/anti-energy-transition policy. According to their website (Alternative für Deutschland, 2020), the AfD calls the energy transition to be based on an unproven hypothesis of man-made climate change.

[1] A political ideology building on Ecology, social justice, grassroot democracy and nonviolence (Wall, 2010)

That "radical overhaul of the homeland" will not influence the climate but influences "the future of our children" massively (Alternative für Deutschland, 2020). The main reasons for this opinion are the alteration of nature and wildlife conservation (AfD kompakt, 2019) and the "cultural landscape" in the sense of the traditional man-made homeland (Alternative für Deutschland, 2020).

A.6. Die Linke

"Die Linke" is a party from the democratic socialist left which supports a change in the system from captalism to democratic socialism (Die Linke, 2020b). The party achieved 9.2 % during the elections in 2017 (Der Bundeswahlleiter, 2017).

They clearly favour the energy transition and defend the idea that it can only be done by public participation (Die Linke, 2020a). However, the reason for their support might not explicitly to increase the acceptance but rather to disempower the "big corporations" (Die Linke, 2020a). The party's media presence concerning wind energy is sparse by the time of writing this political review.

B

Legislation on Credit Risk Assessment

As already mentioned in the introduction to the thesis (chapter 1), a substantial way for wind energy developers to realize their project is to take loans from banks. A loan for wind park projects falls under the definition for a "specialised lending" of the Capital Requirements Regulation (CRR) from the European Banking Authority as it is "created specifically to finance or operate physical assets or is an economically comparable exposure [and] [...] the primary source of repayment of the obligation is the income generated by the assets being financed, rather than the independent capacity of a broader commercial enterprise" (European Banking Authority, 2016, p. 4). The CRR is the application of the Basel accords defined by the Basel Committee on Banking Supervision (BCBS) to European law.

In 1974 the Basel Committee was established with the aim to "enhance financial stability by improving the quality of banking supervision worldwide, and to serve as a forum for regular cooperation between its member countries on banking supervisory matters" (Bank for International Settlements, 2020). Since then the *Basel I*, *Basel II* and *Basel III* accords have been published. Basel II (see Basel Committee on Banking Supervision, 2004) is currently implemented and will be replaced by Basel III on January 1st, 2022 with a 5-year long phase-in time (Basel Committee on Banking Supervision, 2017).

Even though the Basel accords are internationally agreed on and "the EU has actively contributed to developing the new capital, liquidity and leverage standards", the do not represent the European law entirely (European Commission, 2013, p. 4). The reason is twofold as (1) the Basel accords are not a law and need to become such by going "through a process of democratic control" and need to be aligned with the existing law and (2) needs to be applied to all European banks and investment firms and not only 'internationally active banks' (European Commission, 2013, p. 4). However, these changes are mostly regarding the composition of equity and others and not the process of assessing credit risk (European Commission, 2013, p. 4f).

The latter is of importance for this thesis and therefore the Basel accords can be used to understand the behaviour of banks in Germany.

As just mentioned, one of the aims of the Basel accords is to shape the way banks assess the risk of a loan not being paid back and especially how much equity needs to be set aside in order to cover the expected losses. Highly uncertain projects require a high amount of capital to back up the financial risk. The Basel accords (and therefore also the CRR) allows banks to either use external assessments or (with supervisory approval) to develop and use (internally) made models to estimate risk and calculate the resulting capital requirements (Basel Committee on Banking Supervision, 2004, § 52).

The "standardised approach" (Basel Committee on Banking Supervision, 2004, p. 15ff) gives banks the option to outsource the assessment to an external institution which is recognised by the national supervisors. Credits are assessed on a case by case basis and are classified into five categories ranging from AAA to B-. The external credit assessment institution needs the meet objectivity, independence, international access/transparency, disclosure, sufficient resources, and credibility (Basel Committee on Banking Supervision, 2004, p. 23). The directives are vague, and it is up to the national supervisor to decide rather the mapping process of the credit risk to the five categories is adequate.

