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The promotion of onshore wind power in Germany and the amended Renewable Energy Sources Act 2017

Investigation of the Sernow wind park's business-economic feasibility by different marketing options in terms of the new subsidy scheme

Master thesis

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STUDENT REPORT

Title:

The promotion of onshore wind power in Germany and the amended Renewable Energy Sources Act 2017 - Investigation of the Sernow wind park's business-economic feasibility by different marketing options in terms of the new subsidy scheme

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Abstract:

This thesis investigates the effects of the in 2017 amended German Renewable Energy Sources Act (EEG) on an onshore wind project in Brandenburg: the Sernow wind park and its promotion of electricity. The research question for this thesis reads:

What are the options to promote wind turbines in Sernow on the German power market in regards of the EEG 2017 amendment in a business-economic feasible way?

The EEG 2017 prescribes direct marketing of electricity and the subsidy is paid as market premium in regards of market prices. In order to compare the different marketing options on the power exchange, the Sernow wind park was modelled and optimised in windPRO to obtain a generation profile on a time resolution that corresponds with the one of the market prices. The considered marketing options – called scenarios in the at hand thesis – are a day-ahead, an intraday and a mixed promotion. Furthermore, the possible participation for wind turbines on the balancing power markets is examined.

Based on the legislative framework of the EEG 2017, which switches from fixed feed-in tariffs to an auction system concerning the individual subsidy determination, different ways of promoting the generated electricity lead to the following results: even though the Intraday Scenario performs marginally better than the others, all scenarios have a very similar outcome. With the present subsidy scheme from the EEG applied on the Sernow wind park, the way of promotion does not play an important role. The results are however sensitive to different inputs, that can let the wind park become a non-feasible investment. Further, potentials could be identified for wind turbines to participate on the negative tertiary control reserve market, there are however financial obstacles due to subsidy losses and low price expectations.

Preface and acknowledgement

The authors of this master thesis are Bernhard Felber and Clarissa Irion from the Master Program "Sustainable Energy Planning and Management" at Aalborg University, Department of Development and Planning. The thesis was conducted in the time period from 1st of February 2017 until the 2nd of June 2017.

The students conduct research on the effects of the in 2017 amended German Renewable Energy Sources Act (EEG) in regards of the business-economic feasibility for a specific project in Sernow, Germany. Possible revenues from direct marketing are compared and moreover the future option for wind turbines to participate on the balancing markets is examined.

Appreciations are given to the thesis supervisor Anders Andersen for supervision and support during the whole project period. Furthermore, our sincerest thanks go to Mads V. Sørensen from EMD International A/S for his help regarding modelling in windPRO. Moreover, we greatly appreciate the help and information we got from conducting interviews with Henning Parbo from Energinet.dk as well as interviews with Arndt Neubauer (TenneT) and Markus Speckmann (Amprion). Additionally, we would like to thank ENP Energieplan for their help.

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Index of abbreviations

This will be giving a small introduction to some of the words used during the report and their abbreviations.

€	Euro
AEP	Annual Energy Production
BNetzA	Bundesnetzagentur
CHP	Combined heat and power
CO_2	Carbon dioxide
COP	Conference of Parties
DA	Day-ahead
db(A)	A-weightning
DSO	Distributed System Operator
EC	European Commission
EEG	Erneuerbare Energien Gesetz (Renewable Energy Act)
EEX	European Energy Exchange
EPEX	European Power Exchange
ETS	Emission Trading System
EU	European Union
EXAA	Energy Exchange Austria
G	Giga
GCC	Grid Control Cooperation
GHG	greenhouse gas emissions
h	Hour
ha	Hectare
ID	Intraday
IGCC	International Grid Control Cooperation

IRR	Internal rate of return
km	Kilometre
kW	Kilowatt
kWh	Kilowatt hour
LCOE	Levelised Costs of Electricity
m	Meters
MCP	Market clearing price
min	Minutes
Mio.	Millions
NPV	Net present value
O&M	Operation and maintenance
OTC	Over-the-counter
PCR	Primary control reserve
PHELIX	Physical Electricity Index
SCR	Secondary control reserve
SDGs	Sustainable Development Goals
sec	Seconds
T	Terra
TCR	Tertiary control reserve
TIN	Triangle Irregular Network
Tsd.	Thousand
TSO	Transmission System Operator
UN	United Nations
USD	US-Dollars
W	Watt
WTG	Wind turbine generator

1. Introduction

1.1 Global climate and renewable energy status

The anthropogenic climate change is a big challenge that has to be faced nowadays. A steadily growing energy demand and an energy supply still predominately depending on fossil fuels are thereby important factors of influence. To tackle the obstacle of increasing greenhouse gas (GHG) emissions, which leads to a rising temperature and hence boosts the climate change, the changes in the energy supply are essential in the future.

Over the last decades, renewable energies have experienced a global increment. Thereby, especially the renewable energy share for electricity generation grew largest in recent years. In 2015, renewable electricity generation facilities increased by 154 GW which equals a 9.3 % nominal increase between 2014 and 2015. In 2015, renewable power capacity accounted for around 60 % of the newly installed units. The development of the renewable electricity expansion since 2000 is illustrated in Figure 1 (International Renewable Energy Agency 2017, pp.18–19).

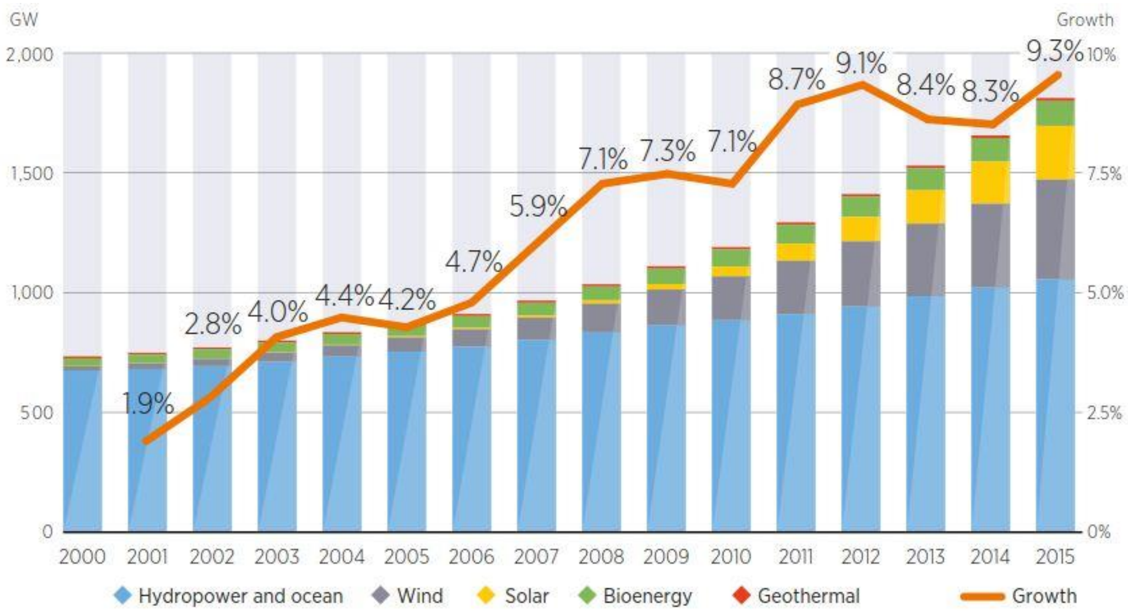


Figure 1: Global development of the renewable electricity generation facilities (International Renewable Energy Agency 2017, p.18)

Ascertained from Figure 1, wind power is facing a significant deployment since 2000 with an increasing tendency. This clearly overruns the increase of solar in the same time frame. Even though renewable electricity generation units are gaining ground (23 % of the global generation), around 77 % of the global generation is still covered by non-renewable sources such as coal and oil. The global energy related CO_2 – emissions added up to 35 Gt in 2014 and are expected to be 42 Gt in 2030, if the existing path is carried forward. When taking a closer look on the global renewable electricity generation structure in 2015, the following picture arises, depicted in Figure 2: wind power contributes with a share of 3.5 %, while the highest share (17.2 %) of renewable electricity is coming from hydropower, whose high share was already clearly visible in Figure 1 (International Renewable Energy Agency 2017, pp.19–24).

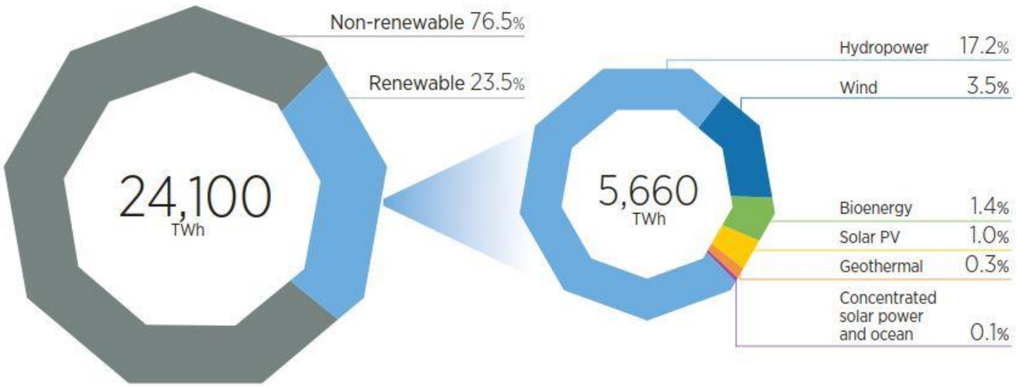


Figure 2: Global electricity generation structure 2015 (International Renewable Energy Agency 2017, p.20)

Besides the development on the supply side towards renewable electricity generation facilities, the global energy demand is expected continuing to rise over the next decades caused by population growth, expanding economies, urbanisation, improved access to energy and rapid industrialisation (International Renewable Energy Agency 2017, p.17). The further electrification of the transportation and the heating system may also have a significant impact on the global electricity demand, as e.g. the in fuel used energy for transportation may to be replaced by electricity.

In order to cope with the different global developments and further to lower the CO_2-emissions, political goals have been defined. Important global political movements in this context are the United Nations (UN) Agenda 2030 and the Conference of Parties 2015 (COP 21).

In the beginning of 2016, the 17 Sustainable Development Goals (SDGs) – various goals adopted during a UN-Summit in 2015 – went into force. These goals address issues around the globe on a universal scale and are the succession of the Millennium Development Goals which expired by the end of 2015. Among others, the SDGs claim for climate action and affordable, as well as clean, energy. Specifically, goal number 7 obliges to "*ensure access to affordable, reliable, sustainable and modern energy for all.*" The UN underlines the necessity of electricity access and the investments in renewable energy sources and infrastructure (UN 2015).

The 21st Conference of Parties took place in Paris in 2015. It is an international agreement among 197 contracting parties, consisting of 196 states and the European Union (UNFCCC n.d.). The agreement aims for a limitation of global warming clearly below 2 degrees Celsius, with the intention to reach a 1.5 degree Celsius limitation between 2015 and 2100 by cutting down CO_2-emissions. Every contracting party is setting its own Nationally Determined Goals. These goals shall be achieved by National Climate Action Plans. Further, are the industrial states obliged to support the developing countries with a yearly amount of 100 Million USD between 2020 and 2025. When failing the individually goals set no sanctions are planned (European Commission 2017i).

If the benchmark of 1.5 degree Celsius should be reached, the global net carbon emissions have to be 0 at the time horizon of 2045-2060 (Rogelj et al. 2015, p.519), which would also require crucial changes in the global energy supply system towards renewable (emission-free) energy sources.

On the 4th of November 2016, the agreement went into force. The requirement was that at least 55 contracting parties - which together account at least for 55 % of the global CO_2-emissions - have ratified the agreement. Until now, 128 parties have taken this legal step (03.02.2016) (UNFCCC n.d.).

1.2 European climate and renewable energy status

10 % - that is the share the European Union (EU) is responsible for of the world's greenhouse gas emissions. Between 1990 and 2015 the emissions have been reduced by a share of 22 % even though the economic performance doubled itself in that time period. For the reduction of greenhouse gas emissions the EU has defined short term and long term goals. The long run aims were defined in 2011 within the energy roadmap until 2050 in order to promote a more sustainable but also competitive and secure energy system.

The primary objective is to reduce the GHG emissions by 80-95 % until 2050, compared to the level of pollution from 1990. Next to that, the focus is on the following fields: energy efficiency, renewable energy, nuclear energy and CCS (Carbon Capture and Storage).The roadmap tends to promote a policy which is a stable base and hence supports businesses in low-carbon investments. This is important as these investments are also on long terms (European Commission 2017c)(European Commission 2016b).

Next to the long term goals, there are ones aiming for the short term as well: these are the 2020 targets and the subsequent 2030 targets. The 2020 targets are currently binding and include, next to a cut of 20 % of the GHG emissions, also a share of 20 % in energy from renewables and an improvement of the energy efficiency by 20 %. Specifically for large-scale power and industry facilities as being part of the Emission Trading System (ETS), a reduction of greenhouse gases by 21 % is pursued, compared to 2005 levels. However, the overall targets need to be transferred to the individual member targets (European Commission 2017a). The EU seems to be on track for the 2020 targets as the emissions were already lowered by 22 % in 2015 compared to 1990 levels (European Commission 2016b). The targets given for the single member states differ among them. However, each of them is required to have a minimum share of 10 % renewable sources for the transport sector (European Commission 2017j).

The EU signed the Paris Agreement and thereby commits itself to lower its emissions by 40 % until 2030, compared to the 1990 level. To achieve this reduction, certain legal actions are about to be taken: a revision of the ETS after 2020, binding emission targets for all the member states for the sectors outside of the ETS until 2030 and furthermore an inclusion in the efforts of land use, the change of land use and forestry (European Commission 2017j). Until now, the following 2030 EU goals do not have a legally binding character: They prescribe, that the GHG emissions have to be cut by 40 % compared to 1990 levels, the share of renewables has to be 27 % as well as the share of improvement in energy efficiency. The package is also aligning to the energy roadmap 2050. Aiming to achieve these targets, within the ETS sectors a reduction by 43 % is intended as well as in the non-ETS sectors a reduction of 30 %, compared to 2005 levels (European Commission 2017b).

Important for Europe’s security of supply are the Frameworks for Energy and Climate 2020 and 2030 as well as the Energy Security Strategy. These strategies are important as Europe overall imports more than half of its energy. Main dependencies are based on crude oil and natural gas. This high dependency can lead to supply uncertainties and disruptions as a consequence of infrastructure failure or political and commercial quarrels. Therefore, the Energy Security Strategy was created proposing long-term measures to decrease the import dependency (European Commission 2017g).

A European goal is furthermore to develop an integrated energy market for all member states (European Commission n.d.). No technical or regulatory barriers should hereby hinder the desired free flow of energy across the EU in order to rise the competitiveness and hence lower the energy prices. Steps for the realisation are a new design for the energy market, the further development of cross-border energy transition and the empowerment of the energy consumers (European Commission n.d.).

1.3 German climate and renewable energy status

As the EU has binding targets for renewable energies, so do the single member states themselves. However, the EU and the national legislations regarding energy issues are strongly linked. These targets depend on the individual resources, attitudes and the single energy markets. This poses a distinguishable way for each of them in order to fulfil the binding targets. Each member state has a National Action Plan, referring to the EU Renewable Energy Directive, describing the national actions needed. This includes the intended mix of the different technologies, individual targets for the different sectors such as electricity, heating and cooling as well as transport and other measures to achieve the by the EU stated aim (European Commission 2017h).

Germany adopted its National Renewable Energy Action Plan in 2010. The overall target until 2020 in regards of renewables is a share of 18 % from renewable sources in the gross final energy consumption. For heating and cooling the desired share is set to 14 %, for electricity to 30 % and for transportation to 12 % (Bundesrepublik Deutschland 2009, pp.13–14). In the plan there are furthermore measures stated, existing as well as upcoming ones, which should promote renewables in order to achieve the binding national aims. One of these measures is for instance the Renewable Energy Sources Act (EEG), already in existence since 2000, but under frequent amendments.

Germany's climate targets were set in 2007 and since then are undergoing annual monitoring. These aims are to cut down the GHG emissions by 40 % until 2020, compared to 1990 levels and by 95 % until 2050. The share of renewables in the gross final energy consumption ought to rise up to 60 % by the year 2050; the share within the gross power consumption has to be at least 80 % (Appunn 2017). Gross final consumption is hereby defined by the EU as

> "*energy commodity delivered for energy purposes to industry, transport, households, services including public services, agriculture, forestry and fisheries, including the consumption of electricity and heat by the energy branch for electricity and heat production and including losses of electricity and heat in distribution and transmission*."
> (European Parliament & European Council 2009, p.27)

Compared to the goals of the EU Germany's goals on the GHG reduction are more ambitious, especially on the long run (Appunn 2017). The four main political objectives which drive the energy transition in Germany are the combat against climate change, the reduction and evasion of nuclear risks, the increase of energy security and the pledge to competiveness and growth (Agora Energiewende 2015, p.1): "*The German energy transition (Energiewende) is a long-term energy and climate strategy towards a low-carbon energy system based on* *developing renewable energy and improving energy efficiency"* (Agora Energiewende 2015, p.5). While now all member states of the EU have targets regarding the reduction of GHGs, the German state propounds its transition in an exceptional scope and speed. Although the steady rise of renewables reduces the GHG emissions and keeps Germany on track to fulfil its targets, the present intense use of coal and the weak ETS affects the set goals negatively. Therefore, in order to reach the set goals the government decided in 2015 to phase out around 13 % of the country's oldest lignite power plants by 2020 (Agora Energiewende 2015, pp.5–6).

The following Figure 3 displays the structure of Germany's 2020 targets and measures:

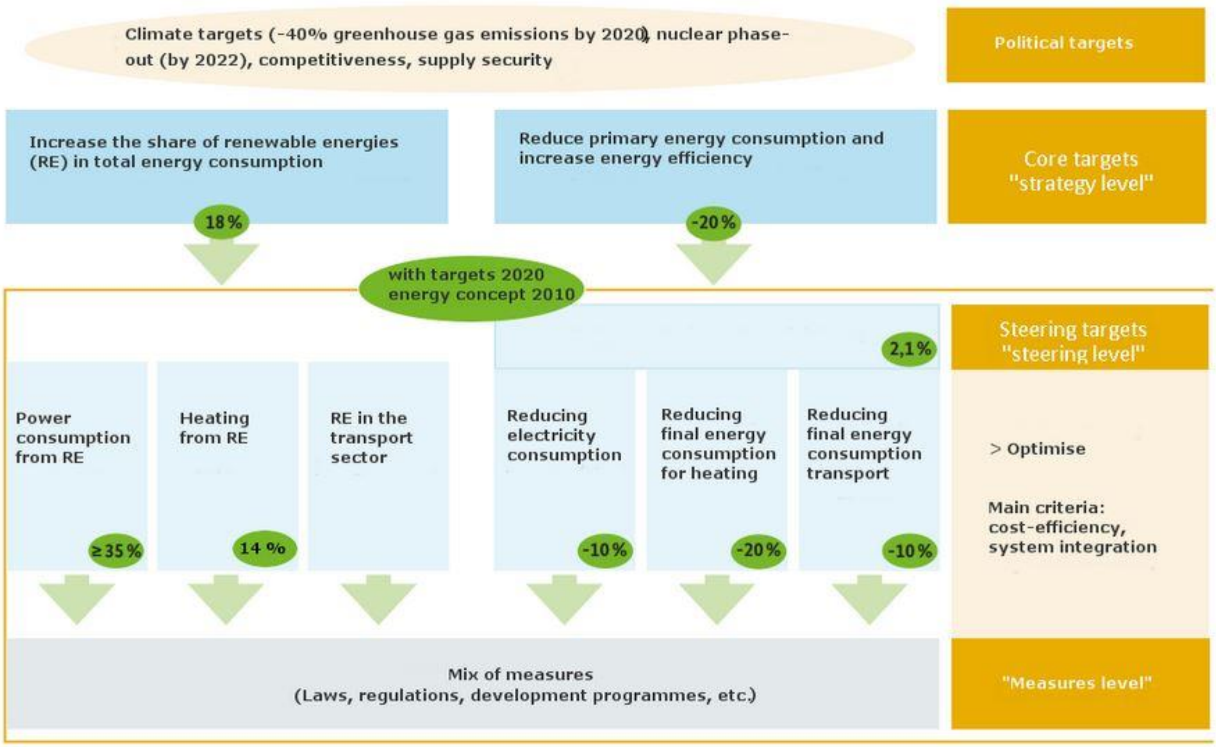


Figure 3: Structure of Germany's targets (Appunn 2017)

As can be seen in Figure 3, the political targets as the climate goals are above all the other more specific levels. On some of them like competitiveness and supply security cannot be put numbers on. A step below are the core targets, the so-called "strategy level" with its main aims. These are leading to the steering level where the sub-targets, related to the core targets are outlined and labelled. To achieve these targets the government proposes a certain mix of measures as for instance laws, regulations and development programs. With this structure the German state aims to fulfil its targets on a European and national level.

Secure supply is one of the targets mentioned but not labelled with a certain number. For Germany this aim is however essential, as the Republic relies to a great degree on energy imports. Lowering GHG emissions with promoting and increasing renewables would also reduce the present imports of fossil fuels. These imports are evoked by the depletion of the country's own resources and the fact the local extraction of these is too expensive. In 2015 the share of imported energy was 62.6 %. Almost all of the oil had to be imported, mainly from Russia, for the transport sector and for heating. For gas, which is primarily used for heating, cooking, industrial consumption and combined power and heat (CHP) plants, the import rate added up to around 90 %. The same number accounts for coal. Especially the phase-out of nuclear energy and the low wholesale prices on electricity have promoted the relatively cheap use of coal (Amelang 2016). Therefore, the further expansion of renewables within the country would help to lower these dependencies, which can cause uncertainties and disruptions.

To trace back to the renewables itself, the rise of them had been quite a success: From a share of under 5 % in the year 2000 where the EEG, the main law to promote renewable energy, went into force, to a share of almost 34 % of the electricity generation in 2016. The share and the composition of it can be seen in Figure 4:

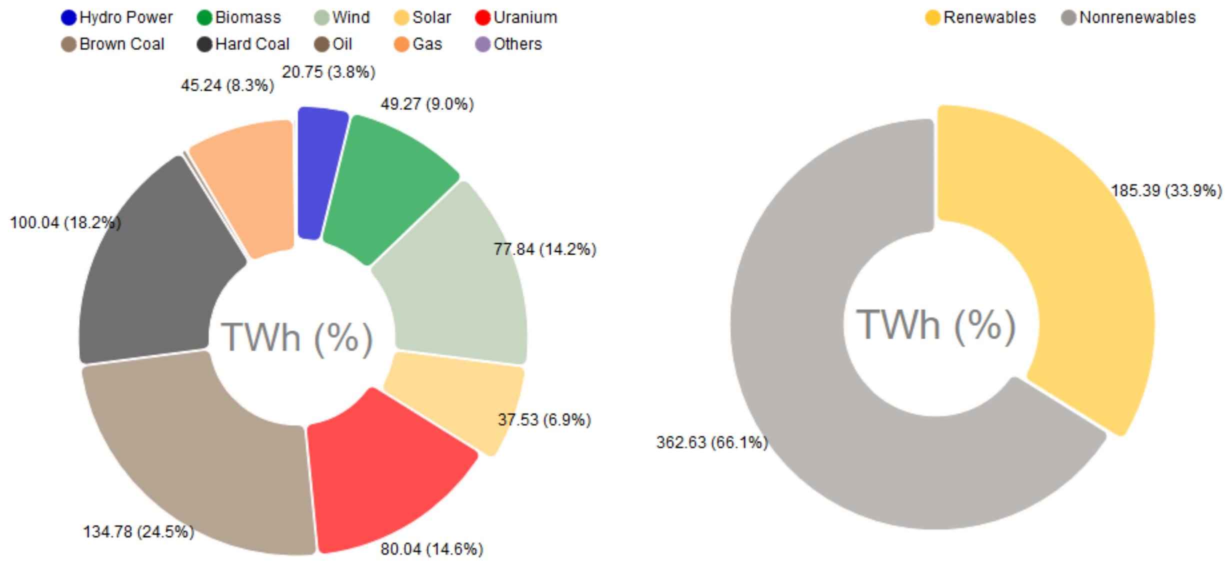


Figure 4: Electricity generation in Germany in 2016 (Fraunhofer ISE 2017b)

When looking at the renewables the highest share within the electricity generation is coming from wind power, with slightly over 14 %. Wind plays a crucial role in the transition to a more renewable energy system. Germany has hereby a leading role worldwide. Globally, Germany has the third highest amount of installed wind capacity after China and the USA (Morris & Pehnt 2015, p.19).

To adapt to the grid expansion the German government decided to only allow a certain wind onshore capacity to be installed yearly: 2,800 MW until 2019 and afterwards, from 2020 on, 2,900 MW yearly, which is determined within the EEG. However, this is significantly below the installed capacity of the last years. Onshore is playing an important role due to the fact that it can offer a cost-effective extension potential in the short and medium term. Future extension constrains may however occur due to the limited areas where it is possible to build wind turbines. Therefore, the German State decided within its National Renewable Energy Action Plan of 2010 to start an initiative together with the federal states which allows, by an advancement of the regional development plans, the creation of sufficient areas (Bundesministerium für Wirtschaft und Energie n.d.).

1.4 Deployment of the electricity market

Over the last the decades, the national electricity markets have undergone various changes. Gradually, electricity exchange markets were established in most EU member states resulting in having day-ahead, intraday and derivate (future) markets. These mostly national markets are in the process of further getting coupled. The expansion of interconnectors additionally helps to increase the markets' efficiency and liquidity. The electricity price itself is driven by various factors as weather conditions, the fuel mix, renewable energy installations, cross-border interconnectors, market-coupling and demand side developments, to name some of them. The wholesale electricity prices within the EU are facing an overall downwards trend since 2008 - a fall of around 70 % between the years 2008 and 2016 – and reached a level they have not been at for the last 12 years (European Commission 2016a, p.4). The development of the electricity wholesale prices is shown in Figure 5.

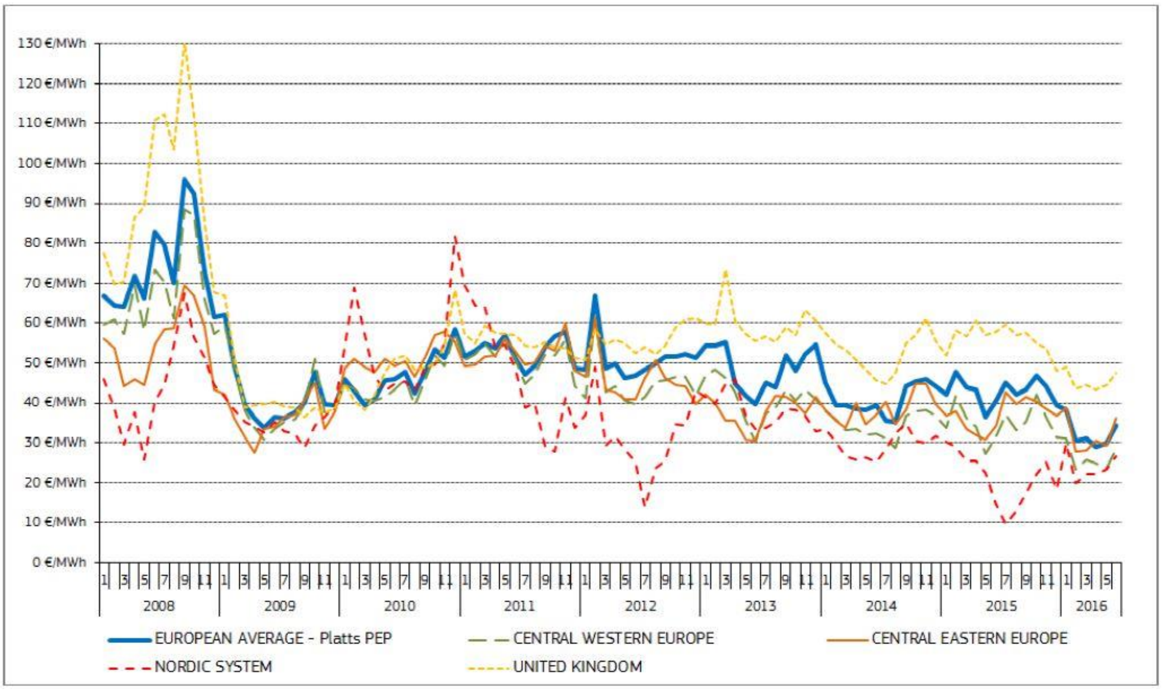


Figure 5: Development of wholesale electricity prices in Europe since 2008 (European Commission 2016a, p.4)

Thereby Figure 5 demonstrates, that the European average price declined to around 30 €/MWh, while in Northern and Central Western Europe the prices were even lower (20-25 €/MWh) on average. A driver for the significantly low European electricity prices in 2016 were – among others – the pass-through of the reduced coal and gas prices. While there has been a downwards pressure on wholesale prices, the retail prices have experienced an increment at the same time. Since 2011, the energy component of the household retail prices steadily decreased, even though the prices for consumers have been rising, visualised in Figure 6 (European Commission 2016a, pp.5–6).