The "Internal Ratings-Based Approach" (IRBA) evolves around the idea of instead outsourcing the credit risk assessment, to do so in house. Basel II offers two approaches: a foundation and an advanced (Basel Committee on Banking Supervision, 2004, § 245). Under the foundation IRBA banks solely provide the probability of default (PD) and rely on supervisory estimates for the maturity of the loan (M) and the gross loss in case of a default (exposure at default, EAD) as well as the net loss (loss given default, LGD). Under the advanced IRBA all four parameters are calculated by the banks. Based on these values the capital that banks need to set aside is calculated. In case they "do not meet the requirements for the estimation of PD under the corporation foundation approach for their SL assets [banks] are required to map their internal risk grades to five supervisory categories" (Basel Committee on Banking Supervision, 2004, § 249). This is called the "supervisory slotting criteria approach". As the specifications for the IRBA is quite detailed, this summary highlights some of the key features:

- "A bank must demonstrate to its supervisors that it meets the IRB requirements in this document, at the outset and on an ongoing basis" (Basel Committee on Banking Supervision, 2004, §. 392)

- A rating system should include both the risk of a borrower default and transaction-specific factors (i.e. should include specific properties of the matter and not be generic) (Basel Committee on Banking Supervision, 2004, § 396).

- The calculated exposures should be evenly distributed over the rating scales (Basel Committee on Banking Supervision, 2004, § 403). In other words, the rating should not be optimistic nor pessimistic.

- "Banks using the supervisory slotting criteria for SL exposures must assign exposures to their internal rating grades based on their own criteria, systems and processes, subject to compliance with the requisite minimum requirements" (Basel Committee on Banking Supervision, 2004, § 412).
- A PD estimation's time horizon is one year. In the beginning it should be done for a longer time horizon though (Basel Committee on Banking Supervision, 2004, § 414).
- "Sufficient human judgement and human oversight" should be included in credit scoring models to ensure enough information is used (Basel Committee on Banking Supervision, 2004, § 417).
- "The bank must have a regular cycle of model validation" (Basel Committee on Banking Supervision, 2004, § 417)
- Banks are allowed to override the output of the rating process on the basis of expert judgement, if the reasoning is explained (Basel Committee on Banking Supervision, 2004, § 428)
- An obligor is considered to have defaulted if either (1) the bank considers it be unlikely that the borrower will pay their obligations in full or (2) the borrower is past more than 90 days on its obligations (Basel Committee on Banking Supervision, 2004, § 452).

Basel II defined the minimum requirements LGD, EAD and PD as following:

LGD According to Basel Committee on Banking Supervision (2004, §§468-473) an LGD estimation needs to include possible economic downturn conditions which can include cyclical variability. If the borrower is significantly dependent on other parties this association needs to be addressed as well. In addition, extra costs due to the default should be taken into consideration. The assessment of the LGD shall be grounded in historical data if possible. Specifically, at least one complete economic cycle but not less than seven years.

EAD The EAD is defined in Basel Committee on Banking Supervision (2004, § 474) as "the expected gross exposure of the facility upon default of the obligor" and must be "an estimate of the long-run default-weighted average EAD for similar facilities and borrowers over a sufficiently long period of time" (Basel Committee on Banking Supervision, 2004, § 475). A bank should be transparent on how the EAD is derived (Basel Committee on Banking Supervision, 2004, § 476). Similarly to the LGD, the EAD must be based on a period that covers one complete economic cycle but at least seven years (Basel Committee on Banking Supervision, 2004, § 478).

PD In Basel Committee on Banking Supervision (2004, §§468-473) it is explained that the average PD shall be based on at least one of the following: internal default experience, mapping to external data, and statistical default models. It is stressed that also information is included in the process which cannot be easily adopted in a model and should counteract its limitations.

It can be seen in the above stated highlights that the framework that the Basel Committee on Banking Supervision gives is vague, and it is intentionally up to the national supervisor to assess the validity of the banks' estimation processes. In case of Germany that supervisor is the "Bundesanstalt für Finanzdienstleistungsaufsicht" (BaFin, in English "Federal Financial Supervisory Authority").

C

Details to Rating Model

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C

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D

Sensitivity of the reduction factor

The reduction factor as discusses in section 3.3.2 is used to simulate a "filling up" or emptying of the available land in Germany due to increasing or reducing number of wind parks in Germany respectively. There are two input parameters influencing the reduction factor: minimum distance to households (see section 3.2.3 and 3.5.2) and "the maximum yield factor" (see section 3.2.3 and 3.5.3).

An issue that arises with the combination of the two is that, if the maximum yield factor is set to 10 % for example and the min distance to 2000 m which according to table 3.1 corresponds to a reduction to 2.8 % of the available land, the maximum yield possible in Germany easily falls below the 101.2 TWh/a of yield that is currently by the wind energy instalment were able to produce in 2019 ($2,897$ TWh/a $\cdot\ 10\,\% \cdot 2.8\,\% = 8.11$ TWh/a < 101.2 TWh/a). This would not make sense. Thus, the minimum and maximum need to be selected in such a way that both inputs' possible ranges are as much covered as possible while the combined reduction does not undercut the yield from 2019. This is visualized in figure D.1. Following, a maximum min. distance to households of 1300 m is set together with a minimum max. yield factor of 25 %.

In figure D.2 the reduction factor r can be seen in function of the above mentioned inputs and varying annual yields. It can be seen that only in the extreme cases, a reduction of the average load capacity comes actually into play. In most cases r is at max 80 % at 200 TWh. This also answers the question of why not higher max yield factors are used (e.g. 200 % and more). The impact of the reduction factor would be even smaller in these cases which makes the exploration of this part of the uncertainty space useless. Only with big required distances to households and small maximum yields, the curve adapted from Lütkehus *et al.* (2013) has a significant impact as it can be seen in the bottom left corner of D.2.

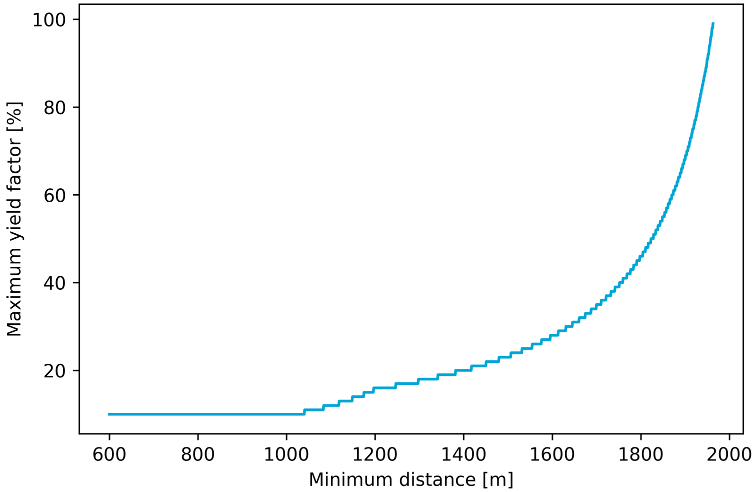

Figure D.1: Trade-off between minimum distance and maximum yield factor to exceed 102 TWh of annual yield.