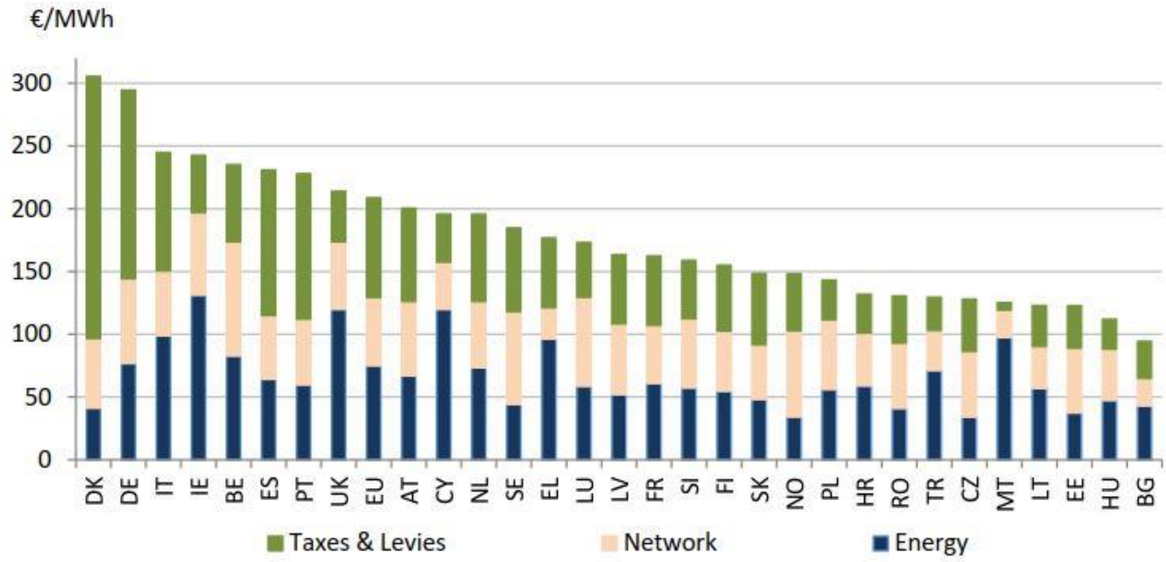


Figure 6: 2015 Household retail prices by EU member countries (European Commission 2016a, p.6)

Figure 6 depicts the cost components of the household retail prices for the EU member countries, consisting of taxes and levies, network charges and energy costs. The driving factors for the price increase were the network charges and the taxes and levies. From a national perspective, Denmark and Germany were the countries with the highest consumer prices (around 300 €/MWh) within the EU in 2015. In Germany, the network costs and the taxes and levies caused around 60 % of the household retail prices (Figure 6).

According to the European regulations, the German electricity market was gradually liberalised. Until 1998, Germany had vertically integrated energy monopolies, which were under substantive supervision and price control. After 1998, the market was liberalised stepwise (Bundesnetzagentur 2005).

Today's German wholesale electricity markets can be generally split up into a day-ahead, an intraday and a derivate market. Even though a vast share of electricity is traded over-the-counter (OTC) between different actors, the volume traded on the stock exchange is becoming more and more. The most important stock exchanges are thereby the European Energy Exchange (EEX) and the Energy Exchange Austria (EXAA) (Bayer et al. 2015, p.21). In 2016, the trading volume on the day-ahead market added up to 235 TWh, the trading volume on the intraday market was 41 TWh representing an all-time high (EPEX 2017b).

The development of the German day-ahead and intraday prices is facing the same trend as the European wholesale prices: since 2011 a steady downwards trend can be observed in Figure 7.

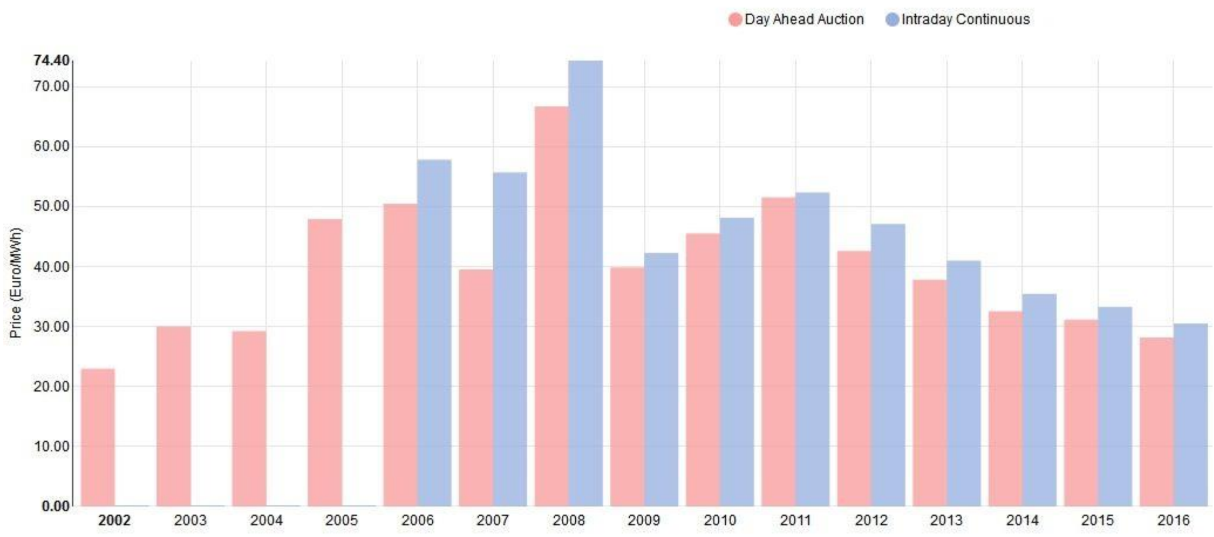


Figure 7: Deployment of the German day-ahead and intraday prices (Fraunhofer ISE 2017a)

It can be seen that in 2016, the average day-ahead price yielded in around 29 €/MWh, while the average intraday price was around 30 €/MWh. Since 2002, Germany, Austria and Luxemburg have a common electricity price zone which means all consumers in these countries pay the same wholesale price for electricity. This price zone is likely to be split up due to structural congestions. The spilt is planned to be implemented in July 2018, which would most likely lead to an electricity price increase in Austria. This split would however not solve the problem having structural congestions within Germany itself and may reduce the socio-economic welfare (Graf & Irschik 2016, pp.4–6) (TSCNET 2016).

2. Problem statement

The following chapter addresses the problem, which is investigated within this thesis. Next to the problem formulation, the research question also delimitations of the project are presented in view of the thesis' scope set. Further, an outlook on the structure of the whole project is given.

2.1 Problem formulation

With the ongoing enforcement of regulations and laws by the EU and Germany, the current electricity market design is inevitable going to change. With the already outlined actions and measures, Germany clearly aims to promote renewable energies in order to lower its GHG emissions. The targets stated are a GHG reduction by 40 % until 2020 and an increase of the share of renewables up to 18 % in the gross final energy consumption until 2020. On the long run, the share of renewables should rise up to 60 % until 2050 in the gross final energy consumption and to at least 80 % in the gross power consumption. This is not only done in order to fulfil the guidelines and regulations posed by the EU but also for its own interest. This interest in a more renewable and efficient economy is guided by the idea of strengthening the domestic energy supply security. Germany is also a highly industrialised country with a limited amount of fossil fuels. Therefore, it relies, especially concerning coal, gas and oil, mainly on imports due to the lack of availability or the expensive degradation within the country. In 2015 the import rate of energy was 62.6 %. The increment of renewable energies within the country would decrease this dependence which can lead to insecurities in the supply caused by political quarrels for instance. In 2014 such a case was occurring as there was a conflict between Russia and the Ukraine and the gas flow to Germany was interrupted. For the future a more secure supply is therefore wanted and can be facilitated with the growth of renewables.

The main law in Germany to promote renewables is hereby the EEG, which came into force in 2000 and pushed the share of renewables in the electricity generation from under 5 % to over 30 % in 2016. Hence, it can be seen as quite a success. To adapt the law to the current situation needed, there have been several amendments over the years, which changed the structure stepwise. It can be clearly stated that with the implementation of this very law it is evident, that the German government intends to promote renewables further. The latest amendment from 2017 changed the so-far existing subsidy system according to EU requirements: from a fixed feed-in tariff system to a more market-oriented subsidy scheme based on auctions. As already mentioned earlier, wind power has one of the highest shares of renewables in Germany and due to sustaining potential it is of persistent interest. Within the at hand thesis, the focus of attention will be on onshore wind power. The onshore expansion of wind power is limited by the amount of 2,800 MW yearly until 2019 (2,900 MW yearly from

2020 on), which is far lower than the yearly installed capacity of the previous years. In 2015 the newly installed capacity amounted to around 3,700 MW, whereas in 2016 to around 4,600 MW (Bundesverband WindEnergie e.V. 2016). Nonetheless, onshore wind power still plays an important role to achieve the set German renewable energy goals. With the extensive expansion of wind energy in the north of Germany and the missing transmission lines to the south of the country so-called grid bottlenecks occur. Hence, the removal of the power is hampered and as a result the German state limits the number of newly installed wind turbines in these affected areas in order to adapt the development of the wind industry to the grid expansion.

Another aspect which is pursued by the German government is a system change towards the use of power in more sectors, such as the transport sector for instance. In order to reduce GHG emissions a public transport system, based on more environmentally friendly fuels, e.g. green electricity is desired. This will also lead to quite a demand increase of the required electricity by renewables. Therefore, an increment of generation facilities is needed and corresponds with the aims of the German state.

While the European and national policies are putting an emphasis on a further increment of wind power, the electricity market is undergoing various changes. The steady increase of fluctuating renewable energies with low generation costs is putting pressure on conventional power plants and the wholesale electricity prices in Europe as well as in Germany. This trend is furthermore supported by the ongoing European electricity market coupling with the vision of becoming one single market. The increment of interconnector capacities among and within member states is fostering this idea of an integrated market. Nonetheless, the challenge of increasing integration of renewables on maintaining grid stability needs to be tackled. A high penetration of fluctuation generation in connection to a low demand causes system imbalances, which may reflect in negative power market prices. Contemporaneously to the shrinking wholesale prices, high taxes and levies as well as network costs do not let the consumers benefit from shrinking retail prices.

Concluding, there are different aspects leading to sinking wholesale prices, which makes a future investment in wind turbines, more specifically onshore wind turbines in context of this thesis, an insecure business and may constrain investments in new facilities. In contradiction to that, a greater extent of wind power is needed in future to reach the related political goals and to promote further security of supply for Germany. To ensure the achievement of the renewable energy expansion goals, the German EEG is continuously revised. The recent amendment of 2017 contains changes of the subsidy scheme towards a more market-oriented system: subsidies, for the yearly defined capacity, are now granted as a market premium in regards of the revenues from the power exchange, individually determined within a tender procedure. The new subsidy scheme design is intending to stimulate the situation. Nevertheless, every investor needs to cope with the current conditions and determine the best possible option to facilitate its’ wind turbines economically, as the generated electricity has to be promoted directly on the market. The newly adopted scheme poses some risks for the investors as the granted subsidy is not defined beforehand and additionally one cannot be sure of getting awarded in the participating auction round. Therefore, it is essential to determine all viable possibilities of attending the power market with wind turbines. It can be stated, that the topic of investigation is clearly significant from an investors’ point of view.

On the German market, wind power can be currently promoted either on the day-ahead, the intraday or on the derivate market. Due to a high volume risk, electricity coming from wind turbines may only be occasionally traded on the derivate market via futures or options. Wind turbines may also be integrated in the German negative tertiary control reserve market within the near future. Denmark is already admitting these as tertiary control reserve since 2012. Next to the currently important markets, the balancing markets in general might be an interesting upcoming marketing opportunity for turbine operators in the future.

2.2 Research question

Investment decisions for onshore wind turbines, like for other renewable facilities, are based on the present electricity market and the technology specific support schemes, as these determine the recoverable revenues for investors. The thesis investigates the following research question within the above described problem setting along an onshore wind park in Sernow.

What are the options to promote wind turbines in Sernow on the German power market in regards of the EEG 2017 amendment in a business-economic feasible way?

In order to answer this research questions the following sub-questions are posed with the purpose to approach the topic step by step:

- *Which form of direct marketing lets the wind turbines in Sernow perform business economically the most feasible when receiving support by the EEG?*

- *How can balancing markets be made accessible for wind turbines and what market potentials can be expected?*

In regards of the first sub-questions a clear definition on what is understood by the law is needed: By definition of the EEG, the mandatory direct marketing is the disposal of electricity generated by renewable power plants to third parties, unless the electricity is used in the close proximity and not transferred through the grid. In order to receive the EEG subsidy, the generated electricity has to be traded on the power exchange. Furthermore, a direct marketing contractor is defined as the responsible one, who is commissioned with the direct marketing, or commercially takes the electricity from the generator without being the end consumer of the power, nor the grid operator (Bundesregierung 2016, p.13). It furthermore needs to be clarified that in the at hand thesis the terms plant operator and investor are equated.

The modelling of the wind turbines yearly yield is very location specific. Therefore, parcels in the village of Sernow (part of the municipality Niederer Fläming in Brandenburg) were chosen as modelling site for the wind turbines. This can be understood as a case study used to answer the research question. In order to compare the business-economic feasibility of the different ways to promote the wind power capacity, the net present value, the simple payback time and the internal rate of return were chosen as outputs.

Based on an hourly wind profile obtained from the windPRO model, different scenarios are compared. These scenarios represent the different ways how to promote wind power on the electricity market, in regards of the EEG 2017 subsidy scheme. Altogether, there are three different scenarios covered within this master thesis. A Day-Ahead Scenario, an Intraday Scenario as well as a Mixed Scenario are formed. This is done to show the different impact on the turbines' economy when conducting the compulsory direct marketing in different ways.

Wind turbines can most likely participate in one or more balancing markets in future. There are however challenges of integrating them. Thereby, the negative tertiary control reserve market is of main interest. As there are no current experiences on the German balancing market related to that at the moment, this topic is discussed on a qualitative level and not treated as an own scenario. Even though certain pilot projects are conducted at the moment by the German transmission system operators (TSOs), the participation of wind turbines on the German balancing markets is still hypothetical and not a realistic option of promotion so far.

2.3 Delimitations

Due to the certain project scope, the present master thesis is facing different delimitations which are described in the following paragraphs.

The project focuses solely on the electricity day-ahead, intraday and the balancing markets in Germany. Besides these markets, electricity can also be traded as futures or options (called derivates). These contracts are set up to trade power via long term contracts and to hedge against unprofitable price volatilities. As this market is usually only applicable for units providing an assured capacity over time, wind turbines most probably struggle to participate. Thus, the derivate market is not considered within this thesis. Further, a large share of electricity trading is done directly between parties by OTC contracts; hence no prices are published for these bilateral contracts. Therefore, this way of promoting the generated electricity is beyond the project scope.

The exclusive technology being examined within the thesis is wind onshore. The focus hereby is only on what revenues the onshore wind turbines can recover on the determined markets, regardless of any demands. It is assumed that due to increasing electricity consumption in the future there will be sufficient demand to sell the generated power on the market or to substitute more expensive generation units on the market.

2016 was chosen as simulation year due to the highest accuracy of data, hence all investments are assumed to be done in 2015 for the investment calculation. This demonstrates a simplified approach as erecting the wind turbines may take more than just one year. The project group is aware that the subsidy scheme of the EEG entered into force 2017, whereas the simulation year is 2016. Due to data limitation the year 2017 cannot be modelled yet, 2016 is hence the year with the highest data accuracy.

The technical design of the wind turbines is limited to the degree of modelling the yearly yield on an hourly basis. Hence, the technical design of specific components necessary for fully implementing the turbines as e.g. grid connection are disregarded.

The business-economic feasibility of the Sernow wind turbines is analysed. Results may differ from a socio-economic perspective and certain alternatives may have higher benefits than the present project.

Furthermore, in order to simplify the economic calculations of the wind farm, it is assumed that the project is to no extent financed externally. The availability of all capital is presumed.

Newly legal subsidies based on the EEG amendment of 2017 are applied to the present project. The analysis focuses on how the EEG supports the project, however it does not propose how the law could be adapted in order to foster improvements.

There will be no stakeholder analysis within this project. The as relevant considered actors will be described but no comprehensive analysis will be conducted in detail as the influence of those is not the focus of the project and would go beyond the scope of the thesis.

The existing spatial regulations were disregarded. Wind turbines in Brandenburg can only be built in legally authorised areas. The chosen location was initially determined as a potentially legal wind power area but finally got cancelled from the legally binding zoning regulations. However, the parcel may be restored as suitable area for onshore wind turbines in future in order to fulfil the national onshore wind power expansion targets.

Within the planning of the wind farm only the distance criteria to the next buildings are taken into account. The distance aspects in regards of environmental issues (e.g. endangered animals and natural restrictions) are not examined further as the permission under the Federal Immission Control Act, which includes this aspects, is considered as being given. This permission is very important for implementing any wind turbine project in Germany.

2.4 Structure of the project

Based on the main research question and the sub-questions it is aimed to approach the topic of interest comprehensively. Therefore, the thesis starts off with a broad view on the topic in order to file it into the broad context and be able to draw conclusions why an investigation of that issue is of importance and what the range of its influence is. Afterwards, it is narrowed down to the main aspects of relevance with which will be dealt closer in the at hand thesis.

In order to set the framework and create a common knowledge base for the problem and the subsequent conduction of the analysis and the scenarios, the theoretical framework is drawn up in Section 3. Afterwards, the methods used are outlined in Section 4. A case description (Section 5) of the chosen location and its environment leads more closely to the actual case which is afterwards detailed examined in Section 6, the analysis. The base components for the analysis are the modelling of the turbine's yield in windPRO and the costs related to the wind park. These costs and the windPRO outputs form the basis for the modelled scenarios and their results presented in Section 7. In the same section furthermore a sensitivity analysis is conducted on different factors. This all aims to answer the first sub-question. Subsequently, in Section 8 a digression about wind turbines on the German balancing markets is made in view of the second sub-question. The results from the analysis and further aspects of interest are discussed in Section 9, before the final finding of the thesis are concluded in Section 10. The overall structure of the thesis is illustrated in Figure 8 below:

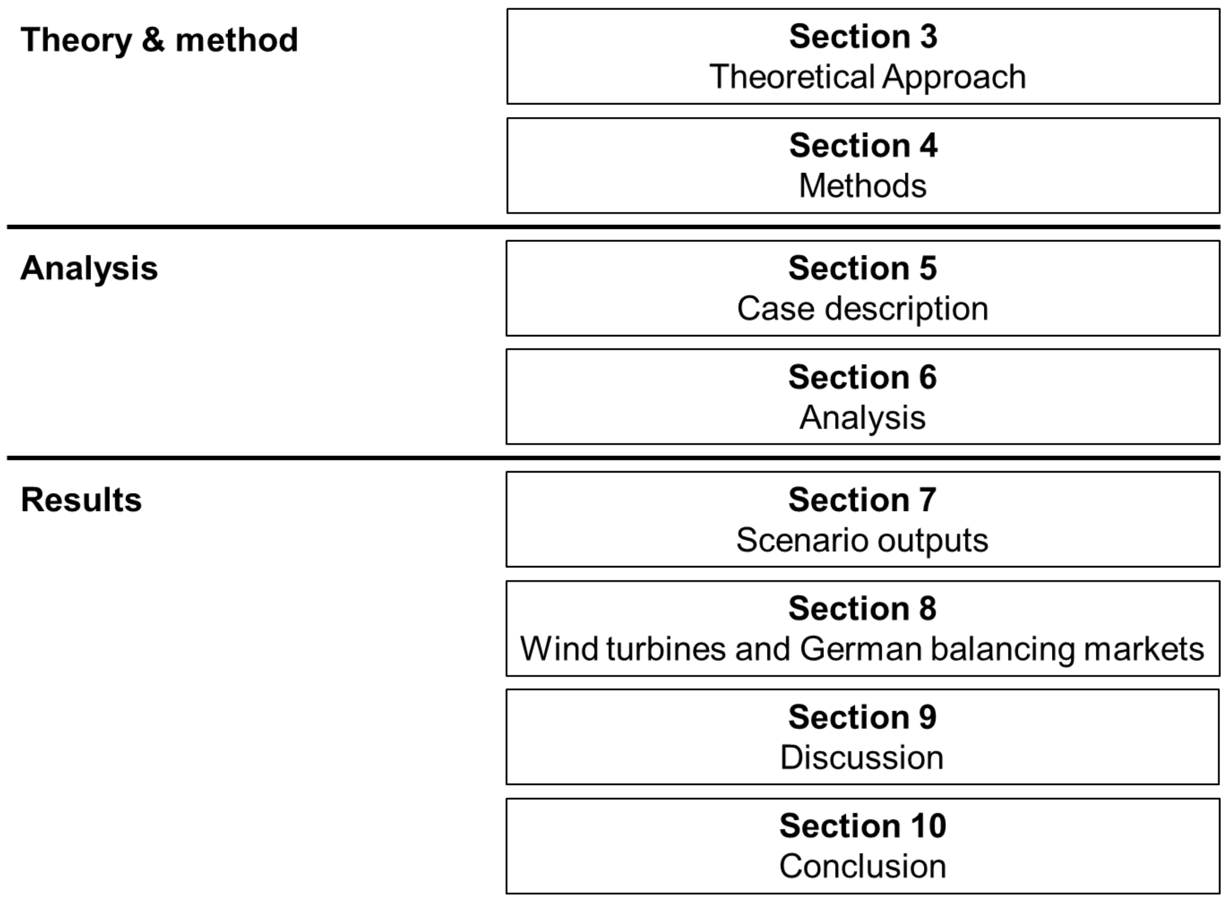


Figure 8: Thesis structure model (personal illustration)

3. Theoretical approach

This chapter elaborates the theories related to the research topic. Thereby, the electricity market development and public interventions play an important role to foster the expansion of renewable energies and to overcome market barriers. At first the guiding ideas that shape today's electricity markets are explained further as well as theories related to the market interventions that aim for a transition of the whole power system (and therefore also the linked markets). Secondly, in order to draw a scheme for the reader the most important market actors and institutions on the present German electricity market are described. This scheme should serve as a simple depiction of the existing market and should not be understood as a stakeholder analysis. As a detailed stakeholder analysis is beyond the scope of this master thesis, the synopsis serves as an overview for a better understanding of the present market design.

Due to the topic of the thesis the focus lies on power markets. Within this chapter it is sometimes needed to go beyond the view of only power markets, therefore the term energy is used instead of power to give a more comprehensive understanding.

3.1 Power market development and renewable energies

The European electricity markets have been undergoing various changes since the last decades and are still in the process of transforming into a system which is to 100 % based on renewable sources. Thereby, two main guiding ideas have been shaping the present power markets. One is to liberalise the national markets and create a single internal European market, which should lower and align the consumer prices, and the other one is of an increased environmental protection concern (reflecting in environmental sustainability). This is especially connected to a stricter climate policy of reducing GHG emissions and reflects in an active promotion of renewable energies. These two guiding ideas demand for changes in the energy system and the organisation of markets.

The legal competences of conducting energy policies are usually distributed over different hierarchical levels, it can be moreover named a cross-sectional matter. Besides these two main guiding ideas of liberalisation and increased environmental protection concerns, further theories can be applied to the power market policy. Decision making is a complex process involving various actors, at hand simply summed up to the European, national and federal level, depicted in Figure 9.

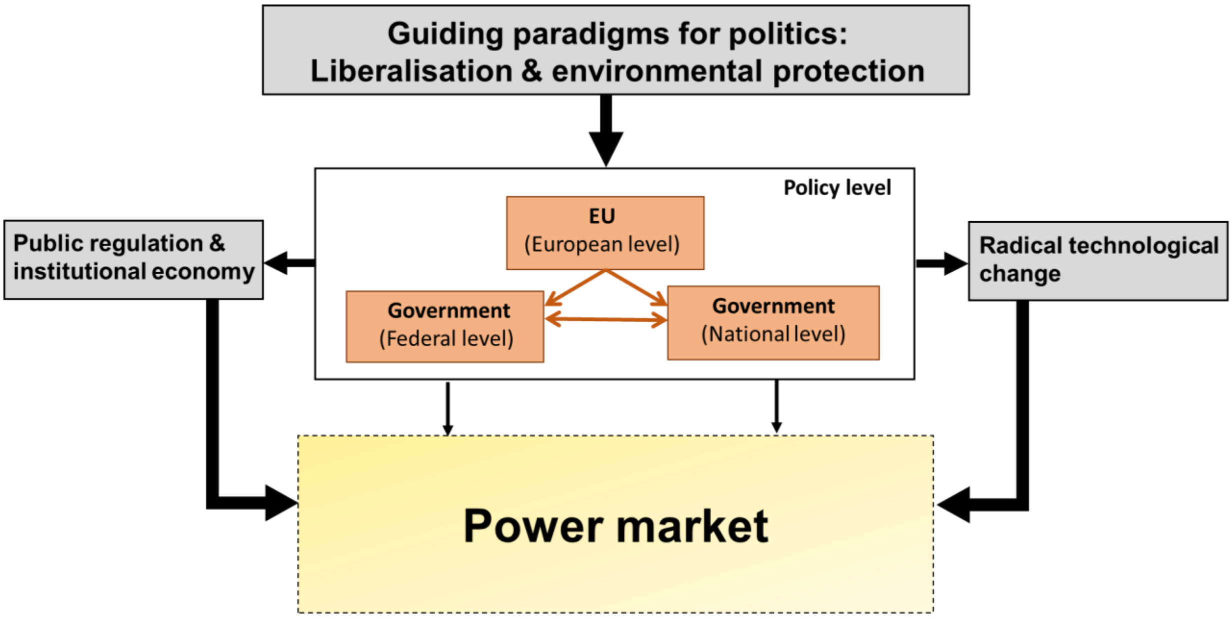


Figure 9: Scheme of theoretical influences on electricity market design (personal illustration)

The theories of public regulation & institutional economy as well as radical technological change foster a power system change towards a renewable system and how such a change may be implemented. Thereby the policy intervention into the market plays an important role: according to the theories, a radical technological change can only be achieved by supporting renewable energies in order to gain ground on the market and by policy intervention to overcome the obstacles set by existing players who may try to constrain such a change at first.

Within the following sections, the theories from Figure 9, applicable to the development of power markets and the system transition, are described in more detail.

3.1.1 Liberalisation of the electricity market

The first directive for liberalising the European electricity markets was published in 1996. The idea behind the liberalising the markets was "[…] *that the greater competition enabled by liberalisation will lower electricity prices for end-users, thus benefiting final consumers.*" (Auverlot et al. 2014, p.9). The aim of an ongoing liberalisation was further "[…] *contributing to bringing peace to the continent by creating a common European market for electricity that would enable any consumer to buy megawatt-hours from any producer, wherever they are within the EU."* (Léautier & Crampes 2016).

Liberalising the electricity markets should lead to an increase of economic welfare: everybody in Europe shall get access to electricity. This development should strengthen the ties between the member states and eliminate the price differences between the countries. The idea of a single European electricity market has already made large steps forward: on the 11.04.2016 at 22:00, the electricity price was 27.86 €/MWh in France, Germany, Belgium, the Netherlands, Spain and Portugal (Léautier & Crampes 2016).

The key points of liberalising markets are the possibility of choosing one's own supplier, the unbundling of generation, grid and trading, a non-discriminating access to the grid, an independent system regulator and an independent system operator (Panos 2013, p.46).

The change electricity markets are undergoing at the moment is facing nonetheless various obstacles. Léautier & Crampes describe in their paper about the "Liberalisation of the European electricity markets" the 5 dimensions of difficulties:

The symbolic difficulty: Electricity is seen as an essential commodity. It symbolises the heart of the industrialised states and a necessary development goal for developing countries. It has become a sign of progression and wealth.

The political difficulty: Most of the EU member states had to change their power system crucially. Away from vertically integrated national – mostly state owned – monopolies to a system with a high degree of competition and less political influence. A political change of such requires a strong and long-term political commitment.

The technical difficulty: Electricity is a hardly storable commodity that is underlying clearly defined physical laws. The whole European grid needs to be aligned and work synchronously. That makes it more difficult to design a common market compared to other goods.

The economic difficulty: In theory opening markets creates a surplus. The benefits are however not distributed equally, thus there are always winners and losers within the system. Winners are considered the ones obtaining lower prices than before the liberalisation and vice versa. It is a necessity to implement policies trying to equal the imbalances.

The cultural difficulty: Before markets were liberalised, power utilities were operated like civil services and not like companies in a competitive environment. A change therefore requires a high degree of adaption of these utilities (Léautier & Crampes 2016).

All these above listed difficulties demonstrate a big challenge for the desired market developments. In this context, especially the economic and political dimensions need to be highlighted. The incumbent and historically grown energy utilities may not have managed to cope with the competitive environment and therefore face crucial financial difficulties now. Additionally, the strong involvement of politics into the economic decisions these companies make – a lot of these historical utilities are partly state-owned – may cause problems due to a mismatch between political and business-economic interests. Historically, losses caused by bad investment decisions were passed on to the consumers. Within a liberalised and competitive environment, these electricity suppliers cannot forward their costs to the community, they are further forced to depreciate unused assets. National policies usually act supporting and favourable of these energy utilities for several reasons: most often national governments are shareholders. Furthermore there is the risk of losing local jobs and the threat of losing control over this important key industry (Léautier & Crampes 2016).

3.1.2 Environmental protection concerns and policies

Another important driver for today's developments of the electricity markets are the environmental policies, which are shaping the present electricity market. The idea of reducing GHG emissions and thereby avoid negative impacts on the environment are the main supporter of transforming the energy system into a renewable and carbon free system.

As shown in Section 1.1, energy industries are causing a vast share of the global GHG emissions, with the tendency of an increasing electricity demand in the future driven by an increment of accessibility to electricity and a growing world population.

Not solely the phenomenon of global warming is usually related to fossil based energy supply, further concerns such as "[…] *air pollution, acid precipitation, ozone depletion, forest destruction, and emission of radioactive substances*." got into focus (Dincer 2000, pp.158–159).

In addition, also the public perception of energy related environmental problems changed: the fact that consumers share responsibility for pollution is more and more commonly accepted. In this context Figure 10 illustrates the historical development and the future scenarios of the European GHG emissions to which the European goals relate to.

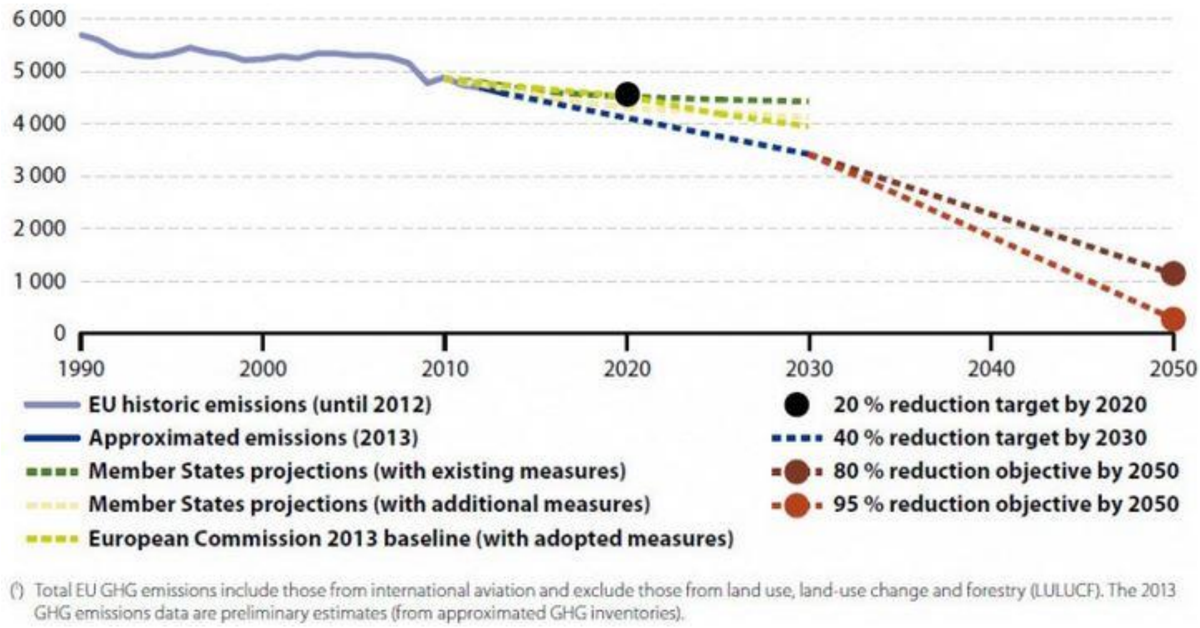


Figure 10: Development and future scenarios of GHG emissions (EUROSTAT 2015)

Figure 10 not only shows the historic GHG emissions in the EU and the different reduction targets for the years 2020 and 2050 but furthermore projections how the emissions will develop with existing, but also with additional, measures. The goal of a 80-95 % cut of carbon emissions in 2050 seems to be very challenging. With the recent reduction trends, these goals are out of reach. Only with high effort these objectives can be achieved. Thus, a change of the energy system, or more precise of the electricity generation system, towards emission-free technologies, is expected to have a remarkably positive impact in the direction of a GHG emission free economy. The increment of emission free power facilities are therefore considered as a necessity to achieve these goals.

A key player for an environmental policy supporting the depletion of the GHG emissions is the EU. In the 1990s, the European environmental policies emerged slowly. Monitoring system of GHG emissions were worked out by the European Commission (EC) in 1993. A common CO_2/ energy taxation failed due to the lagging support from the member states. Programmes for renewable energies and energy savings were weakened during the legislation procedure by the responsible institutions. Progress in GHG reduction was made in the early 90s mainly on a national level, where a cut of carbon emissions was rather a “side effect” of developments than its purpose (e.g. German dash from coal to gas). With the implementation of the Kyoto Protocol, the European policies on climate change gained momentum. The later invented ETS – as part of the European Climate Change Program – further pushed the European environmental policies as the ETS invented monetary units for GHG emissions for the first time. Several legal documents were published between 2001 and 2007, among them directives to promote renewable energies in different sectors (Oberthür et al. 2008, pp.39–42). Deduced from these documents, the idea of implementing renewable energies already played a key role, when European environmental policies evolved.

As described in Section 1.2, the EU has set up its binding 20-20-20 goals, obliging all the member states to common goals in relation to renewable energy expansion, energy saving and GHG emission reduction.

These goals will be extended until 2030 aiming for a renewable energy share of at least 27 %, a cut in carbon emissions by 40 % and an increased share of energy efficiency of at least 27 % (European Commission 2014, pp.4–8). Within the roadmap until 2050, a cut of GHG emissions between 80-95 % (compared to the level of 1990) is pursued.

3.2 Choice Awareness regarding radical technological change

For any desired change it is important to be aware of all the possible options concerning its issue as well as the outcomes of it. Choice Awareness is hereby essential. The theory of Choice Awareness deals with the aspects, the “how”, of implementing a radical technological change such as the transformation from a mainly fossil based system to a 100 % renewable energy system. The desired change might not be accomplished with the existing organisations and institutions. There needs to be a change within these as well since otherwise most likely no alternation occurs as it is not in the interest of the very organisations or institutions (Lund 2014, p.15).

Regarding technological change, a technology as such consist of the following elements: technique, knowledge, organisation, product and profit. If there is a considerable change in any of these dimensions, at least one of the others will follow. Otherwise, it would not be a successful change and abandoned soon. There cannot be a fundamentally change in a technique, initiated by the society, if there is not a change in regards of the knowledge, organisation or the product. A radical technological change is defined as a change which affects more than one dimension. Technological changes are however not done by so-called “end of pipe” solutions, meaning only the improvement of the existing system.

Concerning the change to a renewable system it can be stated that the “*existing institutional set-up may favor (SIC!) established technologies at many levels*” (Lund 2014, p.21). From the established institutions there might not be a desire for changes. Therefore, a trigger from outside is needed to promote a change. A change does not need to affect every actor at once. A system change towards a 100 % renewable system implies, in accordance to the liberalisation, a system shifting away from monopolies to multiple competitive suppliers. This change is however linked to various barriers.

The liberalisation of energy, more specifically for power, was driven by the idea of decreasing prices for consumers. Besides the intended price decrease no crucial structural changes are expected for consumers, compared to the supply side. The change of the system to more renewable energies, which are usually more widely distributed geographically, implies next to the alternation of the technology also one of the organisation and the knowledge. Therefore, it can be seen as a radical technological change (Lund 2014, pp.20–22).

3.3 Public regulation and institutional economy

"*The implementation of radical technological changes* […] *depends on the public regulation also addressing the organisational and institutional circumstances*" (Hvelplund & Lund 1998, p.65). This means in order to initiate a change, regulations are essential to trigger the process and guide it in the desired direction.

Before a regulation can be implemented, an understanding of the market situation is necessary. Every market is formed by a certain amount of institutions. These are most likely static in a neoclassical economy, the current dominant school of economic. Neoclassical economics is defined as a "*determination of prices, outputs, and income distributions in markets through supply and demand"* (New World Encyclopedia 2013). However, for a technological change a transformation within the market is needed. The base of the neoclassic economy, mostly described by its main representative Adam Smith, is the free market. Within this market, there are various independent suppliers as well as buyers. Everybody tries to maximise its' profit and acts with rational behaviour. For all the products on the market there is full information available in regards of price and quality. Therefore, the market place is free and democratic. Regarding the relationship between the market and the public sector in a neoclassical economy, parliaments construct the rules and laws as a framework for the market independently with public regulation measures. Taxes are defined from a neutral point of view. This leads to the assumption that in the neoclassical economy the regulation effects posed by the public sector upon the market and its processes are considered as being neutral. However, in reality it is not the case. The present economy should rather be seen as an institutional economy with entanglements and no optimal condition at all, especially regarding the socio-economic aspects (Hvelplund & Lund 1998, pp.15–17).

However, when looking at the wished change towards a more liberalised market and a 100 % renewable energy system there is a change needed in order to accomplish the transformation. The start of this alteration was triggered by political efforts. For the new solution a system change is needed in which new players, such as organisations and institutions, are essential because a transition cannot be expected to be carried out by existing institutions.

However, in the neoclassical model no public regulations are needed as the market will balance itself. This assumption is quite contrary to the functioning of the real market. In reality the market has to cope with public regulations, business structure, information accessibility and private market power to mention a few influencing aspects. The real market is shaped by a variety of regulations. This is especially applicable for the electricity markets. Existing relations entangle and link institutions and therefore suppliers may not be independent at all which complicates the change. The access to information may be hampered due to commercial interests. In reality, there will always be some public or private hierarchical regulation, an influence to some extent which is organised and guided by a purpose to change the framework of the market or the organisation of cooperation (Hvelplund & Lund 1998, pp.15–17).

When looking at public regulations the context is essential. Within the influence of economic measures the social and institutional context should not be left behind. The implementation of a radical technological change relies on public regulations but has to furthermore address the organisational and institutional circumstances as well.

There are different phases, on a political level, which any technological change has to undergo. A change might face some resistance from the established system and organisations in the beginning. This may recede when the benefits of the change, especially monetary ones, are concretely outlined. As a first step in these phases of being established, the problem has to be clearly defined and furthermore a technically possible solution being provided. The technology has to appear on the political agenda and also be considered as an option. Additionally, it must be proven that it is economically feasible. The legal political authorities have to consider it as relevant before it can be implemented. This can cause some struggles and might need institutional changes. At last comes the challenge of actually competing within the existing system (Hvelplund & Lund 1998, pp.65–71). These steps can be exemplary broken down on the transition towards a 100 % renewable energy system in order to apply it to the very case: The problem, which in this case is the global warming caused by GHG, was already detected in the 1990s and finally put on the global political agenda with the Kyoto protocol. Therefore, in order to lower the GHG emissions the use of renewable energies instead of fossil fuels provide a possible alternative. Even though the implementation of renewables was technically possible, there were however financial constraints.

As Germany committed itself to lower its GHG emissions, various solutions to cut down emissions were put on the political agenda and considered as an option, as e.g. the increment of renewable power. The main act to promote them was the enactment of the EEG in 2000 in order to promote a growth of renewables. However, to that point renewables were not considered as feasible due to the inflexible power system, based on fossil fuels and close entanglements to the state. Especially in regards of implementing public regulations, one should prior be aware of the asymmetry of the financial power of the different technologies, as it is as well the case for fossil energy and renewables. This asymmetry of power may prevent the evolvement of new technologies. Therefore, public regulations are necessary to overcome these obstacles. Based on the position of the fossil fuels, it was decided to subsidise renewables as well and, in order to help them to further compete within the market, to guarantee priority feed-in into the grid. This helped the renewables to undergo the last steps on the political levels and to carry out the technological change to quite some extent so far.

For any change the wished institutions, which should promote the transformation, must be developed or triggered by public regulations as the existing organisations may preliminary do not force such a transition due to several reasons described in Section 3.1.1. That might change with incentives that come along with the change, especially monetary ones. Therefore, public regulation should develop new institutions. For a radical technological change different dimensions need to alter. These, about to be implemented institutions may be defined as rules for transactions in order to determine the development of the market and the participating organisations in it. The set-up rules should contain certain aspects: the time horizon for regulations ought to be longer than the one of the investment made, the extent of the impact ought to be more comprehensive than for only single actors and the costs for promoting the change ought to be paid by the community. It furthermore will affect both, private and public, organisations. However, any desired change does not automatically evolve in the market.

In reality there are strong links between companies and the existing market. To have a successful transformation the political process has to be independent from these interests in order to establish new market conditions. The existing companies do normally not have the innovation capability for the change as it means a loss in market share in the current system. Nevertheless, there are certain obstacles on the way of creating public regulations due to entanglements. These are for instance on a political level the lack of openness of the participating parties and lobbyism. In order to strengthen the political independence to implement public regulations, first of all, an abolition of the entanglements between the state or the political levels and established companies is needed as well as more transparency on the costs and tariffs. This is already aimed to be realised with the liberalisation of the European energy markets (Hvelplund & Lund 1998, pp.65–71).

3.4 Power market transition

As already outlined earlier in this chapter, the power system is currently in a transition phase. The main initiatives which triggered this change are the liberalisation of the power market and the environmental protection which is coupled to the transformation into a 100 % renewable system. The following Figure 11 displays the desired transition path.

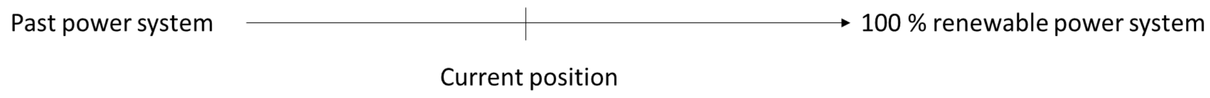


Figure 11: Desired transition of the power system (personal illustration)

The past power system was predominately based on fossil fuels such as coal and oil and was arranged centralised. The market had a manageable size due to the few state-owned monopoly suppliers which led to a low variety of actors within the market. These markets were furthermore organised as national markets. The predominantly used fossil fuels are moreover not a fluctuating source due to its possibility of storing. For these reasons the past energy system was easy to regulate in correspondence with the demand.

However, for different reasons, which were described earlier, a change of the past system was desired. The aim is therefore one single European electricity market which is to 100 % based on renewable energies. For the supply side, the situation got more and more complex due to the high degree of competition. Furthermore, the demand side aims for more flexibility and an empowerment of the consumers: by avoiding asymmetric information consumers get aware of their choices. This development towards a democratic system is gaining more importance within the new system as it enables more self-supply and a vast variety of small producers. Therefore, the new system is rather complex with a growing volatile power generation, the connection of a variety of different markets and the broad inclusion of various actors. For a successful transition several regulations are needed in order to control the market and enable the best possible interaction between all the different aspects and factors which have an impact on that market.

In the following the current position of this transition (market organisation), specifically applied to the Federal Republic of Germany, will be described more detailed with all the relevant actors on the electricity market.

3.5 German electricity market and its actors

This chapter describes today’s shape of the German electricity market, including relevant actors and the market organisation as the liberalisation of electricity markets has brought different changes. This section is meant to give an overview over the power market and further draw a picture of its' present shape.

3.5.1 Electricity supply

On the supply side Germany was and still is mainly dominated by the big four utility companies, namely E.ON, RWE, Vattenfall and EnBW. The following Figure 12 displays the supply areas of these, so called "Big Four", and their range of main influence.

Figure 12: Supply area of the big four utility companies in Germany (EcoPlus Energie GmbH n.d.)

Already during the time of the National Socialism the German electricity sector was consolidated and regional monopolies were established. This trend proceeded: Especially in the early years of the Republic these large, well-established but on the other hand also deeply politicised utilities had power over the electricity market. After the liberalisation of the German electricity market in the late 1990s these former state-owned regional monopolies maintained their structure resulting in a market that is nowadays fragmented and clearly divided. There are demarcated regions of dominance which are shown in Figure 12 above. Each of the Big Four was able to benefit of its company scope and influence to gain vast profits over the last decades. However, in recent years the setting changed. Due to the energy transition and the nuclear phase-out the business model of these companies is at a turning point. The German nuclear power plants are almost exclusively owned by the Big Four. The economic power of the companies has been reduced in the last years. E.ON was worth 92 billion euros in 2007, compared to the 26.4 billion euros in 2015. Another aspect, next to the phase-out of the nuclear power plants is that these companies struggled to increase their renewable portfolio. Only a small share of this market segment is hold by the Big Four, mainly in (offshore) wind. A large share of renewables belongs to citizens' cooperatives and individual persons. However, under the current conditions in which the renewables are on the rise in the electricity generation, fossil power plants are hardly feasible to run anymore. Another aspect in the changing system to more renewables and their subsequent effects, as for instance more and more households generate parts of their own electricity with e.g. solar panels and thus become producers or so called “prosumers” themselves. Hence, they cannot be considered as being stable customers anymore. This rate is continuously growing (Schlandt 2015) (Appunn & Russell 2015).

Currently, the Big Four are still dominant as they hold a share of over 60 % of the conventional power market in Germany and in Austria. Generally, they still have a high share of lignite, coal and nuclear energy whereas a relatively low one of renewable energies. One of them, namely Vattenfall, is a subsidiary company of Vattenfall AB which is completely owned by the Swedish state. The others are partly owned by federal states, towns and cities and operate on the stock exchange. These entanglements with the political level can cause clashing interests. On the supply side there are as well other actors: so-called Stadtwerke. In the early 1990s many of these former publically owned municipal utilities which were holding the regional monopolies, were privatised based on time-limited contracts. These contracts were however not prolonged after expiring due to local councils and citizens voting against it. In comparison to the Big Four, which are still highly centralised, these Stadtwerke own renewable facilities to a large extent and decentralised combined heat and power (CHP) plants which gives them more flexibility in their electricity system compared to centralised systems (Schlandt 2015) (Appunn & Russell 2015).

3.5.2 Electricity demand

With the liberalisation of electricity markets, electricity became a tradable commodity. This especially affects the industries: they often benefit from low wholesale prices due to tax exemptions in combination with their large consumption. As already outlined earlier in Section 1.4, the wholesale electricity prices have declined over the last years. Most of the actors on the demand side, the citizens, are however not influenced to the same extent. The effects of price decreases on the power exchange are often not passed on by the supply companies with the same extent to the private consumers as the demand elasticity may not react to smaller price changes. Consumers purchase the required electricity on the basis of a tariff with a fixed rate per MWh. Since the liberalisation, which was already described in Section 3.1.1, consumers have a free choice of their supplier. If the difference is just marginal, not a lot of consumers choose to invest time in a comparison and hence a switch their provider (Kirschen 2003, pp.520–522).

3.5.3 Bundesnetzagentur

Within the Federal Ministry of Economics and Energy the Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway (Bundesnetzagentur - BNetzA) is a separate higher authority which was founded in the late 90s. It supervises the operators of energy supply networks. It was initiated to ensure a non-discriminative access and usage of the energy supply network for all users, as a requirement for the liberalisation. The BNetzA is responsible for the expansion of the electricity grid, meaning an efficient procedure of an accelerated expansion. It controls as well as sets cap borders for the grid tariffs. These cap borders demonstrate the upper border for revenues coming from grid tariffs collected by the system operator in charge. Furthermore, the BNetzA now carries out the auction rounds in the EEG 2017 (Clean Energy Wire n.d.). The BNetzA is additionally responsible for the asset register in which approvals and commissioning of new wind turbines are notified.

3.5.4 Transmission and distribution system operators

The liberalisation of electricity markets also required the establishment of an independent system operator (see also Section 3.1.1). Germany has four, historically grown, TSOs in charge of maintaining the extra-high voltage transmission grid (380 kV and 220 kV) and secure the security of supply (Panos 2013, p.47). Therefore, one of their tasks is the procurement of balancing energy (see Section 3.5.6.4).

The German TSOs TenneT, 50 Hertz, Amprion and TransnetBW are shown in connection with their control areas in Figure 13. Germany is part of continental Europe’s synchronous grid, an interconnected grid area based on the frequency of 50 Hz, including almost different continental EU member states.

Figure 13: German TSOs (PSI n.d.)

Since 2010, these TSOs have a common Grid Control Cooperation (GCC). The GCC ensures that imbalances are levelled out first between the control areas, before using balancing power. Only the common, nationwide, residual deviations are balanced by the balancing reserves (50Hertz Transmission GmbH n.d.).

The German TSOs are further part of the International Grid Control Cooperation (IGCC). The IGCC is a European regional project that should establish a cross-border imbalance netting cooperation and currently involves 11 TSOs from 8 countries. Part of the IGCC are Austria, Belgium, Switzerland, Czech Republic, Germany, Denmark, France and the Netherlands, see Figure 14 (ENTSO-E 2016b). Small transmission reserves are kept from the TSOs to exchange electricity cross-border. This shall further help to reduce the costs for balancing energy (50Hertz Transmission GmbH n.d.).

Figure 14: IGCC members (ENTSO-E 2016b)

Besides the TSOs, Germany has a variety of distribution system operators (DSOs). The DSOs maintain the grid from 110 kV downwards and are in charge of supplying the end-users and the electricity distribution (Panos 2013, p.47).

3.5.5 Balancing group management

The usage of the grid by consumers or suppliers presupposes the establishment of balancing groups, so called “Bilanzkreise”. Within one control area there are several balancing groups. An accounting grid includes the feed-in points as well as the extraction points which are used by the actors connected to the grid. For every single of these accounting grids there has to be a representative manager announced, who is responsible for the balancing group towards the TSO. Prior to each day these managers have to make a schedule for every 15 min and inform the grid coordinating TSO about it. Base is hereby the expected load from all consumers and generators within the balancing group. The representative manager is the binding link between the grid users and the TSO and is furthermore economically responsible for the imbalances between the feed-in and the extraction (Panos 2013, p.465).

3.5.6 European Energy Exchange and balancing markets

As mentioned in Section 1.4 of the report, the EEX is the most important stock exchange for different commodities in Germany. Besides power, natural gas, coal and oil also European CO_2-quotas and other commodities can be traded (EEX 2016b).

Power is – as other commodities – a standardised product in terms of volume, load type, delivery period and its physical or financial (applicable for derivates) fulfilment (Panos 2013, p.54).

The EEX was invented in order to ensure a transparent as well as financially, technically and economically secure market place. An indispensable requirement for a properly working market place is its liquidity, which is ensured by a large amount of traded volume and a large number of actors (Panos 2013, p.48).

Electricity can generally be traded in three different ways. Via bilateral contracts (OTC-trading) among actors, on the day-ahead and the intraday market, or as derivates consisting of futures and options. These markets will be described in more detail within this chapter. The day-ahead and the intraday market are executed by the European Power Exchange (EPEX), located in Paris. The electricity price for the German price zone is called Physical Electricity Index (PHELIX) (Panos 2013, p.50). In 2016 the volume traded on the day-ahead market added up to 235 TWh, whereas 41 TWh were traded on the intraday market (Fraunhofer ISE 2017a).

3.5.6.1 Day-ahead trading

The day-ahead market is part of the EPEX power exchange. Electricity can be traded the day before the consecutive day until 12:00. The next day, these contracts have to be fulfilled physically. Thereby, hourly contracts as well as block contracts for various hours are concluded. An example for these “blocks” are the base load (every hour during a week) and peak load (Monday until Friday 08:00 -20:00) contracts (Panos 2013, pp.50–53).

The electricity price for every hour is set by a market clearing price (MCP), which is constituted by the intersection of the supply and demand curves. An example of the MCP constitution is given in Figure 15.

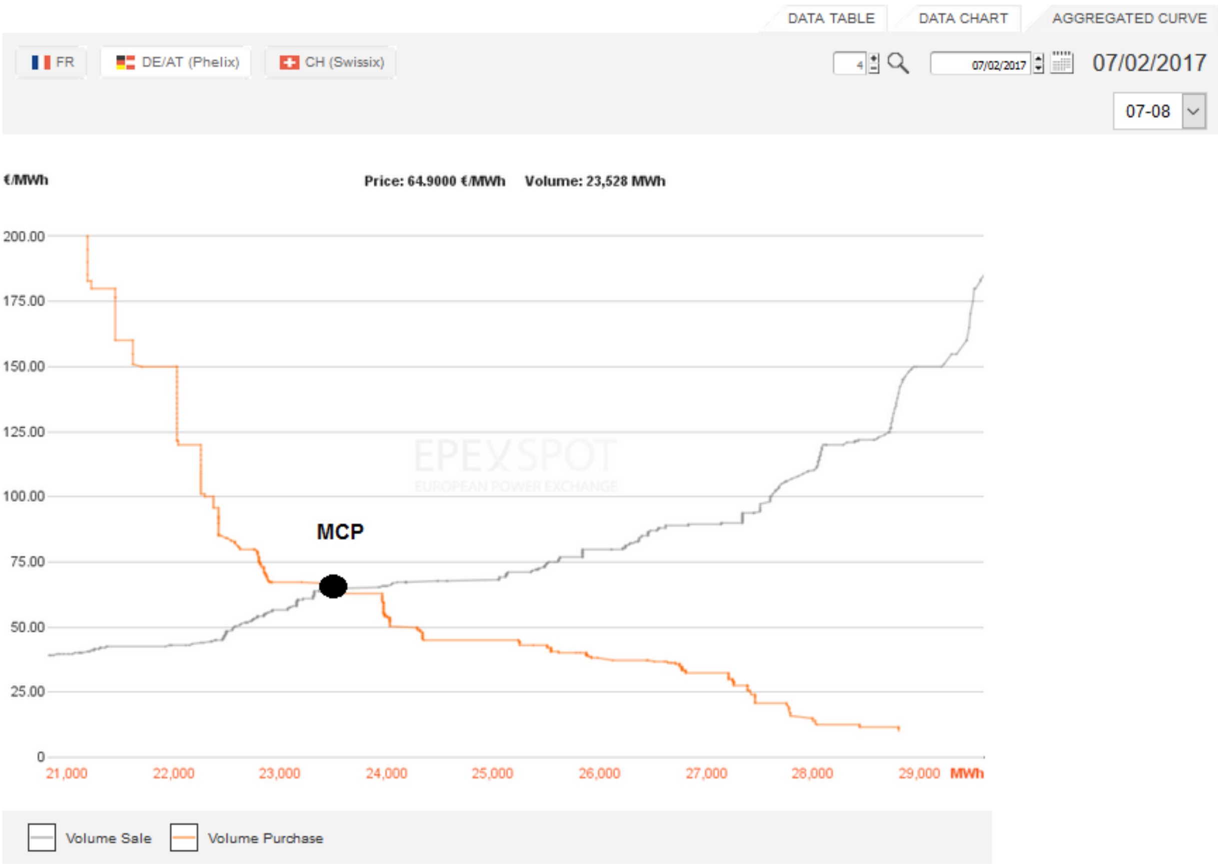


Figure 15: Hourly determination of the EPEX day-ahead market clearing price (EPEX 2017a)

The MCP is thereby the clearing price for a certain hour, yielding in 64.9 €/MWh for that very day (07.02.2017) as Figure 15 above depicts. That means all offers above the MCP are too expensive and these bidders do not sell their electricity while the ones below the MCP are going to sell their electricity. All offers are sorted by their merit-order and the last awarded unit sets the MCP. All the electricity awarded in an hour is then cleared with the same price, thus the higher the margin between the sellers bid and the MCP, the more profitable the transaction.

3.5.6.2 Intraday trading

Compared to the day-ahead market, the intraday market was established to continuously handle imbalances within the same day. The trading time steps are divided into quarterly time steps, as also imbalances penalties are executed within these time steps. Contrary to the day-ahead market, the price is not set by a MCP. Instead, it follows a pay-as-bid principle. That means, every seller and buyer gets for a certain volume the price asked for, if a matching demand is found. All offers are published in an electronical order book and listed according to their price and volume. If an offer matches (the purchasing price must at least be as high the offered price), the offered volume is automatically traded and the transaction conducted. Additionally, market participants can accept an offer electronically, which means they agree with the asked price and volume. Successful transactions are visible to all market participants (Panos 2013, pp.52–53). Offers can be declared as separable or non-separable. This declaration determines if only parts of the offered volume can be bought or not. The intraday market is underlying certain dynamics, especially when coming closer to the trading deadline for a specific quarterly hour. The dynamics further depend on the participants trading strategies, offers can also be withdrawn (Pfleger 2017).

Figure 16 shows an example of the intraday bids on the 6th of February 2017 between 00:00 and 01:00.