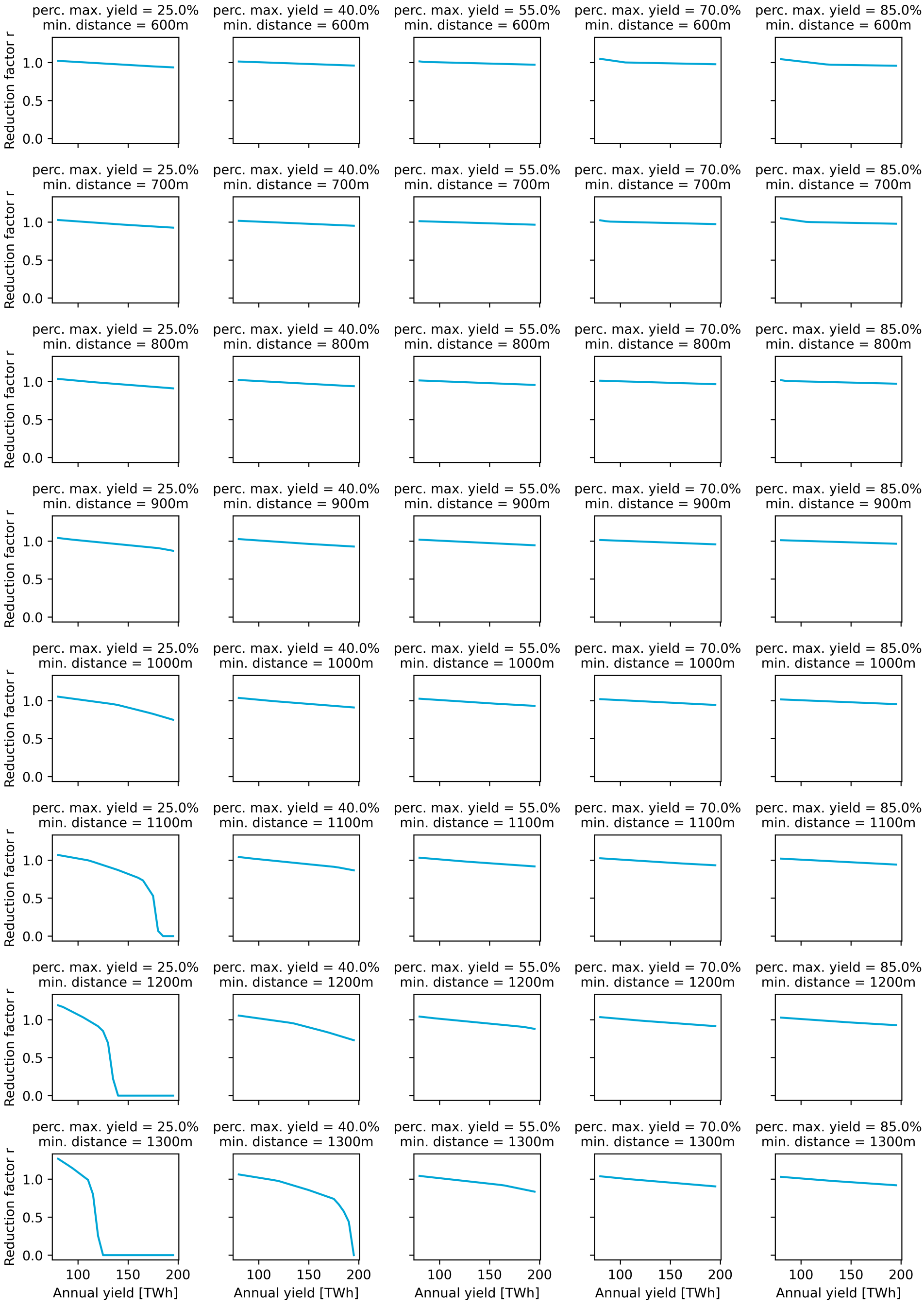

Figure D.2: Reduction factor r in function of the min distance to households and the maximum yield percentage.

D

E

Expert consultation

For the verification and validation of assumptions and information used for the construction of the model, several stakeholders were contacted via E-Mail with an accompanied set of open questions. These stakeholders are the maintenance companies and turbine manufacturers and wind park developers which operate in Germany.

E.1. Maintenance companies and turbine manufacturers

All MC/TMs of table 3.3 have been contacted and asked the following questions:

What was the revenue from German on-shore projects in 2017 and 2019? This question addresses the uncertainty of revenue that was estimated in table 3.9.

Which wind turbine brands are supported by the maintenance service? While table 3.3 was taken from information provided by the companies' websites, it is still possible that is not complete.

How important is the on-shore wind energy in Germany for your company? The answer to this question is used to put the importance of the health of the German on-shore wind energy sector into context.

E.2. Wind energy project developers

Five wind park developers have been contacted for further information. The selection consists only of medium to big companies since grass-root developers' (e.g. from citizens) contacts are difficult to find. They are the following:

- WPD AG

- Volkswind GmbH
- Windwaerts GmbH
- PNE AG
- enercity Erneuerbare GmbH

The question that were send to them are

What percentage of initiated projects are abandoned due too high cost of production? The answer to this question indicates the price pressure that wind park developers experience.

Would the number of wind park projects increase significantly if the maximum bid would increase? An affirmation of this question would strengthen the hypothesis of this thesis.

How is the bidding price calculated? In section 3.3.2 the estimation of the necessary cost of electricity was estimated by assuming that the maximum expenses should be equal to a worst-case scenario in terms of energy yield. This assumption should be validated.

How important is on-shore wind energy in Germany for your company? The answer to this question is used to put the importance of the health of the German on-shore wind energy sector into context.

F

Assumption

1. Banks work with constant yields throughout the years during rating.
2. Banks cannot go bankrupt.
3. Higher local public acceptance reduces the risk of lawsuits.
4. Banks use similar rating classes and interest rates as the KfW.
5. Project developers always choose the next best site for a new WEP.
6. A variation in brand types service by a company's origin only from the market share of the turbine brand itself.
7. The lifetime of a turbine and therefore WEP is 20 years.
8. With higher electricity prices more sites would be financially viable.