	Low (€/MWh)	High (€/MWh)	Last (€/MWh)	Weight. Avg. (€/MWh)	Index (€/MWh)	ID_3-Price (€/MWh)	Buy Vol (MW)	Sell Vol (MW)
▼ 00 - 01	34.90	50.30	40.80	42.00	42.00	41.83	2,767.4	2,752.9
▼ 00:00 - 00:30	–	–	–	–	–	–	–	–
00:00 - 00:15	36.70	53.30	41.00	47.76	47.76	47.52	222.6	222.6
00:15 - 00:30	34.00	53.30	34.00	45.40	45.40	44.51	182.2	182.2
▼ 00:30 - 01:00	–	–	–	–	–	–	–	–
00:30 - 00:45	20.30	53.30	33.00	35.29	35.29	34.83	195.9	165.9
00:45 - 01:00	4.20	43.90	19.00	24.61	24.61	24.59	230.6	200.6

Figure 16: Example of the intraday prices on 06.02.2017 (EPEX 2017a)

As demonstrated in Figure 16 above, the intraday prices usually range between different values within a quarterly hour, due to the pay-as-bid procedure. Therefore, the most representative value for a time interval of 15 min is the weighted average price. Deviations between the buying and selling volume can be traced back to a mismatch between certain bids.

The intraday market is a possibility for market participants to adjust their production schedule to their real production to avoid costs for balancing power. Especially the energy yield from wind turbines and photovoltaic is linked to weather uncertainties, which then can be adjusted on the intraday market.

3.5.6.3 Derivate markets

Another option for trading power is via derivates. In difference to the day-ahead and intraday market, derivates are usually traded for monthly, quarterly and yearly determined standard products. Further, also short-term maturities (day, weekend, week) can be traded (EEX 2016a).

Thereby, so called “options” as well as “future” contracts can be signed. Future and options differ in their mode of price risk and benefit sharing (Panos 2013, p.54), and are concluded to hedge against the risk of unprofitable price developments on the market.

It is important to mention, that compared to the day-ahead and intraday market, the intention of futures and options is not the physical fulfilment and thus it does not affect the actual production schedule: a unit is not operated according to the price agreed in the future contract (E-Control 2017). Long-term contracts for wind power promotion are hardly executed, due to a high volume risk. Thus, this marketing option is not included into the further analysis.

3.5.6.4 Balancing markets

Due to technical reasons, the electricity system needs to be kept in balance between the generation and the demand at any time. The frequency in the system must be kept in a common frequency of 50 Hz or just marginal deviations. Therefore, the German TSOs are responsible to permanently maintain this balance within their control areas. Balancing power can be divided into positive (upward regulation) and negative (downward regulation). Since 2001, the acquisition of balancing power in Germany is conducted on a transparent, open and non-discriminating procedure. The needed balancing capacity is procured within a tender procedure separated by the reserve type, namely the primary (PCR), secondary (SCR) and tertiary (TCR) control reserve. The market follows a pay-as-bid principle. Bids get awarded in a merit-order until the desired capacity is reached. In order to participate in the tender procedure, technical prequalification requirements have to be met depending on the reserve type (Amprion GmbH n.d.). Every balancing type is tendered for a certain period and volume. While the PCR and SCR is tendered on a weekly basis, the TCR is tendered daily (Amprion Gmbh et al. n.d.). Since 2015, Germany, Austria, Switzerland and the Netherlands have a common market for the PCR procurement, in 2016 and 2017, also Belgium and France joined this cooperation. Consumers should benefit from a higher competition in the markets (APG 2017a). Further collaborations are planned: there is for instance already a cooperation upcoming regarding the SCR acquisition and procurement between Germany and Austria (APG 2017b).

Balancing power must be activated immediately after the incident to maintain the grid stability. Thereby it can be distinguished between the balancing capacity, which always needs to be available without actual use, and the actual control power generated from these balancing capacities (50Hertz Transmission GmbH n.d.).

While the PCR is compensated financially by a performance price per kW (€/kW), the SCR and the TCR get compensated by a performance price per kW (€/kW) for withholding the capacity and a commodity price for the actual electricity generation (€/kWh) (BMUB & Fraunhofer IWES 2014, p.21).

Figure 17 gives an overview over the technical activation requirements for the different balancing reserve types in Germany, which are described in more detail below.

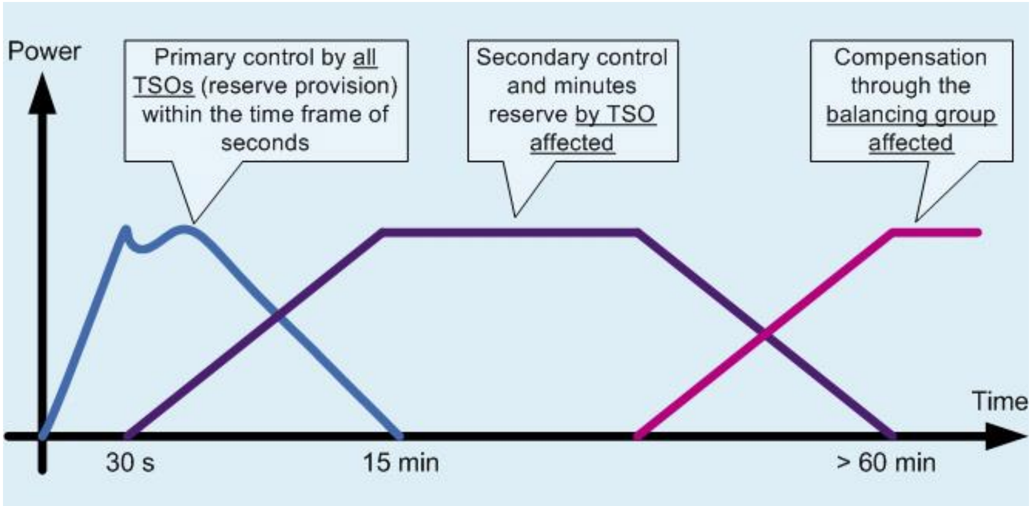


Figure 17: Activation time of the different balancing reserve times (Amprion GmbH n.d.)

As the graphic shows the PCR is activated first. It serves to even out small frequency imbalances immediately, without the TSOs intervening if a certain control area is facing a frequency deviation. Its activation occurs within 15 sec. The time it runs per incident is between 0 and 15 min. In case of further system balance deviations, the SCR is activated. The activation is conducted automatically by the affected TSO and starts within 5 min. If the need for balancing power grows and if it does not decrease, the TCR is activated manually by the affected TSO within 15 min (Amprion GmbH n.d.)(50Hertz Transmission GmbH n.d.).

After a period of maximum one hour in total since an incident, the TSO is not in charge of balancing the system anymore. From there on, the responsibility falls to the party concerned causing the imbalance. This party is then in charge of compensating the imbalances (Amprion GmbH n.d.).

4. Methods

The following chapter presents and explains the different methods used within the at hand thesis. A variety of methods is included in order to answer the formulated research question and the related sub-questions. Included methods of the thesis are next to literature study, interviews, the EEG 2017, data collection and validation also investment calculations. Furthermore, the simulation programs windPRO and WAsP are incorporated.

4.1 Literature study

In scientific research an analysis of the background information is crucial. Before defining the main aspects of a topic to be further examined, a literature research can help to clarify but also to direct into a certain path where additional enquiry is needed. Literature research is mainly used in the start-up phase of the project but also in order to prepare for interviews and to describe the current settings. A comprehensive explanation of the present conditions is essential in order to give an insight into the topic and to promote a joint understanding in the field of action beforehand. The analysis of available information is done within the internet, reports, books, laws, reviews and scientific papers.

4.2 Interviews

Interviews are a method used in qualitative research to collect data. They are part of the at hand thesis in order to gain more nuanced knowledge of the given topic or problem and to clarify different aspects, mainly in a subjective perspective. Therefore, it is important to understand the different possible types of interviews.

The purpose of any interview is to discover the motivations, concerns, views but also experiences of a certain individual on the specific topic. A deeper understanding of the topic is desired with this qualitative research as in comparison to simple questionnaires. Interviews are therefore used when not that much is known about the topic prior and detailed insight is needed.

An interview can be structured according to Kvale in seven steps. These steps are a process from the start-up phase, with the initial idea to the final product, namely the knowledge output. Before the actual conduction of the interview two steps have to be performed prior. These are the thematisation and the choice of the design. In these steps the objective of the investigation is defined and suitable persons found. In the at hand case it is relevant to choose an expert, who is familiar with the topic and can convey knowledge. The design has to be stated prior as well in order to be prepared for the interview and to set up the interview schedule. The desired outcome should be determined beforehand in order to arrange the structure of the interview accordingly. It furthermore helps within the conduction as well to proceed in the wanted direction (Kvale 2009, pp.157–164). The posed question should lead to a range of information regarding the objective of the research, hence open-ended questions are advisable.

Afterwards, the conduction of the interview follows. There are three fundamental types of qualitative research interviews, namely structured, semi-structured and unstructured. Structured interviews are questionnaires with predetermined questions which leave no space for alternation. Follow-up questions are not intended and hence there is no possibility of the interviewer to react to questions or further upcoming topics of interest. Subsequently, structured interviews are in comparison speedy and less administrative effort need to be handled. This type of interview aims to seek explicit clarification for specific topics. The gained knowledge is normally not broad but specified to the question, more superficial than in-depth.

Unstructured interviews contrarily are performed with less to no organisation. Hereby, there are no pre-formulated theories on-hand. This kind of interview could simply start with an opening question and proceed with responding to the participant’s replies. Unstructured interviews are normally time-consuming. They might furthermore be difficult to manage due to the lack of guidance and predefined questions. This type of interview however guarantees more profoundness concerning the research question and is suitable when not much about the topic is known or a different perspective concerning the topic is desired.

In between of these both extremes lies the semi-structured interview. In this several questions act as key elements in order to define the topic field. This type of interview allows the interviewer to alter the field of interest and pursue certain aspects in more detail or response to the participant’s reaction. On the one hand semi-structured interviews give guidance but are on the other hand not as strict as structured ones and hence leave space for variation and modification when necessary. This flexibility allows the elaboration of certain topics in detail which might not have been considered as relatively relevant before the interview (Gill et al. 2008, pp.291–293).

The conduction is followed by the transcription, analysis, verification and reporting. Especially when performing a lot of interviews these aspects are essential as it is useful to categorise the gained aspects and perspectives. The outcome of all these steps should provide material, which was the aim of conducting interviews at first hand (Kvale 2009, pp.154–155). Interviews should be recorded in order to provide a permanent record and to be protected against bias and uncertainties (Gill et al. 2008, pp.291–293). However, one should be aware that during the transcription of an interview some things are lost such as the tone, body language and other forms one is not able to transcribe. This is also the case in written interviews as well as phoneinterviews. The transcription is helpful when specific aspects need to be investigated in order to understand a certain perspective in an analysis by comparing (Kvale, 2009, pp. 235-240).

In the at hand thesis three interviews are conducted. Two of them are written interviews with two of the German TSOs, namely TenneT and Amprion. These interviews seek clarification and the point of view of the different TSOs regarding the implementation of wind turbines in the German balancing markets and an outlook how these markets may develop in the future. Prior to the interviews the object of investigation was defined and based on that contact was made with the desired parties. Due to the distance to the interview partners the structured interview type, in form of a written questionnaire, was chosen. This form leaves no space to alternation, therefore a comprehensive preparation phase was needed to gain a basic knowledge in order to ask specifically. The questions were formulated very precisely to get a narrow and concrete answer. Two interviews with the same questions were conducted – also to see whether the view of the different TSOs varies on the topic. The interviews were conducted via email in German and subsequently translated into English.

The third interview is a semi-structured interview with Danish TSO Energinet.dk. Hereby, the aim was to gain a broader knowledge on the Danish system of implementing wind turbines in the balancing market – Denmark has integrated them in the negative TCR already in 2012 - in order to compare it to the German system sketch. For the semi-structured interview several questions were set up in advance as well to guide the interview into a certain direction which is of specific interest. However, these are key questions and further ones could be added in case of interest or in case of a relevant upcoming topic of which was not thought of before. This type of interview is more flexible. The interview has been recorded and subsequently the main points of interest were summed up.

4.3 Erneuerbare Energien Gesetz

The main German law to promote renewable energies, namely the Erneuerbare Energien Gesetz – Renewable Energy Sources Act (EEG), was first implemented in the year 2000. Since then it was revised various times – in 2004, 2009, 2012, 2014 and latest in 2017. As a result of the implementation, the share of electricity generated from renewables increased from under 5 % in 2000 to 34 % in 2016, mainly driven by increased wind power (Fraunhofer ISE 2017b). The following sub-chapters are examining the 2017 amendment in regards of onshore wind power more closely.

4.3.1 Amendment 2017

In the last amendment, the subsidy scheme underwent a change with a switch from a guaranteed feed-in tariff to a competitive auction system. So far the fixed feed-in tariff scheme was not market based but statutorily defined for each kWh generated. The change was mainly implemented in order to align the subsidy scheme to the EU prerequisites, but also to structure the subsidy scheme in a more cost-effective way. The new system, starting from the 1st January 2017, applies to the key renewable energy sources as onshore and offshore wind, solar and biomass (Gleiss 2016, p.1). For biomass special rules apply in order to promote flexible operation, therefore biomass plants can only receive subsidies for a time period of 20 years for half of their installed capacity (Barnstedt 2016).

Now competitive auction rounds determine whether a project receives financial support from the government as well as the extent of it. The thereby granted subsidy is a value to be paid to the wind turbine owner for a time span of 20 years. It consists of two variegating factors: the revenues for selling the power via direct marketing on the electricity market and the so-called market premium. The guaranteed subsidy is always paid if the market price drops below it. Thereby, an operator always receives a certain floor payment per generated unit. A more detailed insight on these factors is given later on in this chapter in Section 4.3.3 and 4.3.4.

To stay on the more general outline the yearly auction capacity for wind onshore, as already stated earlier, amounts to 2,800 MW until 2019. The German government decided to mostly stick to the grid deployment corridors which were introduced with the EEG 2014. Thus, the expansion in certain areas is limited, as elaborated in more detail later on in this section. With the capacity cap on each auction round it is ensured that these corridors are abided. The tendered capacity increases to 2,900 MW from 2020 onwards nationwide. The auction system applies to all plants with a capacity higher than 750 kW. Units smaller than 750 kW can still receive fixed feed-in tariffs (Watson Farley & Williams 2016, pp.3–6) (Göß 2016) (Endell & Quentin 2016, p.5).

5 % of the annual capacity for all energy sources are open for bids in other European countries. The new system is build according to the Environmental Protection and Energy Guidelines of the European Commission which aim to help the member states to design a common system for state aid and set common standards (European Commission 2017f).

To sum up the reasoning of the last EEG amendments, the main incentive of these were to bring renewables within the support scheme gradually closer to the market and into the sale mode of direct marketing. With the implementation of the auction system in 2017, the payments which are needed to run the renewable power plants are now competitively determined.

Besides, the law's goals to have a better control over the development of the renewables in harmonisation with the grid expansion, an increased planning security for the other participants in the electricity industry is pursued (Bundesregierung 2016, p.1).

4.3.2 Auction design

The German system aims to make the bids of the whole country comparable. A reference site, which will be described later on in this section, is necessary for determining the granted subsidy, paid by the TSO. The extent of the subsidies is now determined by auctions: for onshore wind turbines, these are guaranteed over a time span of 20 years. The only exception is the so-called "6-hour rule", when the day-ahead market price drops below zero for six or more consecutive hours. Then the promotion will be retrospectively suspended for these hours (Endell & Quentin 2016, pp.34– 35). In hours where the market prices exceed the granted subsidy level, the subsidy lapses. Thereby – similar as for the 6-hour rule – the day-ahead price is the determining factor. If, in a certain hour, the day-ahead price exceeds the granted subsidy no subsidy is paid. In case the electricity is promoted intraday, then no subsidy is paid on the intraday market as well for this certain hour. The trader has however still the possibility to sell the electricity, in case the intraday price is positive.

The auctions are divided by technology. In order to be able to participate in the auctions an approval under the Federal Immission Control Act (Bundesimmissionsschutzhandelsgesetz – BImSchG) must be granted for the desired installation. In each of the yearly three or four auction rounds for wind onshore there is a capacity limit, relating to the yearly limit. In an auction round the lowest bid gets awarded, followed by the next higher one, until the capacity volume of that auction round is reached. The system is a pay-as-bid system, meaning that the bid made in the auction round is also the exact value to be received when getting awarded.

Prior to each auction round a maximum price limit is set by the BNetzA. For each bid made a security deposit of 30 €/kW has to be lodged. When getting awarded, the project has to be realised within a time period of two years. Delays are charged with a penalty payment of 10 €/kW and the amount is raised every two months, until after three years the award expires. The capacity bound to a failed project will not be added to the next auction round. It is furthermore lost. Every award is tied to a specific project and cannot be transferred to another one. In the event of identical bids, the bidder with the smaller capacity gets awarded. In case the capacity is identical as well, the award is assigned by lot (Watson Farley & Williams 2016, pp.3–6).

In regards to the cost-efficiency, the government aims to link the installation of renewable energies to the grid expansion. There are restrictions for areas with grid bottlenecks, so called congestion zones. In these areas which amount to about 20 % of Germany's area, the high amount of electricity generated cannot be carted off due to the lacking grid infrastructure and is therefore limited. The development of the wind power in the north of Germany, especially in the in Figure 18 defined areas, lately caused bottlenecks as the main industry is located in the south of the country whereas the electricity generation increased mainly in the north. Within these areas, the newly build onshore capacity is restricted to 58 % of the annual average extension of the years 2013 to 2015. This rule will be overlooked every two years (Appunn 2016). Figure 18 displays these restriction areas, which are based in the most northern part of the German state.

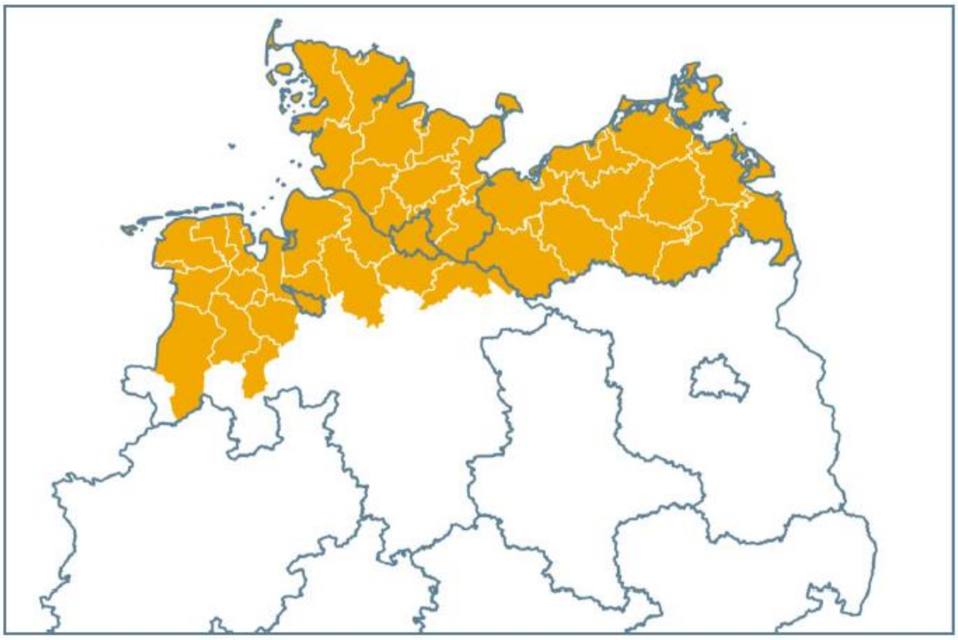


Figure 18: Geographical determination of the congestion zones (Fachagentur Windenergie 2016, p.13)

These congestion zones and the lacking transmission capacities require re-dispatching measures. A re-dispatch is an interference with the power generation of a power plant in order to hinder grid overload in the very grid section. In 2013, exactly 7,965 times of intervention were necessary concerning 4,390 GWh, summing up to costs of 132.6 Mio. €. From 2014 to 2015 these interventions more than doubled up. Especially 50Hertz and TenneT are facing congestion problems. Based on the current state, the BNetzA suggest a grid expansion of more than 2,000 km of domestic power lines in order to transport the wind power from the north to the south (Bundesnetzagentur 2016) (Appunn 2015).

The energy transition in Germany is so far mainly promoted by the citizens. To prospectively guarantee the diversity of the actors there is an exception within the law for so-called citizens' cooperatives. This type of actor, who is also obliged to meet the procurement conditions, has prior to the auction round not to provide the time-consuming and expensive approval under the

Federal Immission Control Act. Instead the expected electricity yield and proof of the availability of the site is sufficient. Projects of this type are limited to an overall installed capacity of 18 MW with a maximum of six turbines per cooperative. Furthermore, just half of the security deposit is needed. Another benefit is that for citizens' cooperatives there is a uniform pricing system. This guarantees them, when they get awarded, that they do not receive the value they stated but instead the highest still awarded bid of that auction round (Watson Farley & Williams 2016, pp.3–6).

4.3.3 Cost calculation for the bid

As already mentioned there is a maximum value for the bid published prior to each auction round. For 2017 this value is set to 7 ct/kWh. From 2018 onwards, the value is determined by the average bid value of the highest awarded bids of the three previous bidding rounds, increased by 8 %. Hereby, the BNetzA can interfere: depending on the actual competitive conditions and the cost situation the organisation may increase as well as decrease the value by maximum 10 % (Watson Farley & Williams 2016, p.4).

The model chosen for the new amended system by the German state is a so-called single-step reference yield model, more specific a single-tier model. Hereby, the bids are made in comparison to a reference site, called 100 % site, defined with the following parameters: 6.45 m/s in 100 m altitude. The wind speeds at different heights are determined by the power law (see Figure 35), considering a shear exponent of 0.25. This shear exponent determines the changed wind speeds at different height (Danish Wind Industry Association 2003b).

The subsidy scheme was invented to guarantee nationwide comparability between the bids and furthermore to ensure that the coastal and windy regions are not overused. In this new model, it is important to conduct an exact assessment of the reference yield, the yield that can be expected for the planned wind turbines at the reference site. Furthermore, it is important to exactly determine the individual site output. The relation of these both values, define the quality factor. The lower the quality factor, the higher the possible subsidies. This quality factor is initially determined by the plant operator and afterwards validated by an expert. It will be reviewed every five years and if necessary adjusted. The costs of the external expert are at the expense of the plant operator. Over- as well as underpayments have to be reimbursed, if there is a deviation of the quality factor by at least 2 % (Watson Farley & Williams 2016, pp.4–5).

To calculate the possible subsidies in relation to the 100 % site, different steps have to be taken. The first step is to define the quality factor of the considered site. Hereby, the planned wind turbine type is essential as both, the site output as well as the reference output have to be determined turbine specific. The site output is defined as the possible electricity generation at the planned location over five years, based on the specific turbine type. The reference value is defined as electricity output which this turbine type would theoretically generate in five operation years at hub height based on a wind speed of 6.45 m/s in 100 m and with a shear exponent of 0.25. Foundation for this calculation is a characteristically measured power curve which is offered by the manufacturers. The reference site is hence a fictive site, defined for each turbine type using “standard conditions”. The reference value is a fictive amount of generated electricity, calculated by using reference conditions with the determined type of wind turbine.

The quality factor describes the relation of the site output to the reference output and defines therefore the less as well as excessive quantity of generated electricity, compared to standard conditions. In the next step the quality factor is assigned to the corrective factor (Endell & Quentin 2016, pp.10–13). To adjust the awarded subsidy to the corresponding granted subsidy per kWh, the corrective factor is used (Watson Farley & Williams 2016, p.5). In case the output of the site is the same as of the reference site, the corrective factor is set to 1.0. If the plant site output is higher than the reference output the corrective factor is lower than 1.0 and vice versa. To determine the corrective factor between the set values in Table 1, a linear interpolation is used. With the corrective factor, possible granted subsidies can be calculated for a certain site (Endell & Quentin 2016, pp.10–13).

Table 1 visualises exemplarily the different steps of the corrective factor in relation to the determined quality of the site as well as the amount of funding that could be received for the total generation of electricity. Hereby, 7 ct/kWh are defined as a maximum in the first auction round of 2017, which will take place on the 2nd of May as the 1st of May is an official holiday, by the BNetzA, whereas there is no lower limit. Bids can be made on all values below the maximum one.

Table 1: Examples of funding levels (Deutscher Bundestag 2016, p.11)

	Amount of funding									
Quality factor	60	70	80	90	100	110	120	130	140	150
Corrective factor	1.29	1.29	1.16	1.07	1	0.94	0.89	0.85	0.81	0.79
Examples of feed-in tariffs in ct/kWh	7.74	7.74	6.96	6.42	6.00	5.64	5.34	5.10	4.86	4.74
	8.39	8.39	7.54	6.96	6.50	6.11	5.79	5.53	5.27	5.14
	9.03	9.03	8.12	7.49	7.00	6.58	6.23	5.95	5.67	5.53

Table 1 displays the different quality factors of each site. Sites with a lot of wind, higher than the 100 % site, get hence a lower granted subsidy, shown with different examples of feed-in tariffs, due to the higher full load hours whereas the granted subsidy is higher for sites with less wind. To adjust the awarded subsidy to the corresponding payment per kWh the corrective factor used. E.g. an 80 % site has a corrective factor of 1.16. Instead of 6 ct/kWh the new adapted value for this site is 6.96 ct/kWh (Watson Farley & Williams 2016, p.5). Above the quality factor of 150 % the corrective factor is set to 0.79 for all higher quality factors whereas below 70 % to 1.29. These borders are determined by the government as the maximum and minimum of using a corrective factor. It is nevertheless possible to bid into the auctions with e.g. a 60 % site, however the used corrective factor in this case will be the one also used for the 70 % site. The same accounts for a 160 % site, for which the corrective factor of the 150 % site will be used (Endell & Quentin 2016, p.12). The corrective factors in between these borders can be determined through linear interpolation by means of the following formula:

$$Corrective\ factor\ [aim] = cf_{left} + \frac{cf_{right} - cf_{left}}{qf_{right} - qf_{left}} * (qf_{aim} - qf_{left})$$

With: cf corrective factor

qf quality factor

Figure 19: Calculation of correction factor (Endell & Quentin 2016, p.12)

Hereby, the exact corrective factor can be calculated. In the following an exemplary calculation is carried out, based on the turbine type used in this project: Enercon E-115. The reference value of this type of wind turbine is set to 51,831 MWh for an operation time of five years. Contrary, as an assumption the actual generation of the turbine for five years is set to 48,000 MWh due to the wind conditions. The quality factor is therefore 93 %, which determines the specific site. The next step is the calculation of the corrective factor. For that the above displayed function can be used:

$$Corrective\ factor\ [0.93] = 1.07 + \frac{1 - 1.07}{1 - 0.9} * (0.93 - 0.9)$$

Figure 20: Actual calculation of correction factor (personal illustration)

The result of the calculation hereby is 1.05 for the 93 % site which is the corrective factor used to adapt the awarded subsidy. Instead of for example 6 ct/kWh awarded subsidy the operator would in that case receive 6.3 ct/kWh as granted subsidy over 20 years when applying the corrective factor.

4.3.4 Remuneration model components

Direct marketing of the generated electricity is mandatory. Every plant operator has to sell its' electricity directly on the power market in order to receive the EEG subsidy unless the electricity is used in close proximity and not transferred through the grid (Bundesregierung 2016, p.13). The generator becomes a trader himself or employs one. Generators sell their electricity on the power stock exchange. To use the direct marketing the wind turbine needs to have remote controllability. The generated electricity is fed in into the grid. The direct marketing company is responsible for the legally required feed-in forecast of the plant as well as for the short-term power trading in order to compensate forecast deviations (Next Kraftwerke n.d.). The generator concludes a private-law contract with a direct marketing operator who gets a service charge in return, determined in €/MWh. These contracts can differ quite a lot between the various providers. The operator assumes the marketing risks as well as costs which he compensates with the service charge. The owner of a power plant has to take risks based on the concluded contract with the direct marketing operator (von Bredow Valentin Herz n.d.).

The generator gets the revenue from the power exchange plus the market premium, which is the difference to the granted subsidy. The market premium therefore varies in dependence of the market price and the granted subsidy. Figure 21 shows how the market premium model works in terms of the EEG 2017.

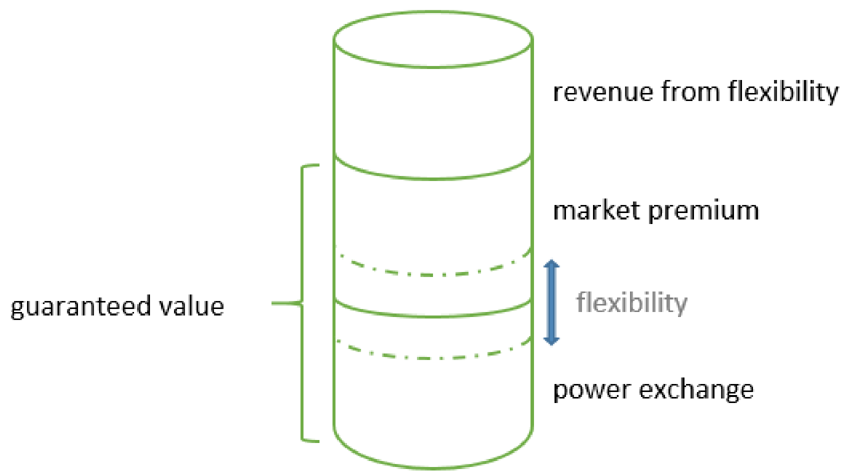


Figure 21: Market premium model EEG 2017 (Next Kraftwerke n.d.)

As it can be seen in Figure 21 that both, the revenue from the power exchange as well as the market premium, can fluctuate. However, the investor can calculate with the granted subsidy of the auction round which he always receives (Kemnade & Sperling 2016). The direct marketing operator pays the plant operator monthly the revenues from the electricity sales, whereas the TSO pays the market premium (MVV Energie n.d., p.2).

The calculation of the market premium by law is defined as the granted subsidy minus the EPEX day-ahead monthly average market value (market price) in ct/kWh. It can be seen as a market clearing performed by the responsible TSO. For onshore wind turbines the monthly average market value of the EPEX day-ahead electricity price for Germany is calculated as following: For every hour of a month, the average value of the day-ahead markets' hourly contracts for the German price zone is multiplied with the amount of total generated onshore electricity according to online forecasts for this very hour. This is an average value for the whole of Germany. The hourly values are summed up and afterwards divided by the amount of the generated electricity, again based on online forecasts, of the whole month (Bundesministerium der Justiz und für Verbraucherschutz n.d.). The monthly average value is defined individually for each renewable technology and published online by the TSOs. The average value can be used in order to see how the performance of the operator's wind farm was in comparison to the national average, and hence whether a profit can be expected due to more successful trading or not.

The above described calculation method is important for the TSO and the allocation of the money flows regarding the EEG subsidy. However, from the perspective of an investor, which is the perspective used in this thesis, the actual calculation is not relevant as every kWh coming from an awarded unit gets at least the granted subsidy. The subsidy gradually decreases with a higher market price and finally lapses, when the market price exceeds the granted subsidy. Assuming a wind turbine gets awarded at the price of 7 ct/kWh and a corrective factor of 1.0, the subsidy scheme is elaborated along Figure 22.

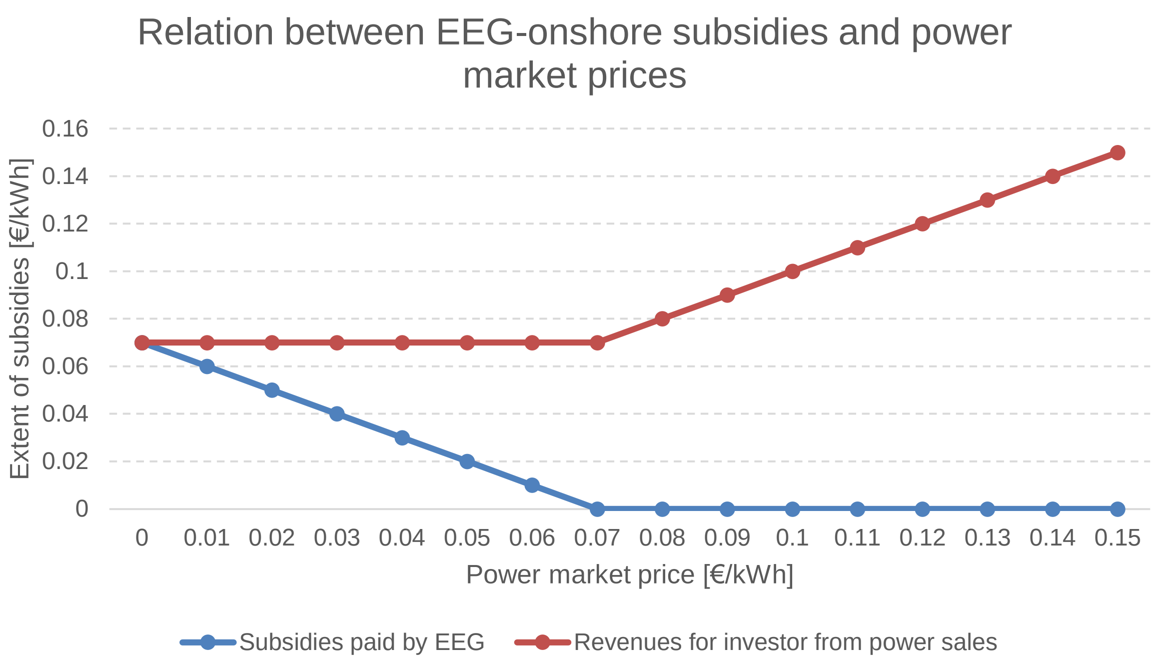


Figure 22: Example of the EEG onshore subsidy scheme (personal illustration)

The investor gets a floor (7 ct/kWh in this example), that will always be paid over 20 years (except the 6-hour rule applies). If the market price exceeds the granted subsidy of 7 ct/kWh, the subsidy lapses and the investor only receives the market price.

The design of the new system may favour big companies, like the big four utility companies, who have the abilities and financial resources to take higher financial risks. Furthermore, they could use their profits from other sectors within the company to compensate for low bids, doing a so-called cross-subsidy. The calculations to make a bid are not easy as the future is uncertain and predictions on the forthcoming market and wind conditions are not always reliable. The revenue one gets should cover the marginal cost of the organisation, so that the arising expenses are at least covered. With the change of the support scheme it is expected that the landscape of actors might change crucially. Large energy companies could benefit from the new system due to their economy of scale. Based on these aspects, the German government set up the exception for citizens' cooperatives described above in Section 4.3.2 in order to promote their participation also under the new support scheme.

4.4 Data collection and validation

In the following chapter the collected data for this project is described and validated. Thereby, a central question is, how obtained data can be validated and about the degree of appropriateness.

Kleindorfer et al. discuss the topic of validation in simulations in their paper "*Validation in Simulation: Various Positions in the Philosophy of Science*". The warrant given for a model from the researcher can be discussed in the same way as scientific science theories in general. Hence, the term of how "valid" a model (and its underlying data sets) is, strongly refers to the scientific "world view". The problem of validation is often seen as an either/or one: either a model is valid and a warrant about validity can be given or no reliable statement can be made based on the model and the whole simulation is speculative. This, very polarised, system can be referred to as objectivism. Over the last decades, new streams of philosophical views came up, called relativism. Relativism claims, that all models should be understood as such and represent validity and invalidity at the same time (Kleindorfer et al. 1998, pp.1087–1097).

Extreme objectivists would claim that the whole model built can be separated from its context and its builder while extreme relativists would say, that the builder, the context and its model are inseparable. Model validity for relativists is therefore a matter of opinion and this makes them all equally valid or invalid.

Derived from the theoretical positions described above, the opinions about validation are very contradictory and are strongly depending on the scientific view. The authors of this thesis follow a very rationalistic and practical approach. Instead of claiming the simulation and its consisting data sets as true or false, they should be accepted as a figure of reality. Models are useful tools that help describing the situations and try to forecast insecure developments.

Nonetheless, the data used for the model must be discussed in the spotlight of appropriateness. To give the reader an overview of the used data throughout the report, Table 2 illustrates the most important data sets and its sources. The used data sets are obtained from various sources and are explained and discussed further in this section.

Table 2: Compilation of used data sets throughout the modelling (personal illustration)

Compilation of the various data sources used during the report	
Data set	**Source**
EPEX 2016 Day-ahead prices	EPEX
EPEX 2016 Intraday prices	EPEX

Hourly weather and climate data 2016 (EMD-ConWx mesoscale data)	windPRO
Height contour lines Sernow (Radar Topography Mission Data - SRTM)	windPRO
Roughness areas/lines Sernow 2006 (Corine land cover 2006)	windPRO
Technical turbine data (power curves, c_b-values)	windPRO
Investment and operation and maintenance (O&M) costs	Deutsche WindGuard (Study)

Market prices

As already elaborated further in Section 1.4, wholesale electricity market prices constantly decreased since 2011 and yielded in an average day-ahead price of around 29 €/MWh and an average intraday price of 30 €/MWh in 2016. It is questionable if this price deployment will further develop, as in the months between January and March 2017 the day-ahead price yielded in around 40 €/MWh and the intraday price yielded in around 45 €/MWh (Fraunhofer ISE 2017a). Besides this fact it can be observed, that the trading volume on these markets has been increasing over the years. Thereby wind power had an observable effect on the market prices: a negative correlation (an increase of one variable leads to a decrease of the other one) between e.g. the day-ahead prices and the forecasted wind power capacity on the German market cannot be neglected. Figure 23 demonstrates this correlation on the 01.02.2016. This day was chosen due to the high penetration of wind power and low penetration of solar power.

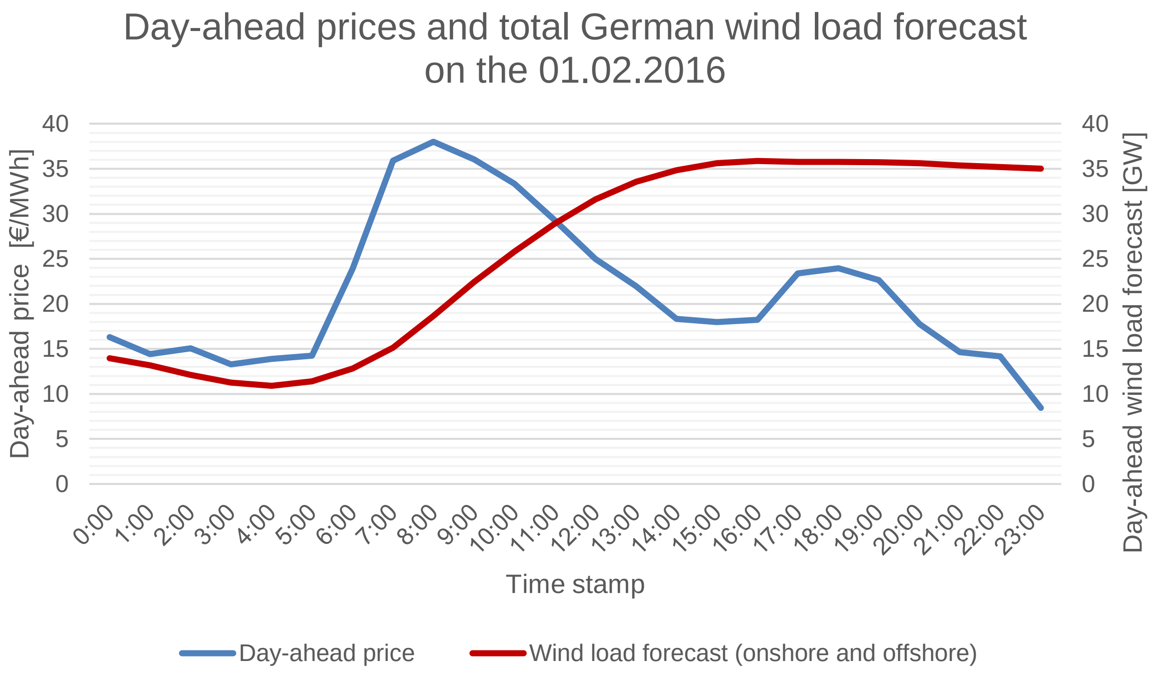


Figure 23: Correlation between day-ahead prices and wind load forecasts in Germany on the 1.2.2016 (ENTSO-E 2016a)

As can be seen in Figure 23 the daily load forecast of wind power between 12:00 and 13:00 was thereby around 31.6 GW (29 GW onshore and 2.6 GW offshore), the solar load forecast added up to 2.2 GW. A tendency can be observed, that with a higher wind load forecasts the day-ahead prices tend to sink. The effect of peak (high demand) and off peak (low demand) times has thereby to be taken into consideration.

WindPRO modelling inputs

Besides the power market trading data, obtained weather data for modelling the wind site are crucial. Wind speeds and their direction at hub height on a detailed time resolution play an essential role for modelling the turbines. These data sets were obtained from the EMD-ConWx database, which is providing meso-scale data with an hourly resolution and a spatial resolution of around 3 km x 3 km. The database also contains historical data up to 20 years. Experiences have shown, that this data may be off up to 15 % compared to the actual wind data in some places in central Europe, however these are the only available datasets for the Sernow wind site in 2016. Besides the wind speeds and its direction at different heights, also parameters as pressure and the wind speeds' standard deviation can be extracted from this data base (Wiki-WindPRO 2016). To account for the fact, that the EMD-ConWx meso dataset may be off, a data calibration is conducted. The authors have access to measured wind data from the Sernow wind site between 2002 and 2004 in 80 m altitude, representing the exact wind speeds at site. These datasets are compared to the EMD-ConWx data (2002-2004) in 80 m and checked for the deviation in every hourly time step (Table 3). The average deviation over these three years is thereby applied as a correction factor in windPRO on the 2016 wind speeds.

Table 3: Average wind speed deviation of measured data to weather data (personal calculation)

Average wind speed deviation of the measured data to the EMD-ConWx data [in %]			
2002	**2003**	**2004**	**Total average**
93 %	90 %	89 %	91 %

As illustrated in Table 3 above, the measured wind speeds in 80 m height are off around 10 % on average over the examined years. While in 2002 these speeds added up to 93 %, this value was 89 % in 2004. This value determines, that the EMD-ConWx data needs to be lowered by around 10 %. The total average value of the three years (9 %) is further used as correction factor in windPRO. Insecurities about varying wind speeds however remain, thus the effect of this factor on the result is further elaborated and discussed within the sensitivity analysis in Section 7.2.1. This discussion is necessary, as wind speeds can vary significantly among years and thus the yearly yield might vary strongly over the years.

It must be further recorded, that it is indispensable to use corresponding weather and market data from the same year. Otherwise the authors of the model risk to get an untypical generation profile for that year which may not be representative.

Height contours lines were obtained from windPRO within a 20 km x 20 km square around the site centre. The Radar Topography Mission Data recorded at the end of 2014 had the highest resolution and is therefore the most accurate data set. The height contour lines were cross-checked with topographical maps valid for the area. These height contour lines were further used as the input for the height calculations.

Another aspect to be considered within the model are the roughness classes and roughness lengths. Above 1 km of the ground the wind is scarcely influenced by the surface. Below that the friction, from e.g. trees or buildings, has an influence on the wind speed as it is slowed down by it. Usually the terrain around the desired site for the turbine is rarely consisting of a homogenous surface, thus the roughness needs to be considered up to a distance of 10 km to the site centre. There are different roughness classes defined which are characteristic for a certain landscape and are used to estimate the wind conditions on the chosen location. Road surfaces are situated in a low roughness class of around 0.5, whereas landscapes with scattered trees and buildings are characteristic for high classes as 3-4. Roughness classes are associated to roughness lengths. The roughness length z_0 is defined as the height above ground, measured in meters, at which the wind speed theoretically equals zero (Ragheb 2017, pp.1–3). The roughness areas (which are converted to lines in succession) were obtained by downloading the Corine Land Cover 2006 within a 20 km x 20 km square around the site centre. This source can be considered as not entirely sufficient for a detailed and accurate roughness classification but as helpful and supportive. To account for the insecurity of inappropriateness, the roughness areas were manually adopted and cross-checked with maps from the area. Divergences between the Corine Land Cover were corrected to achieve a high degree of data accuracy.

Technical inputs (e.g. power curve) were taken from the prefabricated windPRO wind turbine catalogue. Most of the available turbines on the market are available with a description of their technical data. The database is constantly updated. Next to the general data about the generator, hub height, blade width also the power curve and other aspects are included. This catalogue is regarded as appropriate and the data can be assessed as reliable. Nonetheless, the risk of choosing a turbine type technically not utilising the maximum wind potential of the wind site due to technical inappropriateness is given. E.g. may a turbine have a higher yield when increasing the hub height or the rotor area for affordable costs than the one chosen for modelling. This is strongly dependent on the wind site conditions and needs to be determined individually, also in correspondence with the turbine manufacturing company. Strong wind turbulences may decrease the wind turbines assigned technical lifetime.

Investment and O&M costs

The following paragraphs will evaluate the potential costs and revenues chosen to be used for the wind farm in Sernow. Especially, with the introduction of the auction system in Germany in which the subsidy will be defined individually, it is important to estimate the electricity generation costs. The costs are taken out of an updated analysis from 2015 by the Deutsche WindGuard. The study is based on collected data from 2013 (WindGuard 2015, p.IV). The costs can be divided into different categories which will be stated and analysed subsequently. All costs are inflation-adjusted. The project group is aware of the fact that average costs from the Deutsche WindGuard study may not depict reality to its full extent. However, procurement of exact data on all cost components and services is in not possible within the framework of the thesis. In reality the prices are determined by a combination of different factors, for instance might higher main investment costs be coupled with lower O&M costs due to agreements with the manufacturer.

The main investment costs include the wind turbine itself as well as its transport and installation. Increasing hub heights above 100 m lead to rising costs. Another determining aspect for the main investment costs is the rotor diameter as a larger one increases the main investment costs as well (WindGuard 2015, pp.IV–V)(WindGuard 2015, pp.4–7).

The incidental investment costs are estimated based on inflation-adjusted data previously collected. They include all costs which arise next to the main investment costs when implementing a wind turbine. In these costs next to the fundament, the grid connection, the exploitation, the planning as well as other costs are included. The planning costs include the preliminary phase, the actual planning phase as well as the approval under the Federal Immission Control Act. These are very time-consuming aspects of the project. The costs hereby differ among the German federal states. For the at hand project average values were used (Pietrowicz & Quentin 2015). This values were cross-checked with other studies and hence the used assumptions can be seen as reliable. The before mentioned other costs could be for instance needed compensatory measures. In the last years the trend of rising costs can be seen, however not each of the cost components itself is rising. With the development of taller hubs heights, bigger rotor diameters and more capacity the requirements of the tower rise steadily. But this evens out due to technological development. Since 2012 there has been a slight increase of the fundament costs. The grid connection costs mainly stayed the same since then. They strongly depend on the size of the wind farm and the distance of the closest grid connection point. The exploitation costs slightly increased over the last years as turbines are augmented build in more complex terrain as for instance mountain areas and forests. As for the planning the same occurs: a slight increase especially due to the rising complexity of environmental investigations and acquisition. As for the other costs it depends as well on the project itself. However, it can be stated that in general the costs are rising due to compensatory measures. It is assumed that the overall costs might be slightly decreased lately but that could not be intercepted due to an inflation affected price increase in labour and material (WindGuard 2015, pp.IV–V) (WindGuard 2015, pp.10–14).

Operation costs include all costs accruing during the operation period, namely O&M, lease, commercial and technical management, insurance, savings and other costs. 30 % of the operation costs are a fixed position whereas 70 % are variable costs. The latter depending on the income. These costs vary from project to project. Commercial and technical management and insurance as well as miscellaneous are mainly fixed operation costs whereas financial reserves are completely fixed ones. Lease, maintenance and repair are variable costs. The share of the individual O&M cost components can differ from the first ten operation years to the second ones. For lease the tendency is the same as before or a slight increase, set to 5- 6 % of the revenues. The other aspects are considered of being consistent in the last years (WindGuard 2015, pp.IV–V)(WindGuard 2015, pp.14–19).

Direct marketing is compulsory when receiving subsidies in terms of the EEG support scheme. The costs depend on the site location, farm size, size of the portfolio and the contract period. Usually these contracts are not running over the whole period of 20 years but are mostly concluded short-term. The actual costs for the whole time period can only be estimated. Within the study the costs are defined in consent with empirical values from different sources (WindGuard 2015, p.19).

4.5 Modelling

4.5.1 Creation of the windPRO model

For planning and conducting yield analysis of wind farms, computer based calculations are indispensable. Especially in the wind branch, compared to for instance the solar branch, these programs are rather complex due to the tasks to be carried out. Strongly depending on the wind speeds the electricity yield can vary significantly. As the wind speed is cubically considered in the yield calculation, even a small alternation of it causes changes in the output. Wind atlases – which provide average local wind data – can therefore only provide indications. This is especially the case when the hourly data is taken from a measurement mast in a distance to the plant site and furthermore not at the same hub height as the very site. Any alternation of the height can cause a variation of the electricity yield. Next to profit forecasts and the determination of the optimal wind turbine allocation these efficient computer programs can do an estimation of the sound and shadow pollution as well as a visualisation of the turbines in the landscape. Furthermore, detailed economic and financial calculations and ones concerning avoided emissions can be included. It can be stated that these programs have to deal with a variety of different tasks. There is a big range of programs on the market: from simple and free ones to expensive and complex ones which need some training effort (Quaschning & Zehner 2003, p.68).

In the at hand thesis the simulation software windPRO will be used. It is evident for the students that there are other programs with which the analysis could also be conducted. The students choose however windPRO as it is one of the most used programs in the wind branch and suitable for modelling complex conditions. Additionally, it allows to calculate the yearly yield on a very detailed time resolution.

WindPRO was invented in 1986 by the Danish company Energi- og Miljødata (EMD), based in Aalborg. The program is constructed module-based and considers a widespread variety of different aspects in conjunction with planning and implementing a single wind turbine or a whole wind farm. Next to the basis version, additional modules can be purchased depending on the individual usage requirements and the budget. WindPRO offers all the needed tools for planning. With its extensive range of features the program sets standards in the software sector regarding the planning and analysis of wind farms. However, the relatively high costs make it preferably affordable for professional application. There are some aspects the software does not take into account: these are other renewable energies in general and stand-alone systems (Quaschning & Zehner 2003, pp.70–78) For the at hand project these delimitations are however irrelevant as solely wind turbines are the centre of attention and not a system simulation.

Another software of interest is the “Wind Atlas Analysis and Application Program” (WAsP). This program is an essential tool in wind farm planning due to the fact that a lot of programs, like windPRO, build upon its output data. It will therefore be used within this thesis. The program is a standard tool to calculate the power yield but is also used for the optimisation of wind turbines in a specific site. It was developed in the late 80s and is distributed by the Danish Risø National Laboratory. The WAsP software is based on wind statistics, measured with anemometers in 10 m height. Usually the place of measurement is not identical with the one where the turbines should be placed. Therefore, the software models the wind flows and takes hereby the terrain conditions into account in order to calculate the wind distribution for the exact site (Quaschning & Zehner 2003, p.74). The WAsP is thus a supplementary software to windPRO.

WindPRO consist of different modules. With the BASIS one, the groundwork for any other calculation modules is set. Before creating a model certain components are imported or determined such as the exact coordinates of the site, the wind data as well as maps (also pre-geo-referenced ones). The Map Management System links maps to the program. These can be imported, scanned or downloaded online. The subsequent modelling is based on these digital and geo-referenced background maps. The software includes a wind turbine generator (WTG) catalogue which contains the input data of a wide range of wind turbines including all their technical parameters.

In the BASIS module, up to 25 object types can be placed on the graphical interface. When calculating the AEP (Annual Energy Production) for a wind farm, several inputs need to be determined beforehand. The most important inputs thereby include the surface roughness, height contours, wind speeds and its related directions, technical specifications for the WTG and obstacles close to the wind site. Most data can be loaded online and/or digitalised and edited personally. Heights (called z-values) related to all site objects are calculated from the height contour lines using the TIN (Triangular Irregular Network) method. In this method, the height data is extrapolated from three points, in order calculate the elevation at any point. The surface roughness is derived from the roughness lines. Any wind profile furthermore depends on the roughness of the surrounding surface. Turbulences occur and vary whenever there is a change of the roughness indicated by a change in the landscape (EMD International A/S 2017a) (Aalborg University & EMD International A/S n.d., pp.9–10, 33). Figure 24 gives an impression of the used windPRO interface showing the site of Sernow.

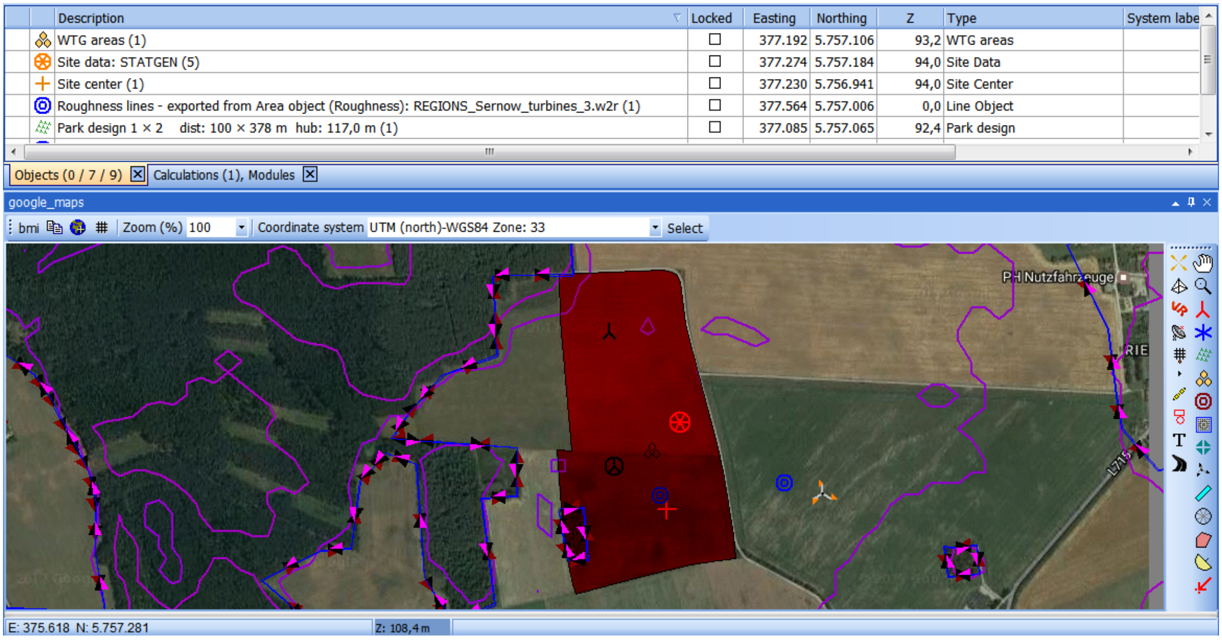


Figure 24: WindPRO interface showing different object types used for the site in Sernow (personal illustration)

There are different energy modules which perform the actual calculations of the energy yield. One is the METEO model. It performs a simple energy calculation. Base for this is the wind data and the specific wind turbine power curve as well as the power coefficient, defined in Section 6.1.1 in Figure 33. In any case a shear exponent is used in order to correct the height of the data from the measuring height to the desired hub height (Danish Wind Industry Association 2003b). The needed power curve is always connected to the chosen wind turbine type. It is adjusted for the local air density, which is provided within the climate database or calculated from the locally taken measurements. The METEO is considered the simplest calculation as it calculates the AEP directly from the wind speeds at hub height not considering wake effects from other turbines. Wind turbines can change the wind conditions for other nearby turbines, what reflects in lower yields for affected turbines. The identification of these wake effects can be regarded as very important as the total wind park yield may change significantly. The output from different single wind turbines can be compared by the METEO model. However, typically the conditions of the mast and the desired wind turbine are not exactly the same considering the location and the hub/measured height. Therefore, the WAsP model is used. With the METEO model measured wind data can be imported, analysed, synthesised and presented also as a preparation for the use of WAsP in wind statistics. Long-term reference data from extensive worldwide data bases can be approached online (EMD International A/S 2017b).

The MODEL module is used for wind flow modelling in order to be able to do extrapolation, horizontal as well as vertical. It is not a single calculation in itself but more the access to a set of different calculations with, for instance, WAsP. Output could be hereby the creation of wind statistic, the production output or the wind resource map (EMD International A/S 2017c).

In comparison to that, the PARK module calculates the AEP of a whole wind farm including furthermore the wake effects. Base hereby are the two modules METEO and MODEL. Needed for the calculation are the position and the type of the wind turbine as well as the wind data. Within this feature the design of the wind farm offers several options such as cloning of turbines and the creation of ones in an equal distance (EMD International A/S 2017d). Due to its ability to consider wake effects and model the different conditions of the site, the PARK module is applied in supplement to the WAsP model to calculate the AEP within this master thesis.

4.5.2 Data based calculations in Excel

The windPRO model serves the purpose of generating an hourly production profile for the modelled wind turbines. This profile is then further processed in Excel and connected to the electricity prices. Excel is used to set up the three different scenarios explained in Section 6.4. The scenarios are thereby represented by the different electricity market price time series.

All scenarios use the same wind turbines as generation facilities. As the very detailed and location specific yield is obtained from the windPRO model due to better data accuracy, this generation profile is directly used within Excel for the further calculations. Based on the generation profile and the market time series the investment calculations can be carried out.

Generally, the authors of models must be critical about its outcomes. Models are a simplified picture of reality and have clear limitations. For instance, this model is representative for the year 2016. Inputs (e.g. as market prices or wind speeds) may vary depending on the simulation year and the extent of subsidies might change in future.

4.6 Investment calculations

An investment is an act of investing money in a certain project or measure, it starts with an initial expense and causes specific cash flows (expenses and revenues) over time. Investment calculations shall help to assess the absolute and the relative (compared to alternative investments) advantages of a project or measure (Panos 2013, p.173).

Thereby, it can be distinguished between the business and the socio-economic perspective. While the business economic perspective considers all different costs from an investors view, socio-economic calculations go beyond that (Kørnøv 2007, p.604). Hereby effects are assessed from a society perspective which does not necessarily correspond with the business-economic view.

An investment calculation can be conducted either statically (non-discounted payments and revenues) or dynamically (discounted payments and revenues). Static calculations are primarily used for small investments (Panos 2013, p.174).

For comparing the different scenarios in this master thesis, the net present value, the internal rate of return and the payback time are chosen as output criteria. Furthermore, the levelised cost of electricity are described in this section.

4.6.1 Net Present Value

The most important basis for all dynamic investment calculations is the net present value (NPV). It consists of the sum of discounted cash flows over a certain time period minus the initial investment. The NPV formula is demonstrated in Figure 25. Commonly the time of commissioning is used as a reference point for the NPV calculation, in practice often represented by the technical lifetime (Panos 2013, p.174).

$$NPV = \sum_{t=1}^{T} \frac{\text{Cash Flow}_t}{(i+1)^t} - \text{Initial Cash Investment}$$

Figure 25: NPV calculation formula (personal illustration)

Basic inputs for the calculation are thus the yearly cash flow, the investigated time period (*t*) (usually represented by the technical lifetime of an investment), the interest rate (*i*) and the initial investment.

The interest rate is used to account for the variation of payments over time. If applied for the NPV calculation, this interest rate is called discount rate to account for the fact, that the different payments and revenues are temporally distributed. An appropriate discount rate may depend on different factors (e.g. the liquidity of a company and the economic circumstances), thus it has to be chosen individually. Furthermore, this rate may be chosen according to alternative or opportunity interest rates. The rate demonstrates the expected return from a different use and is generally used when capital is scarce (Lund & Østergaard 2010, pp.2–5).

Interest rates can be divided into real and nominal ones. While the real interest rate is inflation adjusted, the nominal one is not. Thus, the real interest rate can be seen as the nominal interest rate minus the inflation (Panos 2013, p.159).

For the NPV calculations, the real discount rate was set at a level of 4 % according to the EU Impact Assessment Guidelines (ECEEE 2015). The time period is defined as 20 years, according to an average technical lifetime of a wind turbine. The project group is aware that real discount rates are mainly used within socio-economic analysis. As the determination of the discount rate is however a discussable factor and needs to be appointed individually, it may vary a lot. This fact is therefore further elaborated within the sensitivity analysis (in Section 7.2.4)

4.6.2 Internal Rate of Return

The internal rate of return (IRR) is an economic ‘rentability criteria’. It represents the specific interest rate, where the NPV equals 0. The IRR can thus be understood as the interest rate obtainable when not making a profit of deficit and usually serves as the ‘minimal revenue’ benchmark for investors (Panos 2013, p.179). The IRR must be higher than the discount rate in order to be a profitable investment (Lund & Østergaard 2010, p.8).

The IRR is determined by using the non-discounted cash flows over the investigation period minus the initial investment and can be found by consequently solving the formula in Figure 25 by the term *i*. Its’ calculation by hand is very time consuming as it is determined by an iteration process, however computer tools as e.g. Excel can perform the IRR calculation very quickly (Panos 2013, pp.179–180).

4.6.3 Payback time

The payback time (also called payback-period) describes the amount of years an investment takes to yield in a profit. More simply said, it determines the number of years it takes for an investment to let the revenues exceed its costs. This payback time must be in general shorter than the technical lifetime, otherwise no positive result can be achieved within the lifetime of an asset. If the payback time is calculated without using the discount rate it is called simple payback time. When putting a discount rate on all the payments and revenues accordingly, it is referred to as dynamic payback time. In practice, payback time calculations are usually conducted as simple ones. If using the dynamic payback time, investments being (statically) just about economically acceptable, risk not achieving a positive result due to discounting (Panos 2013, pp.185–187).

4.6.4 Levelised Cost of Electricity

In the energy sector the usual economic-efficiency criteria for projects are the levelised cost of electricity (LCOE), which evaluate the cost of a technology over its lifetime per generated unit. It is derived from dividing all costs incurred by a technology over its operating lifetime by the amount of electricity generated in that time. This generates as an outcome an amount of power in monetary terms due to which technologies, even with different lifespans, can be easily compared (Panos 2013, pp.177–178). The general equation for calculating the LCOE is the following:

$$LCOE = \frac{I_0 + \sum_{t=1}^{t=n} \frac{A_t}{q^t}}{\sum_{t=1}^{t=n} \frac{W_{el}}{q^t}}$$

With:	W_{el}	generated amount of electricity in the specific year in MWh/a
	I_0	investment expenditure
	A_t	operating expenses in €/a
	t	the very operating year
	q	discounted factor $q = 1 + \frac{i}{100}$
	i	imputed interest rate in %/a
	n	imputed operating life

Figure 26: LCOE formula (Panos 2013, p.178)

When calculating the LCOE a discount rate should be used in order to bring back the payments to the present day value (Panos 2013, pp.177–178). LCOE can be used in order to assess the cost-effectiveness of different energy technologies as it removes the bias. Critically, it should be kept in mind that LCOE is a static measure whereas the market prices are dynamic and volatile. Therefore, it should be better seen as a bottom line, for which monetary amount the generated energy should be at least sold in order to break even over its lifetime (Branker et al. 2011, p.4471).

5. Case description

This section describes the wind site of Sernow chosen for the modelling. Sernow is located in the north-east of Germany, as can be seen in Figure 27, south of Berlin in the federal state of Brandenburg. The municipality of Sernow is located in the region Havelland-Fläming (Gemeinsame Landesplanungsabteilung Berlin-Brandenburg n.d.).

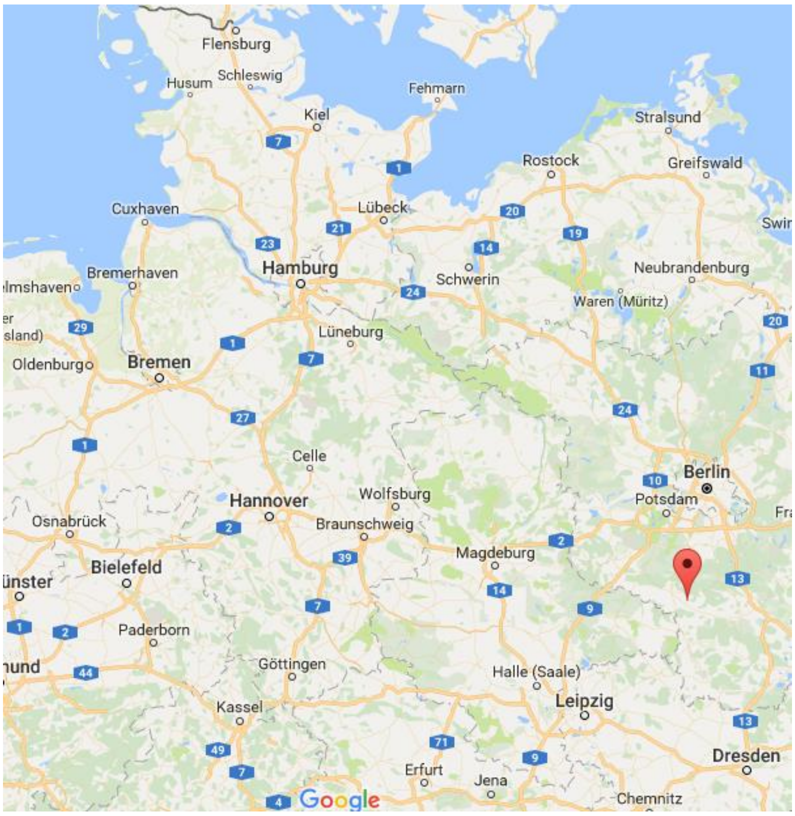


Figure 27: Location of the site (GoogleMaps 2017)

In order to assess the wind conditions of the site the mean wind speed is an important factor. Figure 28 displays the average wind speeds in Germany in 100 m above ground in order to give an overview. The exact location where the turbines are planned is highlighted with a pink star.

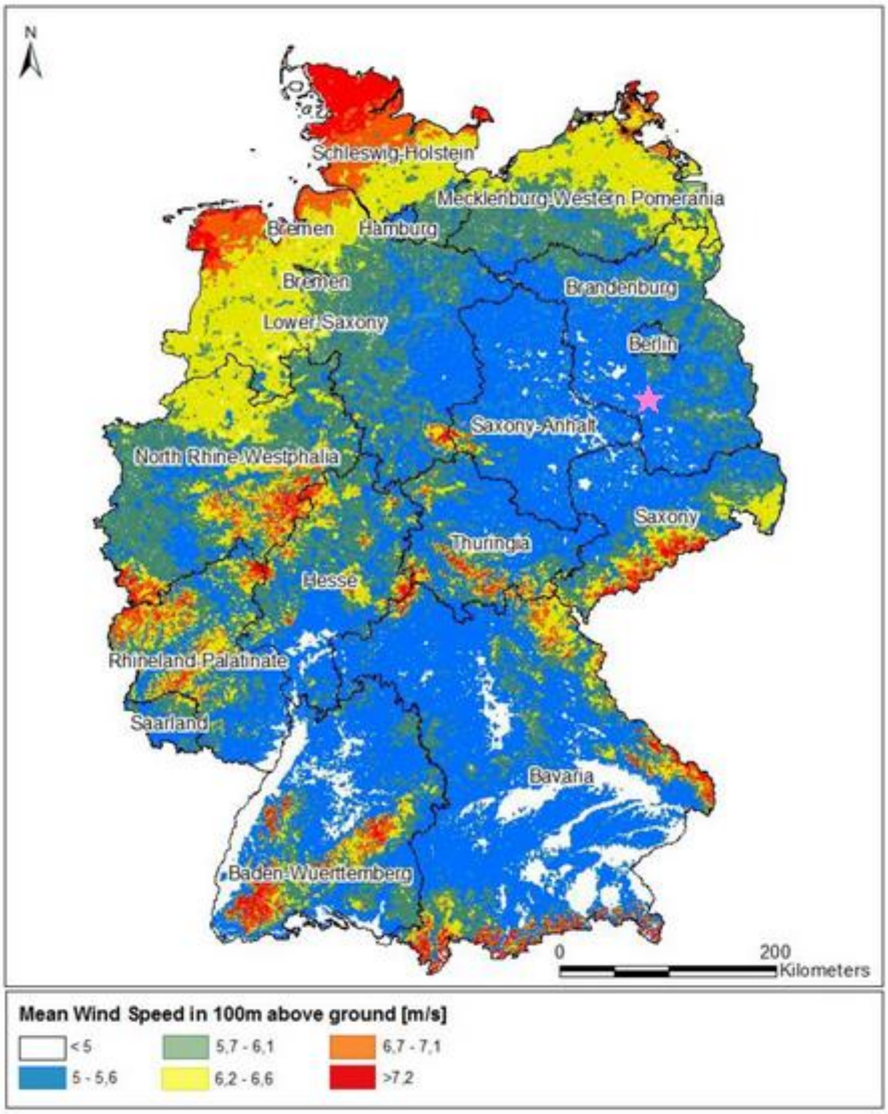


Figure 28: Mean wind speed in Germany 100 m above ground (**Blankenhorn & Resch 2014)**

The figure above displays, that the site is not located in the windiest regions of Germany, as the average speed yields in 5 – 5.6 m/s. However, the map is just to give an overview as it is a rough estimate over large areas. When having a closer look, the wind speeds can vary a lot as it depends on the local conditions. In general the desired area where the turbines will be sited is already quite developed with wind turbines as many are located in the surrounding and even more are planned or approved (Ministerium für Wirtschaft und Energie des Landes Brandenburg n.d.).

The prospective site is located in Brandenburg, one of the 16 German federal states. The aim set by the federal government is a share of renewables in the primary energy consumption of at least 30 % until 2030. In comparison, Germany did not set any specific goal for the share of wind power until 2030. For the target attainment of Brandenburg wind power plays a significant role. The installation goal for 2030 is set to 10.5 GW of installed capacity and to 22.8 TWh of power from wind turbines. A desired political goal is to designate 2 % of the federal state's area for wind power as wind turbines are only allowed to be built in specific areas, so called suitable zones. For indicating and determining these suitable zones, the five regional planning consortiums of Brandenburg are in charge (Umweltbundesamt 2017) (Fachagentur Windenergie an Land 2017).

The exact location of the very land parcels (Figure 29) in contemplation adjoins the decided zone, but is currently not included as a suitable wind zone. However, it can be seen as a potential area in case more land is needed to fulfil the target. As stated earlier, these land use regulations are not taken into further consideration as it is beyond the project scope.

Figure 29: Parcels for erecting the wind turbines (GoogleMaps 2017)(personal illustration)

As shown in Figure 29 the area for erecting the wind turbines can be characterised as farmland. In the west of the site, woodlands predominately occur while from the north, south and east the land is very open. The size of the two selected parcels amount to approximately 36.3 ha.

As for the land structure of the region, it can be roughly said, that it is a relative flat area. The differences in the close surrounding are marginally in height and mainly vary around the 100 m mark. The topography of the site and its surrounding can be considered therefore as very suitable for turbines. In Figure 30 and Figure 31 the on-site circumstances can be seen, including the height differences due to the forest.

Figure 30: View on one of the parcels facing west towards the forest (personal data)

In Figure 30 already existing turbines further west, behind the forest, are visible in the distance. Both of the pictures highlight the flat area without any obstacles despite the forest in the west.

Figure 31: View on the parcels facing north (personal data)

For the project three turbines with 3 MW each and a whole park capacity of 9 MW are planned. Three turbines exploit the available area the best when taking the distance requirements into consideration.

6. Analysis

The at hand thesis deals with different scenarios in order to analyse possibilities to promote the Sernow wind park in regards of the present EEG 2017 subsidy scheme. Different marketing options are hereby represented by the different scenarios. The scenarios have a common baseline: they use the outcomes from windPRO as input. Therefore, the windPRO model can be seen as common necessary input determining the exact generation profile for the simulation year 2016. Based on this generation profile, the modelled wind turbines can bid into the different markets and participate in the tender procedure for the EEG. Figure 32 displays the structure chosen to approach the topic of the analysis.

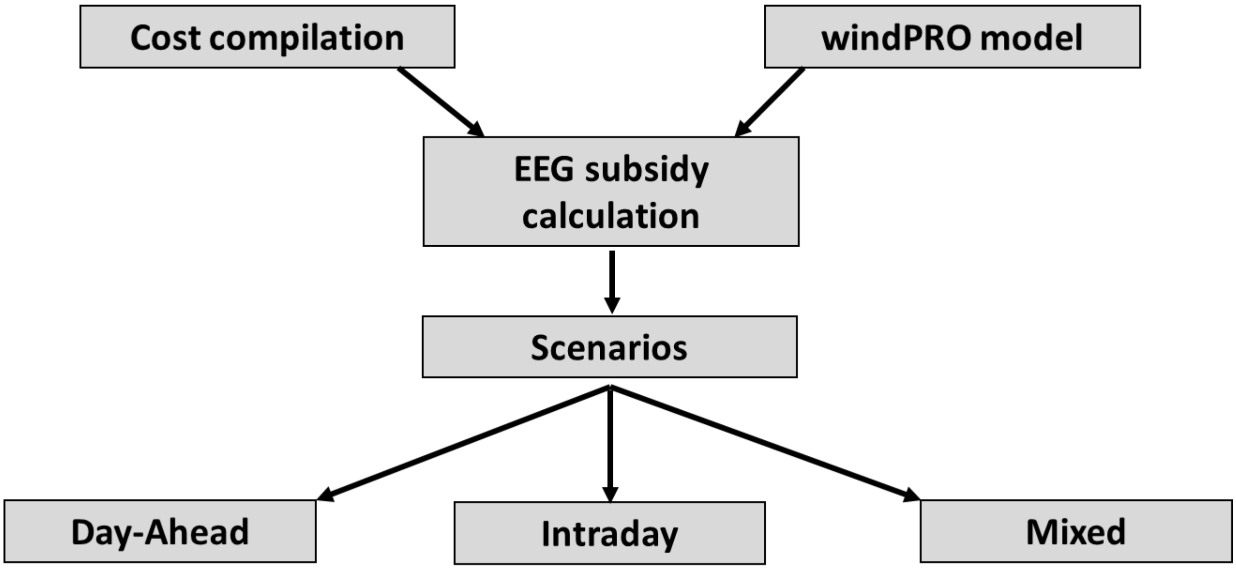


Figure 32: Structure model for analysis (personal illustration)

In order to conduct a comprehensive analysis several aspects need to be taken into account. The above depicted Figure 32 shows the different steps which will be taken throughout the analysis. WindPRO is used to model wind conditions and other influencing parameters at the desired location in Sernow and further to set up a valid model with an hourly generation profile. After the optimisation of the model the next step is to consider and collect all relevant costs. These two aspects, the modelling of the wind turbines in windPRO and the relevant cost parameters, build the foundation to calculate the LCOE for the wind turbines in order to determine a benchmark for the bid to be made under the auction system. Based on these inputs, the scenarios and their analysis can take place as the basis is set to which all the scenarios refer to.

Three scenarios are chosen which are all promoted in addition to the EEG subsidy scheme, the EEG prescribes a mandatory direct marketing. The common market place for all the scenarios is the EPEX power exchange. In the at hand thesis only one year will be analysed in detail, namely 2016. The wind data used for modelling as well as the electricity prices from the EPEX are chosen aligned for 2016 to be able to compare and analyse the interaction and subsequently draw veritable conclusions. In the first scenario the generated electricity is traded on the day-ahead market, in the second scenario on the intraday market and in the third scenario on both, the day-ahead and the intraday market in combination. The specific features of the markets were already detailed outlined in Section 3.5.6.

6.1 WindPRO model

6.1.1 Description of the model

The windPRO model builds the common basis for all scenarios. The two parcels described in Section 5 define the project area and add up to a territory of around 36.3 ha. The project area limits the potential area to erect wind turbines (WTG-area).

The distances between the turbines are set to 3 times the rotor diameter in the cross wind direction and 5 times the rotor diameter in the main wind direction. The values can be regarded as required minimum distances according to literature (energypedia 2015) (Panos 2013, p.375). The distances to the parcel borders are set to 60 m in accordance to the rotor radius in order to avoid overlaps between the rotor and other parcels outside the project area.

Obstacles should be included in the model if they are within a 1,000 m radius of a turbine and are within 50 times the height distance of an object. Furthermore, the top of an obstacle has to be higher than ¼ of the turbines hub height (Aalborg University & EMD International A/S n.d., p.35). No considerable objects were found in the project area that could affect the wind turbines performance. The required distance of wind turbines to close-by settlements, according to the regional legislation, is 1,000 m. This value is not exceeded by the wind park, as all turbines are within a larger range.

The Enercon E-115 model was chosen as turbine type for modelling and three turbines of this kind are planned to be placed in Sernow. The main technical parameters of the turbine type are demonstrated in Table 4.

Table 4: Main technical parameters of the Enercon E-115 model (Bauer & Matysik 2015)(ENERCON 2016) (ENERCON n.d.)

Technical parameters of the Enercon E-115 model	
Capacity	3 MW
Hub height	135.4 m
Rotor diameter	115.7 m
Rotor area	10,515.5 m^2
Designed for average wind speed at hub height	8.5 m/s
Technical lifetime	25 years

The capacity of the Enercon E-115 turbine amounts to 3 MW, the hub height is 135.4 m. Due to the wooded terrain around the wind site, this turbine type was chosen with a hub height of 135 m, as a significantly higher wind speed can be achieved with an increased height. The rotor diameter is around 116 m, the rotor area adds up to 10,515 m^2. The expected technical lifetime of this turbine is determined by Enercon with up to 25 years.

According to Enercon, the turbine type is designed for onshore sites with an average wind speed at hub height of around 8.5 m/s. As shown later on in this section, the Sernow site has an average wind speed of 6.5 m/s. When taking a closer look at the mean wind speeds and their frequency depending on the wind direction, it appears, that the wind speed from the main wind directions average in 8 m/s (WSW) and in 7.2 m/s (W) (Figure 37). Hence this turbine type seems very suitable to optimise the yield from the main wind directions. Figure 33 illustrates the power curve, the power coefficient (c_e) values and the thrust coefficient (c_t) – a parameter for calculating the wake effects (Gebhardt 2017) - for the Enercon E-115 with the technical parameters presented in Table 4. For a clear understanding following definitions are considered as being helpful: The power curve is defined as a graph depicting the electrical output for a turbine at different wind speeds (Danish Wind Industry Association 2003a). The power coefficient is moreover defined as a measure for the wind turbine’s efficiency to convert kinetic energy from wind into electricity. Hereby, the actual electrical power generation is divided by the wind energy flow on the turbine blades at a certain wind speed (Watson 2015).

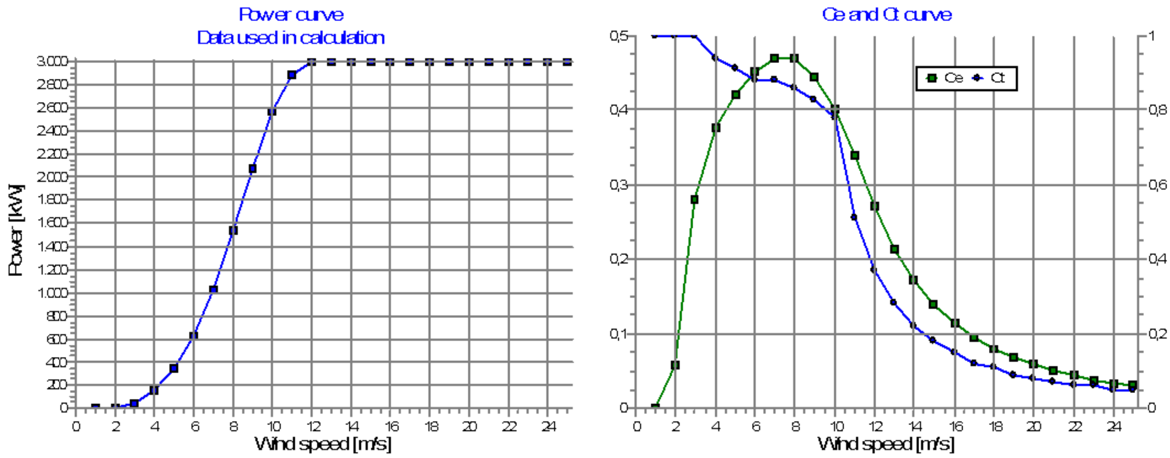


Figure 33: Power curve, c_e and c_t values for the chosen Enercon E-115 (personal windPRO model)

By taking a closer look at Figure 33 it becomes apparent, that this turbine type is able to extract most of the kinetic energy coming from the wind at wind speeds between 6 and 9 m/s. Even though the turbine has not reached its maximum power level at that point, the power coefficient is peaking at around 45 %. This makes the turbine capable of generating efficiently during part load operation. The cut in speed of the turbine is 2 m/s, the cut off speed is 25 m/s. The turbine reaches its maximum power level at around 12 m/s. In general it can be stated, that Enercon turbines are more cost intensive than others. This may reflect in higher investment or operation costs for the turbine. As the project group does only have access to average costs for turbines, the costs and the choice of the turbine is further discussed in Section 7.2.3.

As stated previously, the terrain around the wind site is very flat and mainly varying around the value of 100 m above sea level. The landscape is however covered by scatter woods that affect the wind speeds in the region, as can be seen in Figure 34.

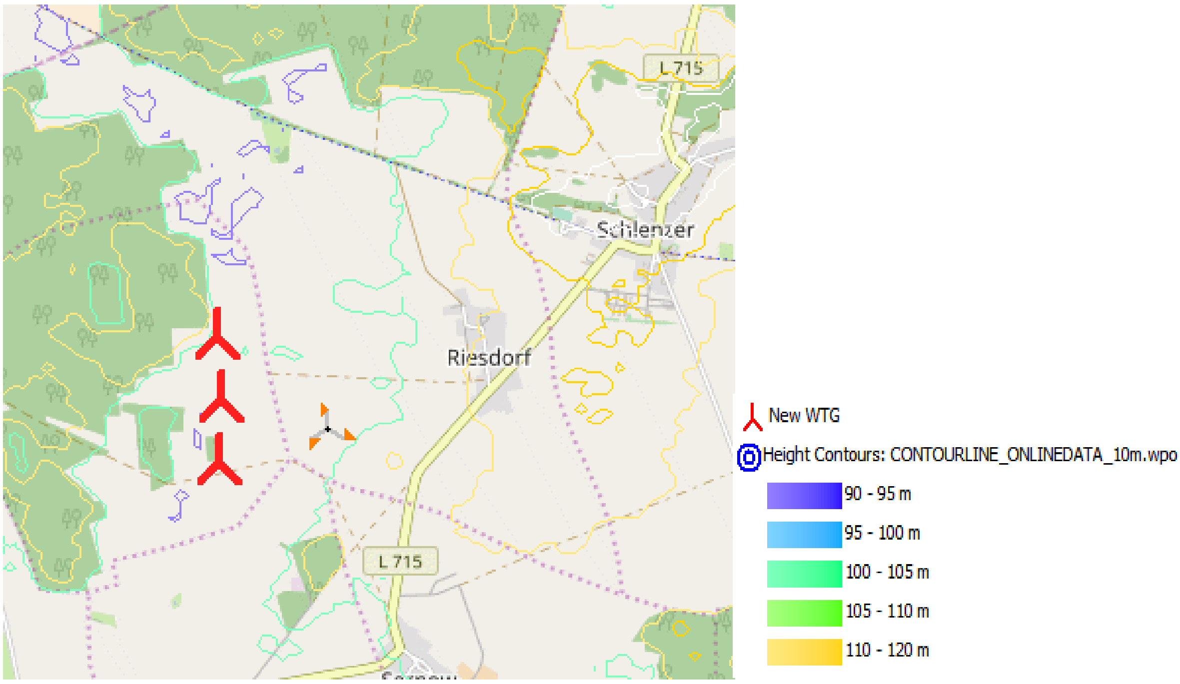


Figure 34: Illustration of the surface land cover and the height contour lines close to the site (personal windPRO model)

Even though the whole area can be described as a mix of wood- and farmland, especially the close by areas in the direction of NW, W, SW and NE are covered by large woods. There is further a small woodland on the wind site itself. The height contour lines of the area are downloaded online and validated as well as adopted manually if deviations to compared maps could be observed. The same procedure is applied to the surface roughness lines.

These land covers have an impact on the wind situation, reflecting in different roughness lengths and wind shears. The roughness lengths determine at which level above ground the wind speed equals 0. Wind speeds at hub height can be calculated by the power law, using a wind shear exponent that appoints the change of wind speeds with different heights. The shear for specific sites varies depending on the investigated wind direction and the measured height. If measured data at different hub heights are available, the shear can be calculated from these heights. The wind speeds for different heights may also be calculated with a logarithmic wind profile. The theoretical logarithmic wind profile is however a rough estimate and may be inappropriate depending on the surface land cover and the terrain. Due to less influence of the surface on wind with rising height, the wind speeds increase with the height. As these speeds do not increase linearly with height, a logarithmic profile approximates this increment best (ENCO Energie-Consulting AG n.d.). Both, the power law formula and the formula for the logarithmic profile are shown in Figure 35.

Power law :

$$V(z) = V(z_{ref}) \times \left(\frac{z}{z_{ref}}\right)^{\alpha}$$

Logarithmic law :

$$V(z) = V(z_{ref}) \times \frac{\ln(z/z_0)}{\ln(z_{ref}/z_0)}$$

$V(z)$	wind velocity in desired height
$V(ref)$	wind velocity at measured height
z	desired height for calculating the wind speed
$z(ref)$	reference height of measured wind speeds
α	shear exponent
z_0	roughness length

Figure 35: Formulas for calculating the wind speeds in different heights (Asset Management Consulting Corporation 2010)

The site-specific shear can be seen in the wind statistics, varying in dependence of the wind directions, the year and the measured wind speeds. The average share calculated for the Sernow wind site amounts to 0.27, the roughness length yields in 0.859 m. All wind speeds, their directions and related weather data used for the calculation are obtained from the EMD-ConWx data set and are calibrated by comparison to measured data. This data calibration procedure was described in Section 4.4. No displacement heights are considered due to the calibration to the measured data at site.

A basic step for the yield calculation of wind turbines is the wind speed at hub height. As the EMD-ConWx data does not provide data at a height of 135 m, a synthetic wind profile for that height – based on the 100 m data set – was created.

For the site in Sernow it can be derived from Figure 36, that the wind frequency in 2016 was highest from the directions WSW, W and WNW at the hub height of 135 m. The highest wind speeds are occurring in WSW and W, ranging mainly between 5-10 m/s but also reaching speeds of 10-15 m/s of around 4 % (WSW) and 2 % (W) of the year. The wind speeds rarely peaked in 15-20 m/s in WSW, W and SSW (Figure 36).

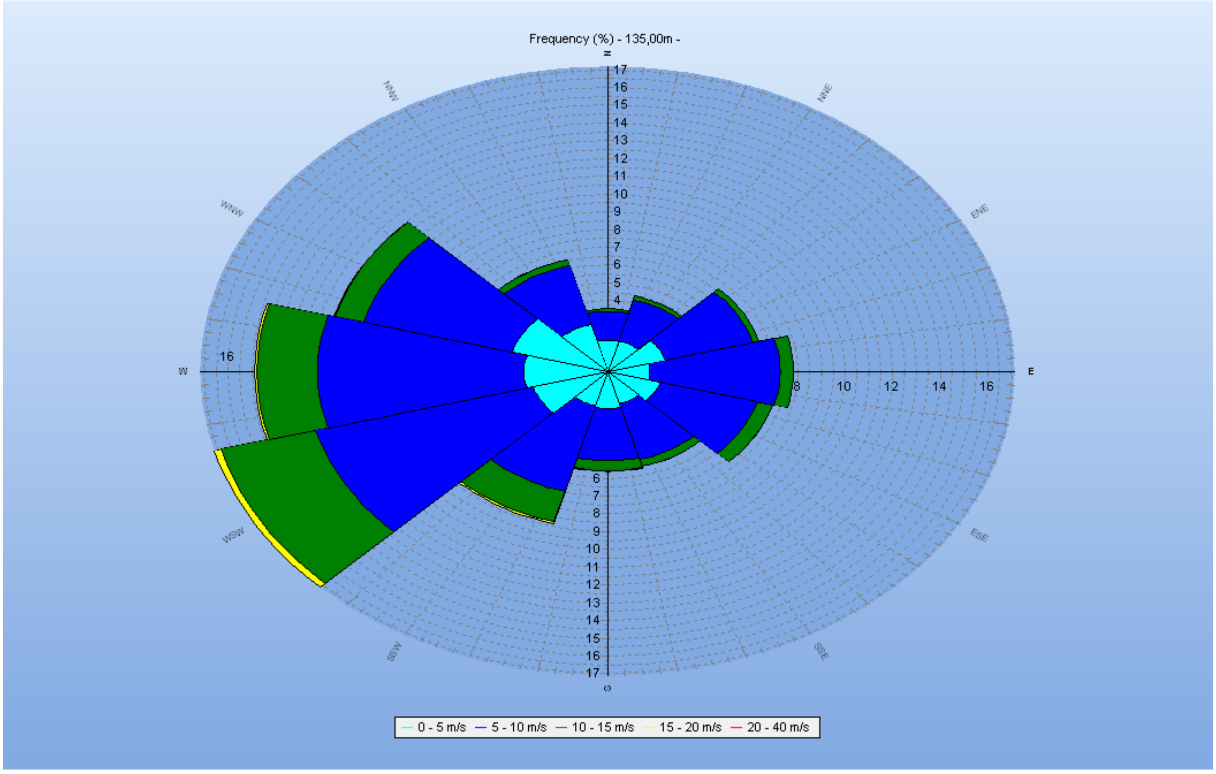


Figure 36: Frequency table of wind speeds at hub height of 135 m (personal windPRO model)

Apart from that, Figure 37 illustrates the mean wind speeds in 2016 at the turbine hub height of 135 m, varying with the wind direction.

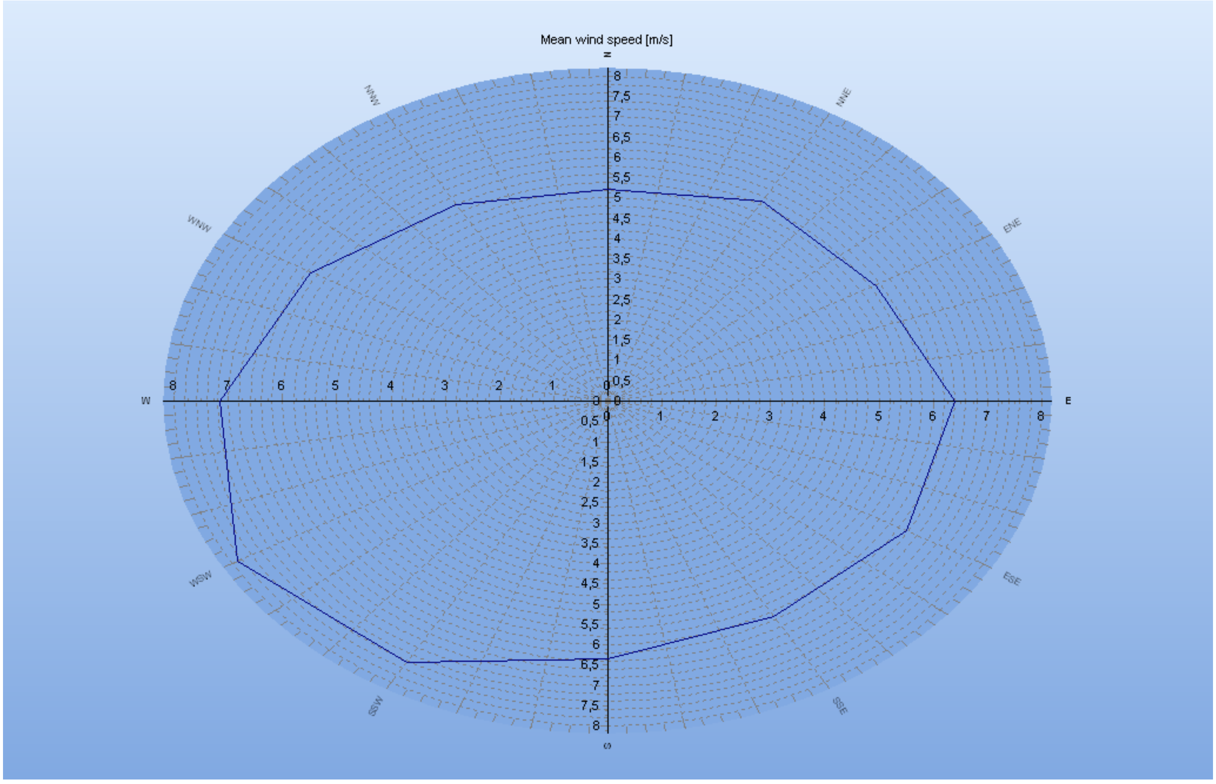


Figure 37: Mean wind speeds at hub height depending on the direction (personal windPRO model)

The average wind speeds differ a lot depending on the direction. While from the main wind directions these speeds average in around 8 m/s (WSW) and around 7.2 m/s (W), they drop around 5 m/s from N. The overall mean wind speed at hub height of 135 m yields in 6.66 m/s. It can be ascertained from Figure 36 and Figure 37 that the highest mean wind speeds at the site also occur with the highest frequency.

The calibrated wind data sets are then further used in combination with the height contour and roughness lines to calculate the wind statistics for this site. These wind statistics then serve as input for the WAsP model (described in Section 4.5), which calculates the wind park's wake effects and the wind conditions at the exact turbine locations. In order to get the most accurate wind statistics at hub height, these were adjusted according to the turbines hub. Usually WAsP calculates these statistics standardised for the heights of 10 m, 25 m, 50 m, 100 m and 200 m. The statistics at hub height are determined by interpolation. To model more closely to the present wind situation, the hub height of 135 m is added manually as WAsP parameter to get more accurate results.

A wind resource map at turbine hub height for the WTG-area is calculated based on the wind statistics, the surface roughness lines and the height contour lines. This resource map shows the wind resources at hub height within a 10 m x 10 m resolution, covering the whole WTG-area. In accordance to this resource map and the distance requirements between the turbines and the WTG-borders, the exact locations of all three turbines are optimised to obtain the yearly maximum park yield. The specific locations of the wind turbines are based on the wind resource map and a full park optimisation, using the windPRO optimisation tool and the before mentioned distance requirements (represented by the red ellipses). The result presents a wind park layout with the maximum possible yield, whose layout is demonstrated in Figure 38.

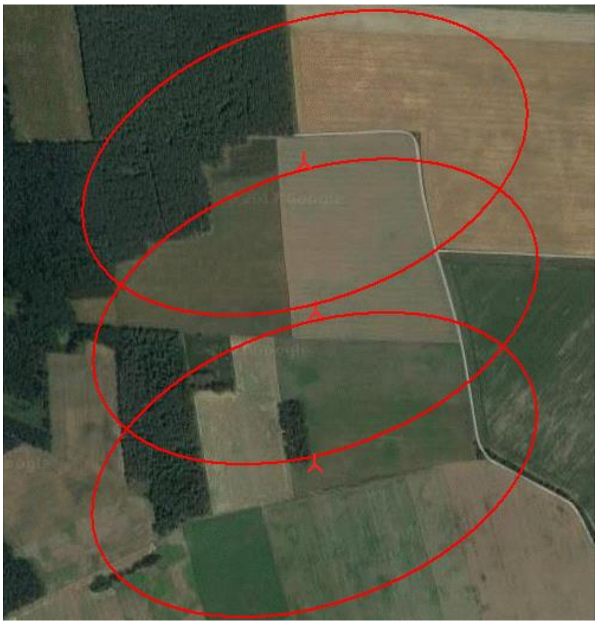


Figure 38: Final wind park layout (personal windPRO model)

Subsequently, this optimised layout will be the base for further calculations. However, before a final yield calculation for the wind park is conducted, the requirements related to noise and shadow based on the Federal Immission Control Act must be met. The relevant requirements are the following:

The immission caused by wind turbines have to stay below certain benchmarks, depending on the affected (noise sensitive) areas. In case of the Sernow site the benchmarks for general residential area applies for the surrounding settlements. Thereby, the immissions should not exceed the value of 55 dB (A) during the day and 40 dB (A) during the night outside of residential buildings (Umweltbundesamt 1998, p.7). The outcomes of the noise calculations conducted in windPRO are illustrated in Figure 39.

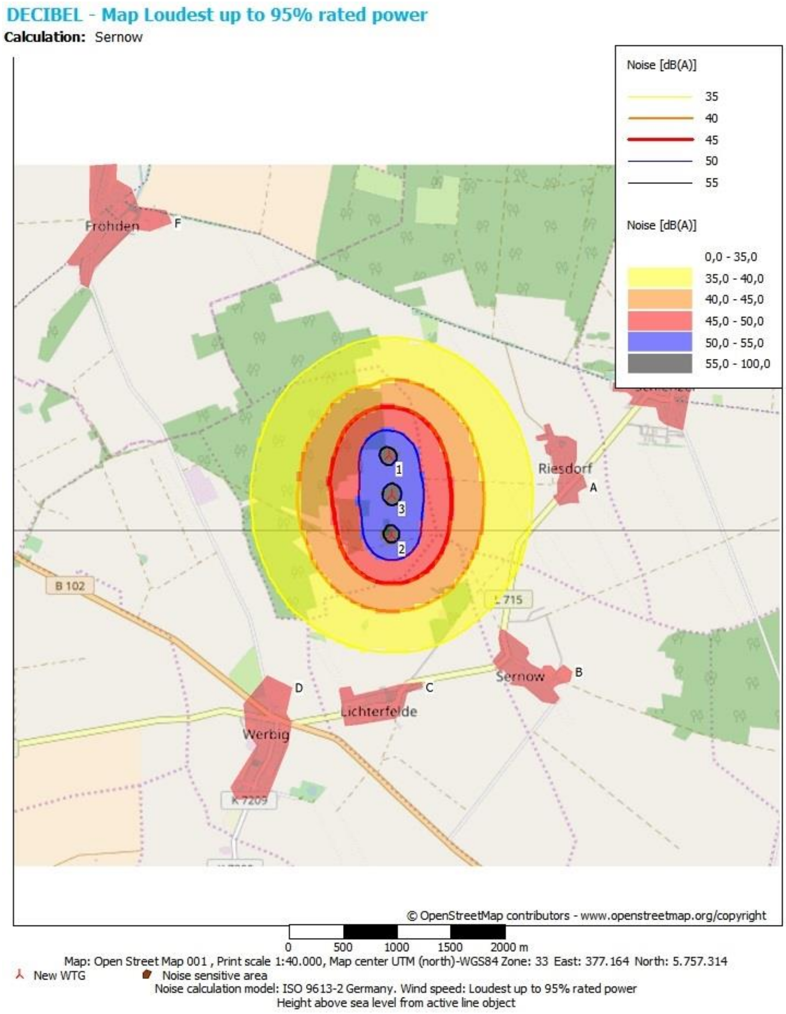


Figure 39: Noise immissions for the Sernow wind site (personal windPRO model)

As Figure 39 displays, all noise requirements are fulfilled at site. The calculated acoustic noise level at the border of the closest settlement of Riesdorf gets down to 35 dB (A). Hence, the requirements for acoustic noise at the site can be considered as fulfilled. Certain rules apply to the flickering effects of wind turbines in Germany. In the worst case, the flickering in general must not exceed 30 hours per year (Agatz 2016, p.102).

The shadow calculations in windPRO show, that no shadow effects of the wind turbines on the surrounding settlements can be observed due to the high distances (all distances are more than 1,100 m), therefore, this topic is not elaborated further. It can be concluded, that neither the acoustic noise nor the flickering constrain the implementation of the wind turbines and all necessary requirements are met.

6.1.2 Outcome of the model

This section presents the main outcomes from the windPRO model. Three turbines adding up to 9 MW are planned at the location in Sernow. In relation to the outcomes one fact has to be mentioned beforehand: the effect of existing turbines on the site's wind situation. Already erected turbines may affect the wind resources at site, which might have an impact on the turbines yield at the spot. But as there is no available data about the possible effects of other turbines on the planned ones, this factor cannot be taken into consideration. The closest turbines in the surrounding are within a distance of approximately 1,500 m, wherefore the effects on the wind resources at site are furthermore regarded as minor by the authors. The main outcomes from the windPRO model can be obtained from Table 5.

Table 5: WindPRO result (personal windPRO model)

Main outputs from the windPRO model	
Installed capacity	9 MW
Annual expected electricity generation wind park (including wake effects)	28,696 MWh/year
Annual electricity generation wind park (-5 % losses and uncertainties)	27,262 MWh/year
Mean yearly generation per turbine	9,087 MWh/year
Full load hours per year	3,029 h/year
Capacity factor	34.6 %

The wind park has an estimated yearly yield of around 27,262 MWh. This outcome includes a 5 % reduction of the initial result, due to losses and uncertainties. For any wind park, it should be stated that there are losses of the energy yield to be expected in respect to the rated output. There are different potential sources of energy losses such as for instance wake effects (but these are already included in the at hand depicted results), turbine availability, electrical transmission efficiency, environmental losses and curtailments in which the park needs to be shut down to mitigate issues associated with planning or grid export. The stated 5 % already include the maximum turbine availability of 97 %, stated in the updated technology data for energy plants by the Danish Energy Agency (Danish Energy Agency 2016, p.84). The project group is aware of that other before mentioned losses could occur and therefore the determined value was set to 5 %. Besides that, higher losses could lead to a lower energy yield. This aspect will be further examined in the sensitivity analysis (Section 7.2.1).

The average generation per turbine and year yields in approximately 9,000 MWh, this equals an amount of approximately 3,030 full load hours per year and a capacity factor of close to 35 %. As described earlier in this section, the main wind directions are WSW and W, thus the highest yield can be achieved from these directions (Figure 40).

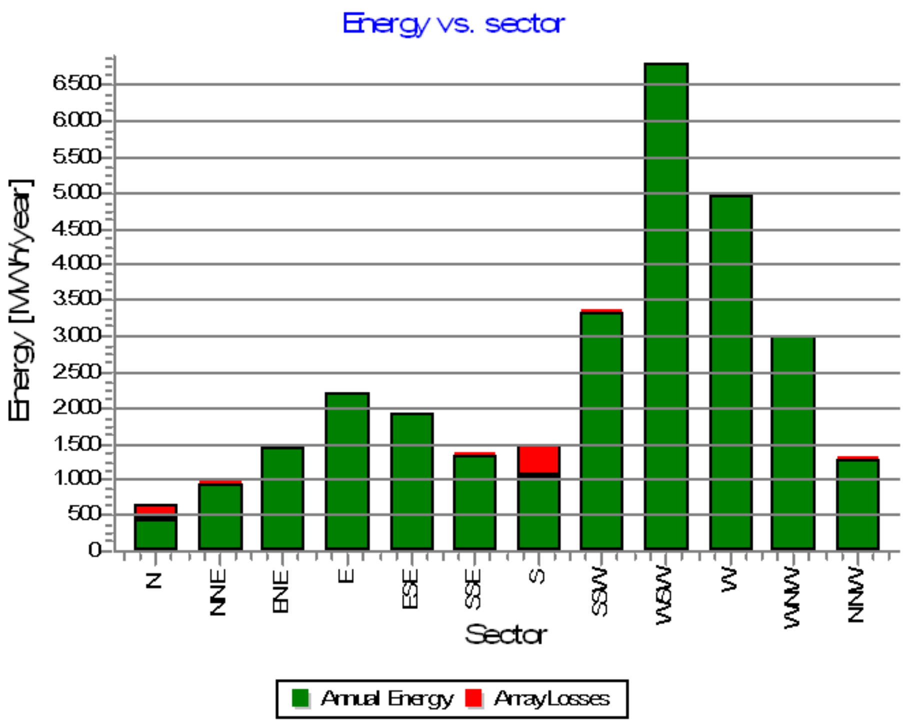


Figure 40: Energy park yield per sector (personal windPRO model)

The array losses due to wake effects mainly occur from the directions of N and S, due to the park layout (Figure 38). The yearly park yield from WSW results in around 6,800 MWh, the yield from W in around 5,000 MWh. Compared to that, the yield from the cross wind directions of N (around 500 MWh) and S (around 1,000 MWh) is relatively low. The duration curve of the wind farm shows the following picture (Figure 41).

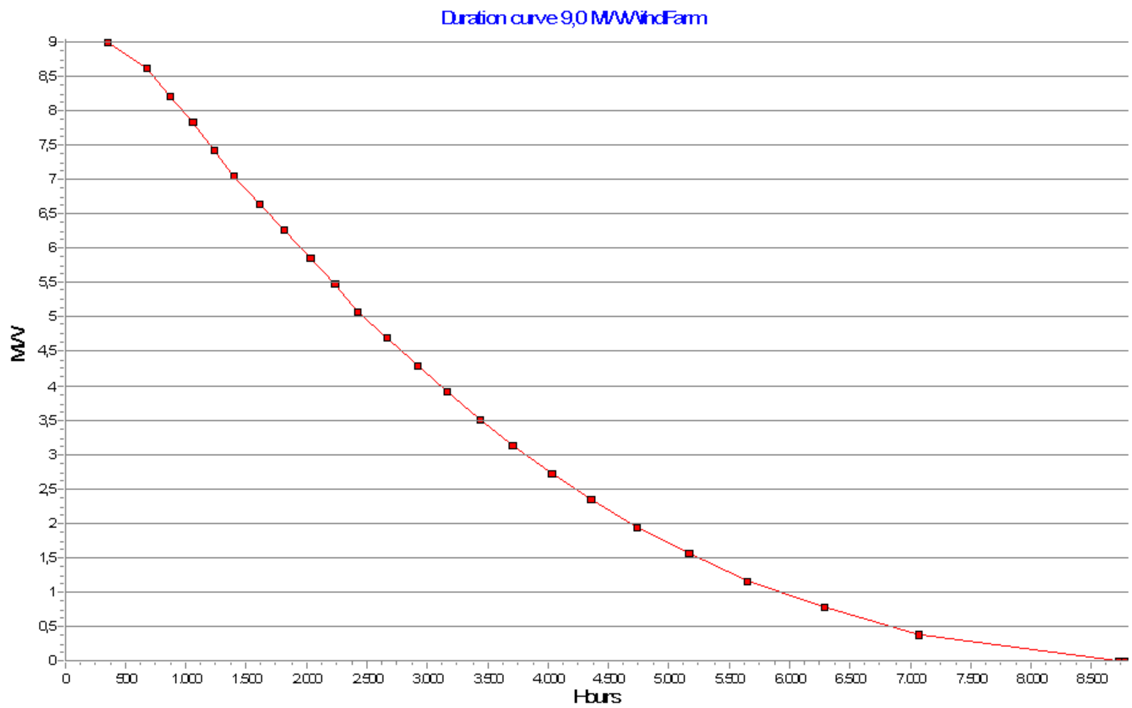


Figure 41: Duration curve of the wind park (personal windPRO model)

The duration curve above shows the amount of hours of a year in which the park is operating at a certain load. The wind park is running on full load for 350 hours a year, around 3,000 hours a year it is operating between 9 MW and 3.5 MW. As described above, the chosen Enercon E-115 turbine is designed for operating in part load (highest power coefficient at the range of 7-8 m/s) and reaches its maximum power at a level of around 12 m/s (see Figure 33). Therefore, the turbine is capable of achieving high yields during part load operation, what reflects in Figure 41. The park has further a significant number of hours, namely 1,200, at an operation between 0.1 and 0.5 MW, which can be traced back to the cut in speed of 2 m/s. This turbine type is capable to start operation already at low wind speeds.

Generally, it has to be kept in mind that this result is specifically valid for 2016 and may vary over the years due to the weather conditions. The sensitivity analysis will however identify and discuss the effect of altered wind speeds on the outcome.

6.2 Cost compilation

The economic parameters used for the calculations are based on the technical inputs of the Sernow wind park. Therefore, the overall capacity to which the individual cost components refer to are 9 MW. Table 6 lists the relevant input parameters which are the basis for the economic cost calculations.

Table 6: Economic calculation input parameters (personal illustration)

Inputs	
Capacity	9 MW
Generation	27,262 MWh

For the inputs of the scenarios the capacity as well as the generated electricity are relevant. The hereby stated generated electricity includes a loss of 5 %, already more closely outlined in Section 6.1.2.

Next to that, Table 7 shows the actual costs of the wind park. The individual sub-components of the economic parameters, in for instance main investment costs, incidental investment costs and operation costs, will not be listed at this point as a detailed numeration was already outlined in Section 4.4. The O&M costs are hereby average costs and are not separated into fixed and variable ones. Taxes and network charges are considered as being not relevant in this calculation as they are revolutionised to the end costumers (ENP Energieplan 2017).

Table 7: Economic parameters (personal illustration)

Economic parameters		
Cost components	**Costs per kW**	**Total**
Main investment costs	1,120 €/kW	10.08 Mio. €
Incidental investment costs	387 €/kW	3.48 Mio. €
O&M costs	61 €/kW/year	552 Tsd. €/year
Direct marketing expenditures	0.2 ct/kWh/year	54.5 Tsd. €/year

The actual investment costs consist of the main and the incidental investment costs and in total sum up to 13.56 Mio. €. The investment costs already take the height of the tower and the rotor diameter into account. This is important as there are significant cost differences between the heights. Usually, a higher hub height leads to higher investment costs if the capacity is not changed accordingly (WindGuard 2015, p.IV). The investment is done prior to the timespan of 20 years for which the subsidy is granted. The O&M costs in the Deutsche WindGuard study are given per kW for an 80 % site: 56 €/kW. Therefore, before being able to calculate the operation costs the value needs to be adapted to the actual site conditions (quality factor). The calculation of the quality factor is shown in Section 6.3. The yearly running costs, also called operational expenditure, consists of two factors, namely the O&M costs and the costs for direct marketing, and in total sums up to yearly 606.8 Tsd. €.

6.3 EEG subsidy calculation

In order to be able to calculate and define the amount with which one should bid into the auction system it is prior necessary to calculate the quality of the particular site. The theoretical basis for this calculation was presented in Section 4.3.3. Therefore, the estimated generated electricity at site is necessary as well as the reference value stated by the wind turbine manufacturers. The value for the chosen wind turbine type, Enercon E-115, in the desired hub height of 135 m has been published by Enercon online. The reference value indicated per wind turbine for five years amounts to 51,831 MWh. Based on these two values, the reference value from the manufacturer and the actual generation at site, the quality factor can be determined. However, in order to compare the values the generated electricity output at site has to be adapted to the five years. In this very case the quality factor is 87.7 % (88%).

The quality factor in the at hand thesis was determined solely along the modelling year 2016 and projected for five years, as the whole analysis is based on this year. The authors are aware that this might be unprecise as the generation from the turbine varies from year to year. The impact of a changing quality factor is shown in the sensitivity analysis (Section 7.2.1).

Once the quality factor is set, the corrective factor can be determined based on the procedure presented in Section 4.3.3 . The corrective factor for the 88 % site is hence 1.09. This factor will be used to adapt the specific awarded subsidy for which the subsidy is granted. As the site has a lower yield than the reference site, which is represented by a quality factor lower than 100%, the corrective factor will hence let the awarded subsidy rise according to the calculated corrective factor.

The next step is to calculate the LCOE, which evaluates all costs of a technology over its lifetime in €/MWh and can be seen as an indication for which amount one should bid in the auction system. Hereby, it has to be stated that it should not be seen strictly as the bottom line which is implicitly needed in order to break even over the wind turbines’ lifetime as there are entanglements with the power exchange on which the generated electricity is sold. On the one hand the amount gained on the power exchange can be higher than the guaranteed subsidy by the auction but on the other hand in case the 6-hour rule applies, no subsidy is paid at all. Therefore, the LCOE should be better seen as a reference point. 2015 is chosen as the investment year, in which simplified all investments occur and the wind turbines are build. Hence, the year 2016 was chosen as the first year in which the subsidy is granted for a period of 20 years. This simplification was done due to the needed compliance with the market data and their highest accuracy.

The calculation of the LCOE was already described in Section 4.6.4. At this point it is important to state that the awarded timespan is chosen as imputed operating life time but moreover the technical lifetime would be up to 25 years, according to Enercon. This difference between the 20 and 25 years is considered by the scrap value. The project group is aware that this value exists, however it will not be taken into account further as usually after the 20 years for which subsidies are granted, the wind turbines will be repowered in order to be able to get new subsidies. All in all, the LCOE amount in this very case to 5.9 ct/kWh.

Hence, the bid in the auction round is assumed to be made and awarded for 6 ct/kWh and, with using the for this project individual calculated corrective factor of 1.09, the granted amount rises in reality to 6.54 ct/kWh. The results presented in Section 7.1 are based on the bid of 6 ct/kWh and can be regarded as “lower border”, as this is the bid necessary to cover the LCOE. The effect of a higher bid will be discussed in the sensitivity analysis, presented in Section 7.2.2.

6.4 Scenario description

In the following the chosen scenarios will be outlined more closely and elaborated further regarding their underlying assumptions.

6.4.1 Day-Ahead Scenario

In this scenario electricity is traded the day before the successive day with the physical fulfilment taking place on the next day. The price for electricity is hereby set by an hourly market clearing price as previously elaborated in Section 3.5.6.1. The number of negative hours thereby yielded in 97 in the year 2016, the hours where no subsidy is granted due to the 6-hour rule resulted in 55. According to the EEG subsidy scheme, in all residual hours of the year the operator receives a granted subsidy of 6.54 ct/kWh as floor payment – according to the calculation in Section 6.3 – if the market prices drops below the granted subsidy. All electricity generated by the turbines is assumed to be promoted on the day-ahead market, but in case no subsidy is obtainable due to the 6-hour rule, the turbines are assumed to be regulated downwards.

6.4.2 Intraday Scenario

Another option for trading electricity is the continuous intraday trading. The Intraday Scenario assumes, that all electricity from the wind turbines is solely promoted on the intraday market. Like on the day-ahead market, the physical fulfilment is hereby the goal as well. In difference to the day-ahead trading, intraday trading is conducted to equal imbalances during a certain day, the time resolution for trades is consequently reduced to quarterly intervals. Intraday trading gives market participants the possibility to balance deviations between their planned and their real electricity generation. Thereby, the price determination differs from the day-ahead market: trades are concluded on a pay-as-bid principle described in Section 3.5.6.2. Thus, no common MCP is available, furthermore prices depend on the individual contracts and may vary significantly within a certain quarterly interval. In order to get a representative and recoverable price for every 15 min interval, the volume weighted average value was found most accurate. This value represents the volume weighted average price of all contracts concluded within a very quarterly hour. This volume weighted average price is thus subsequently used in the same way as the MCP in the day-ahead market for the related time interval. The project group is aware, that traders could use different strategies of promotion due to the pay-as-bid principle but such strategies are very much dependent on the traders' expectation. Thus, the simplified approach of the weighted average price as MCP for the related quarterly hour seems most accurate. As described in Section 4.3.2, it is determined by the day-ahead price if a subsidy is granted for a certain hour. In case the day-ahead price exceeds the level of granted subsidy, the subsidy lapses also if the electricity is promoted intraday and the intraday price may be below the subsidy level. Hence, the intraday trading can be regarded more risky compared to the day-ahead trading, as for a very hour subsidies might not be received.

The yearly generation profile of the wind park is divided equally into quarterly steps, in order to correspond with the quarterly market prices. It is for example assumed that an hourly generation of 4 MWh equals 1 MWh in every quarterly hour.

For all hours, in which the 6-hour rule - determined by the day-ahead auctions - applies, no subsidies are granted. These hours are the same as on the day-ahead market, as this rule only applies to six or more consecutive negative hours on the day-ahead auction. But in divergence to these hours on the day-ahead market, electricity may still be sold on the intraday market. Even though no subsidies are granted in a certain hour, a profit can be made if the intraday price is positive. This is an important difference to the Day-Ahead Scenario. In case no profit can be made, the turbines are assumed to be regulated downwards.

6.4.3 Mixed Scenario

The last scenario is a combination of the two prior ones. It will be examined whether in cases where the generated electricity could not be sold on the day-ahead market, a trading on the intraday market is profitable. The promotion on the day-ahead market has thereby priority: in hours where no profit can be made on the day-ahead market, electricity will be sold on the intraday market if possible. The 6-hour rule is valid in the same ways for the other two scenarios, the Mixed Scenario represents a consequent intraday optimisation in case the day-ahead prices are unprofitable and no subsidies can be obtained.

To account for the different time steps of the day-ahead and intraday market, the hourly generation profile was equally subdivided into quarterly steps. This is done in the same way as in the Intraday Scenario. In case no profit can be made, the turbines are assumed to be regulated downwards.

7. Scenario outputs

In the following sections the results of the scenarios are presented and furthermore a sensitivity analysis on specific aspects conducted.

7.1 Scenario results

This section illustrates the outcomes of the different scenarios. The result underlies the following main input parameters: a real discount rate of 4 %, a lifetime of 20 years and a guaranteed subsidy of 6.54 ct/kWh over its lifetime. The results are presented along the calculated outputs described in Section 4.6, namely the NPV, the IRR and the simple payback time. Furthermore, the yearly cash flow for every scenario is shown. This cash flow is defined by the yearly operation income (the revenues from electricity sales) minus the yearly operation expenditures for each scenario. The detailed results can be obtained from Table 8.

Table 8: Outcome of the different scenarios (personal calculation)

Scenario results				
Scenario	**NPV [Mio. €]**	**Yearly cash flow [Mio. €]**	**IRR**	**Simple payback time [years]**
Day-Ahead (DA) Scenario	2.11	1.154	5.70 %	12
Intraday (ID) Scenario	2.15	1.156	5.73 %	12
Mixed Scenario	2.14	1.155	5.72 %	12

As Table 8 illustrates, the ID Scenario performs best of all scenarios with a NPV of 2.15 Mio. €, an IRR of 5.73 % and a payback time of 12 years. All scenarios have an IRR of around 5.7 %. As these IRR are higher than the discount rate of 4 %, all scenarios achieve a positive result.

The DA Scenario and the Mixed Scenario perform marginally worse with a NPV of 2.14 Mio. € and a NPV of 2.11 Mio. €. As described in Section 4.3, the subsidy payment is solely based on the day-ahead auction. Thus, there is still the possibility in the ID Scenario to make a profit within all hours without granted subsidy in case the quarterly intraday price is positive. The Mixed Scenario is a consecutive development of the DA Scenario, thus the NPV is higher than the DA Scenario. The NPV of all scenarios is demonstrated graphically in Figure 42.

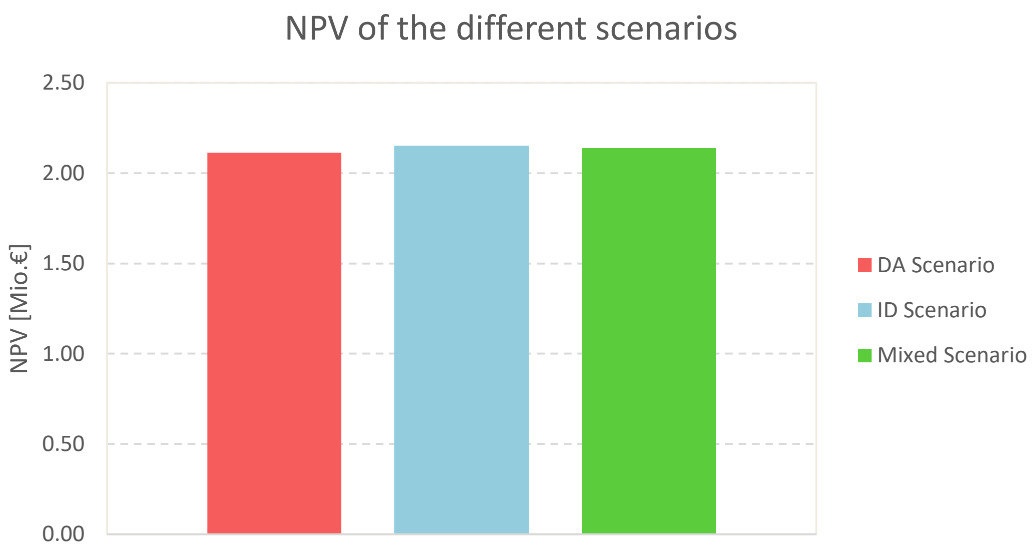


Figure 42: Different Scenarios' NPV (personal calculation)

Even though the ID Scenario performs best, it is also linked to the highest insecurities and risks. Assumptions were made regarding the usage of the weighted average price, in reality the price for every intraday trading contract concluded does however differ individually. Furthermore, is the promotion in this scenario attached to a higher risk related to the granted subsidy (elaborated in Section 6.4.2).

Even though the ID Scenario has the best outcome under given assumptions, the overall picture shows that the differences between the scenarios can be considered as non-significant: the difference between the DA Scenario and the ID Scenario adds up to 40 Tsd. € over a lifetime of 20 years whereas the simple payback time of all scenarios adds up to 12 years. These marginal differences can be explained by two main arguments: Firstly, the spread between the yearly average day-ahead and the yearly average intraday price gradually decreased over the past years and these average prices almost equalled in 2016 (see Figure 7 in Section 1.4). Secondly, the granted subsidy of 65.4 €/MWh is far beyond the yearly average day-ahead and intraday price in 2016, therefore existing price differences between these are further outweighed and the yearly cash flows are very similar by being promoted differently. The investment and O&M costs are furthermore the same in all scenarios which explains the alike performance.

The simple payback time for the ID Scenario is in detail illustrated in Figure 43. As all the payback times for the different scenarios follow the exactly same pattern, the ID Scenario can be regarded as representative for the others as well.

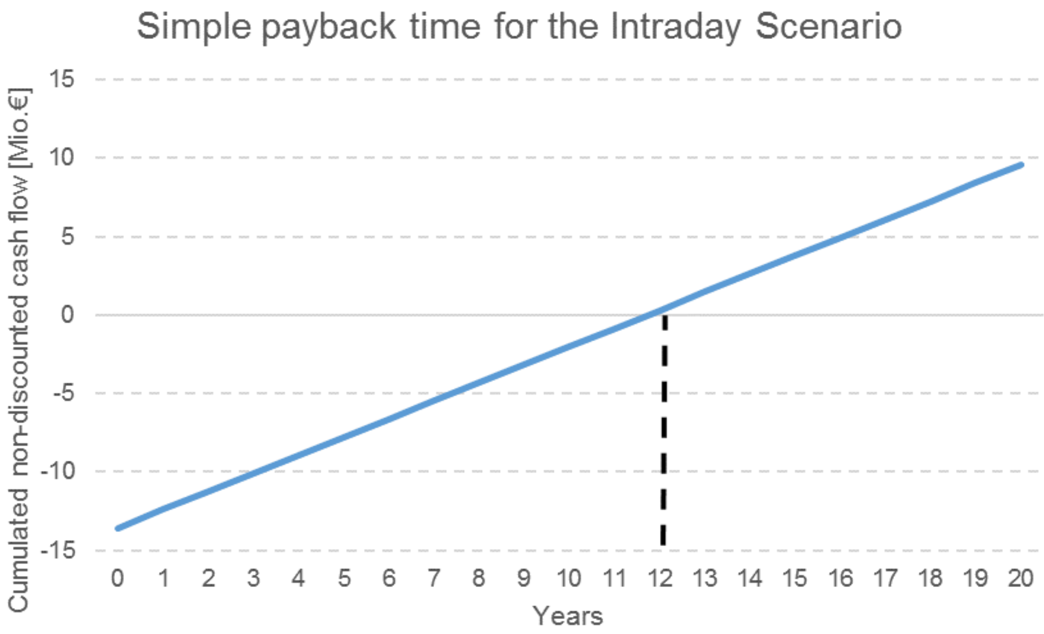


Figure 43: Payback time ID Scenario (personal calculations)

Demonstrated in Figure 43 the investment pays back statically (not discounted) after 12 years in the ID Scenario. If the cumulated discounted payments and revenues would be used for this scenario, the payback time would increase to 17 years. This occurs due the discount rate, which consequently decreases the payments and revenues in future. A discount rate of e.g. 0 % would not account for temporally distribution and a payment today would have the same value as in 20 years. The discount rate has a simultaneous effect on the other scenarios as well due to their alike cost distribution.

This Section has shown, that the ID Scenario performs the best but it has to be kept in mind that the scenarios outputs just differ marginally. The Sernow wind park could achieve in total a result ranging from 2.11- 2.15 Mio. €, depending on the way of promotion.

It generally has to be considered, that the output is specifically valid under the given model parameters, inputs and assumptions. Furthermore, it is a demonstration of the specific year 2016 applied on a specific case. Even though these results demonstrate how the EEG applies to the Sernow wind park, it has to be interpreted carefully as it only shows the project specific consequences. A more comprehensive investigation of the EEG may be elaborated in further work to draw more general conclusion from other perspectives. The Sernow case can however give an impression of what to expect from the new EEG 2017 for investors.

Different model inputs may change the at hand results crucially, hence a sensitivity analysis is conducted in the next section to investigate what effects on the outputs can be expected by varying several input factors.

7.2 Sensitivity analysis

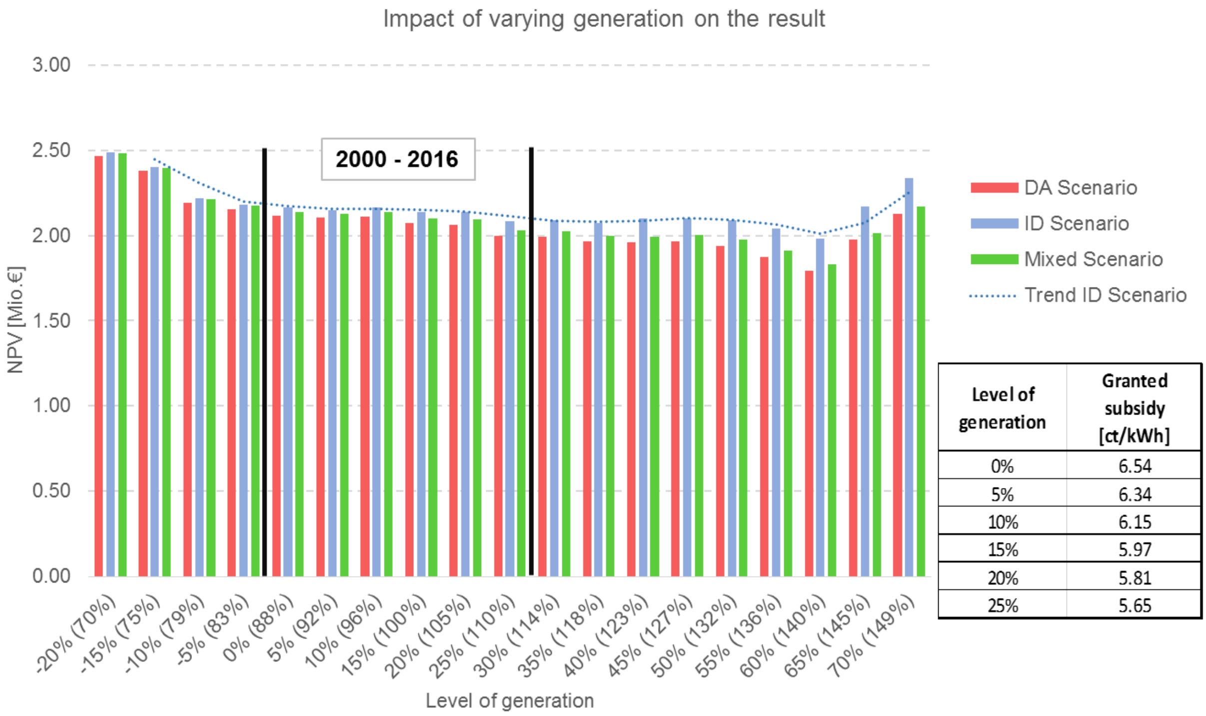
The subsequent sensitivity analysis is discussing and elaborating how the results from the analysis might alter if different input parameters are changed.

Thereby, only single inputs are changed in order to see how the output deviates from the initial result. An exemption is the variation of the yearly generation of the Sernow wind park, as more than one input is changed at the same time. Within this sensitivity analysis, a variation of the electricity generation, the awarded subsidy, the investment and O&M costs, the discount rate and the electricity prices is conducted. In order to compare the outcomes with varying inputs, the NPV was chosen for graphical comparison. A change of the NPV will also indicate a change of the IRR and the payback time in a comparable way.

7.2.1 Electricity generation

As stated previously in this section, a different electricity generation of the wind park has a more comprehensive effect on the result than solely a reduction or increment of the total amount of electricity. These comprehensive effects occur due the change of the granted subsidy. The lower the yearly generation, the higher the granted subsidy. The subsidy increase and decrease is bound to specific borders depending on the quality factor of a site. In addition, the market price time series may play an important role with decreasing subsidies.

The yearly yield of wind turbines is strongly dependent on the wind speed at hub height. These wind speeds usually vary a lot among and within years, thus the obtainable electricity yield may differ significantly over a certain range of time. Data analysis for the Sernow site shows, that the chosen year 2016 was a very weak one in terms of the average wind speed. In other years, the yearly generation would have been up to 25 % higher than in the modelling year. 2016 appears to be the weakest wind year at site since 2000, hence an increased generation of 25 % can be seen as a realistic maximum. A varying generation and its effects on the result for the Sernow wind park is demonstrated in Figure 44. The table in the right corner of Figure 44 shows the granted subsidy related to the level of generation, within realistic ranges at site.



Level of generation	Granted subsidy [ct/kWh]
0%	6.54
5%	6.34
10%	6.15
15%	5.97
20%	5.81
25%	5.65

Figure 44: Sensitivity generated electricity (personal calculation)

As illustrated in Figure 44, an altered electricity generation, up to a 25 % increase of the yearly generation, does not have a significant impact on the result. While the percentage outside a bracket demonstrates the generations' increase or decrease, the number within the bracket shows the linked quality factor. The Sernow wind park has a quality factor of 88 %, hence the corrective factor is located between two classes, highlighted by a yellow frame in Table 9. Values between the ones illustrated in Table 9 can be found by linear interpolation.

Table 9: Quality factor and corrective factor for the Sernow wind park (Deutscher Bundestag 2016, p.11, personal editation)

	Amount of funding									
Quality factor	60	70	80	90	100	110	120	130	140	150
Corrective factor	1.29	1.29	1.16	1.07	1	0.94	0.89	0.85	0.81	0.79
Examples of feed-in tariffs in ct/kWh	7.74	7.74	6.96	6.42	6.00	5.64	5.34	5.10	4.86	4.74
	8.39	8.39	7.54	6.96	6.50	6.11	5.79	5.53	5.27	5.14
	9.03	9.03	8.12	7.49	7.00	6.58	6.23	5.95	5.67	5.53

Even though the black columns in Figure 44 define the realistic range within the years between 2000 and 2016, a wider range of a generation deviation is shown to depict a broader picture. The best NPVs can be achieved at the outer ranges with a quality factor of 70 % or 140 %. While between 60 % and 70 % the granted subsidy is not declining with an increasing generation, it falls rapidly as soon as the 70 % are exceeded. Depicted in Table 9, the differences of subsidy reduction with an increased generation are very similar between 90 % and 140 %. These differences diminish after the 140 % benchmark: the corrective factor only reduces itself by 2 % in the interval of 140 % to 150 %. This explains the high NPVs in these “outer classes”, seen in Figure 44. The necessary increase and decrease of generation to fall into these outer classes is however unrealistic in the at hand case of Sernow.

A trend that can furthermore be observed is the gradually better performance of the ID Scenario with a higher quality factor. This trend can be explained by the increasing importance of market prices with a decrease of the granted subsidy. The lower the granted subsidy, the more the market prices matter.

In relation to the generation and the linked granted subsidy there is a financial uncertainty that has to be highlighted at that point: the varying correction factor that adjusts the awarded subsidy to site quality. The quality factor is determined by the site generation in comparison to hypothetical generation at a reference site for a specific turbine type. The site generation is calculated by the investor and checked by the authorities.

As mentioned previously in the at hand thesis the quality factor for the Sernow site is solely determined based on the yield for 2016. Thereby, there is a risk of an inaccurate quality factor. As Figure 44 has shown, the result is hardly affected by a changed quality factor. Therefore, the quality factor can be considered of minor influence if being varied within realistic ranges. It may however have an effect on the temporal time distribution of payments.

In five year intervals, this site generation is examined again to avoid an under- or overpayment of subsidies. But these examinations every five years also contain certain financial risks for the turbine operator: e.g. if the wind conditions are beyond the expectations the deviation between the expected and the real generation has to be paid back retrospectively, in case it deviates more than 2 %. This may reflect in a changing cash flow after five years and might lead to certain strategies investors follow, as under- or overestimating the yield within the first 5-year period. So if for example an investor would on purpose underestimate the yield by –10 %, then the granted subsidy paid too much has to be paid back retrospectively. If the yield is estimated +10 %, the granted subsidy paid too less gets reimbursed after five years. Taking the DA Scenario as an example, this different temporal distribution of payments would reflect in the following way: when assuming –10 % of generation the NPV would change from 2.11 Mio. € to 2.06 Mio. € and contrary, when assuming a generation of +10 %, the NPV would rise to 2.17 Mio. €. Effects in the NPV and the related cash flow occur caused by a different temporal distribution of payments and a different discount rate. A long term under- or overestimation is however very unlikely due to the examination and adaption every five years. One needs to be aware, that every subsidy scheme can be misused to a certain extent by its profiteers. But the possibilities of misusing the EEG 2017 subsidy scheme seem to be very limited.

The overall picture shows, that a varying electricity generation from the wind park does not have a significant impact on the result within realistic ranges. Thereby, it can be observed that a reduced granted subsidy does outweigh the additional generation and vice versa. It furthermore illustrates, that the best results could theoretically be achieved at a quality factor of 70 %, which would require a hypothetical reduction of 20 % of the yearly generation.

7.2.2 Level of awarded subsidy

As described in Section 4.3, wind turbines have to participate in a tender procedure in order to obtain subsidies. Thereby, operators can make a bid in ct/kWh. If the bid is accepted this awarded value (subsidy) is corrected according to the quality of the site and a granted (corrected) subsidy is paid for every kWh over 20 years. For the Sernow wind park it was assumed, that a bid of 6 ct/kWh is accepted. Due the quality factor of 88 %, this value is corrected by 1.09 and yielding in a granted subsidy of 6.54 ct/kWh over 20 years. Within this sensitivity section, solely the awarded subsidy is changed. Figure 45 shows the results with a different awarded subsidy ranging from 5 ct/kWh to 7 ct/kWh, the amount in the brackets is the related granted subsidy.

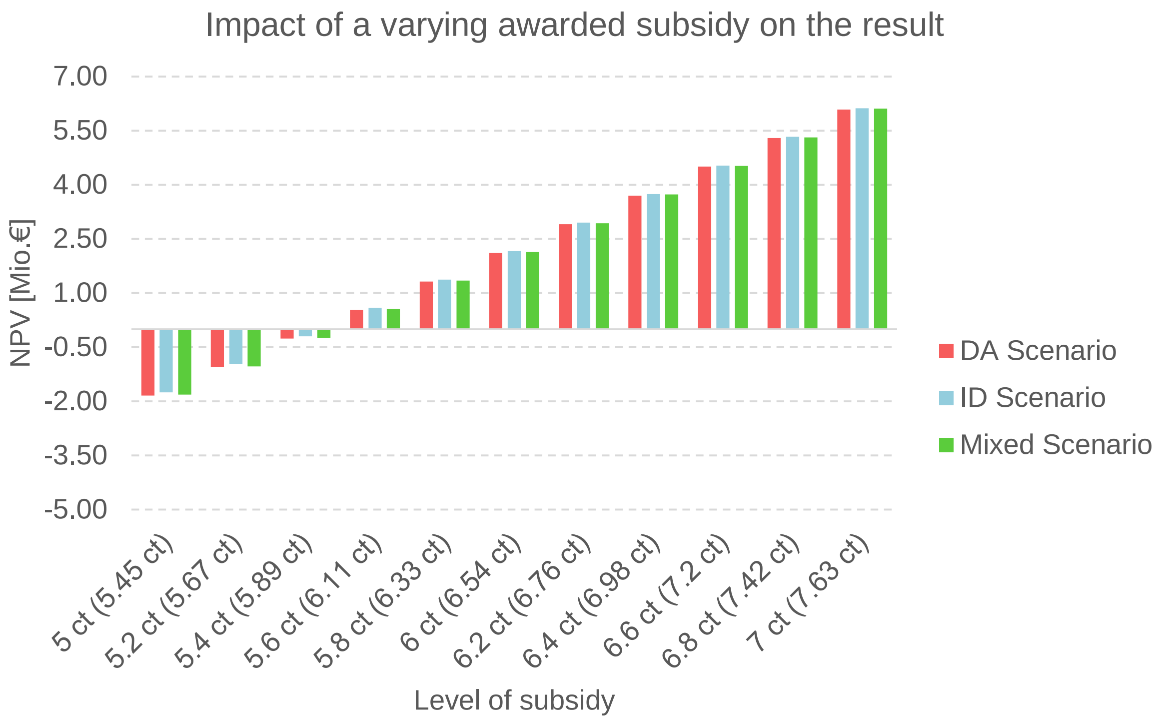


Figure 45: Sensitivity of the awarded subsidy (personal calculation)

If the awarded subsidy is lowered in all scenarios from 6 ct/kWh to 5.4 ct/kWh, then all of them turn out being unprofitable (Figure 45). These 5.4 ct/kWh imply a granted subsidy of 5.89 ct/kWh that is slightly lower than the LCOE (5.9 ct/kWh) of the Sernow wind park. With a higher level of an awarded subsidy, the NPVs would gradually increase until the maximum of 7 ct/kWh is reached. This demonstrates a payment cap determined by the BNetzA. These caps are yearly adjusted in future. By receiving the maximum awarded subsidy, the NPV would almost triple up compared to the scenario baseline.

A change in the awarded subsidy can have a clear impact on the wind parks performance, higher bids are however linked to the risk of not getting awarded if the competitors bid cheaper. So e.g. if an investor would accept a smaller margin from the wind park in Sernow, receiving a lower subsidy is more likely. If an awarded subsidy of 7 ct/kWh is granted instead of 6 ct/kWh, a significantly better result can be achieved but this is related to higher risks and the investor may risk not getting awarded. It is therefore up to the investor how much risk is wanted to be taken and what the expected margins from the project should be.

7.2.3 Investment and O&M costs

The investment costs, assembled together from the main and the incidental investment costs, and the O&M costs are an important factor concerning the profitability of any project. Figure

46 displays the conducted sensitivity analysis of the total investment costs, varying within - 40 % and +40 % range compared to the initial results.

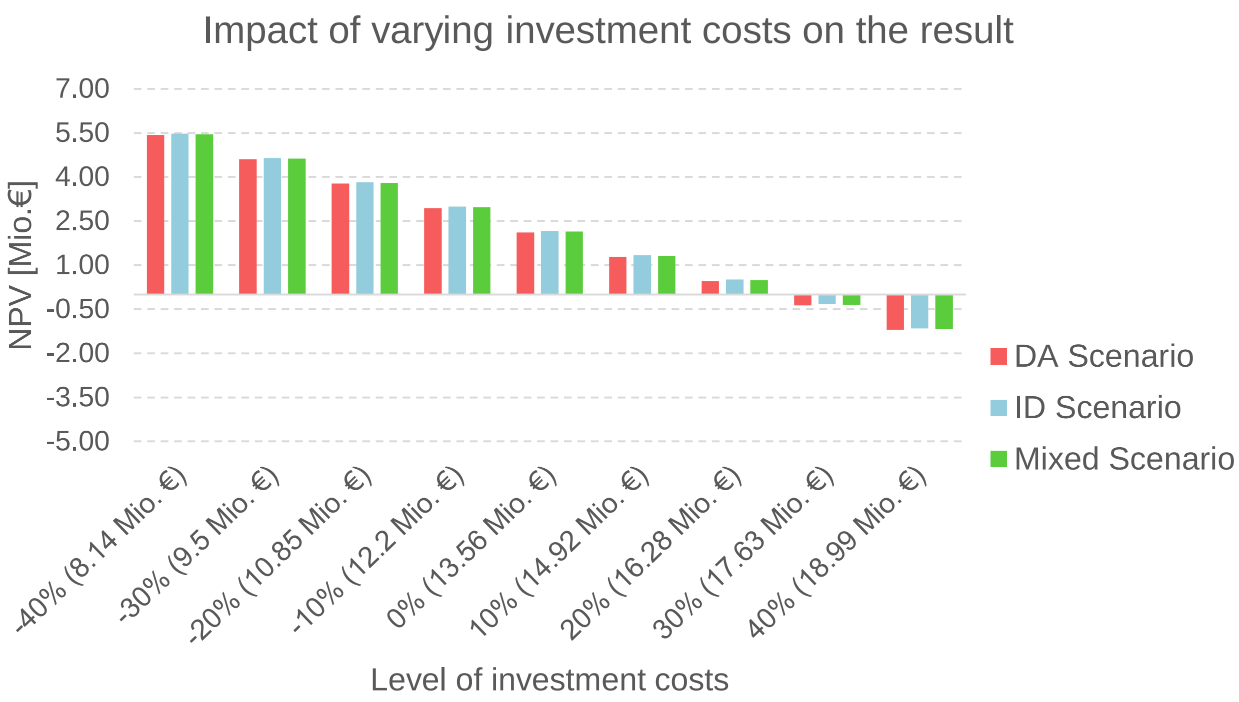


Figure 46: Sensitivity investment costs (personal calculations)

It can be clearly seen in Figure 46 that the investment costs have a visible effect on the NPV. Lower investment costs of 40 % lead to quite some increase of the NPV from the initial 2.11 Mio. € to 5.4 Mio. € in the DA Scenario. Overall, the lower the investment costs the more profitable the project is. On the other hand, with an increase of the investment costs by 20 % the project can still be seen as profitable whereas between +20 % and +30 % it tips over and the NPV turns negative. It should be stated, that plant operators or investors might have a desired revenue expectation, therefore even if the NPV is still positive, the project might not be implemented. These expected revenues are however strongly dependent on the investors considerations and have to be determined individually. A change of investment costs affects all scenarios in the same way, as all are based on the same investments in the same year. Thus, the same effects on the NPVs with a gradual increase or decrease can be observed.

Closely linked the investment costs are the O&M costs. The sensitivity done on them is depicted in Figure 47, within the same range as for the investment costs: -40 % to +40 %.

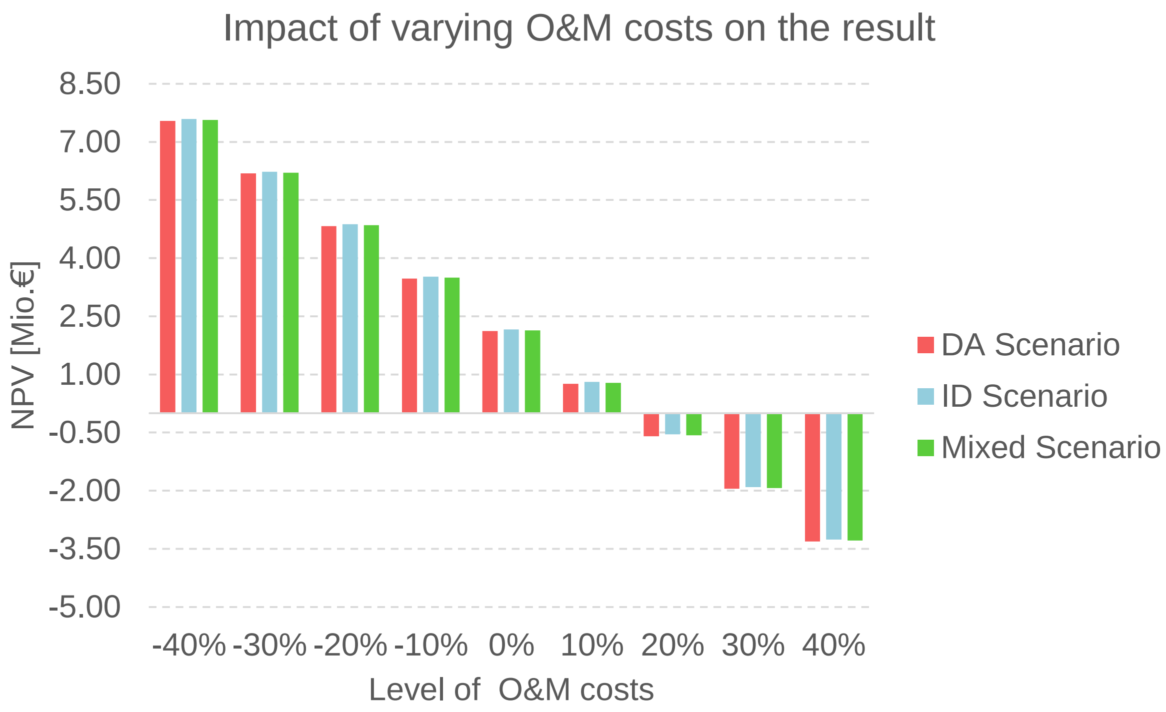


Figure 47: Sensitivity O&M costs (personal calculations)

Figure 47 shows a similar trend as Figure 46 does: lower O&M costs lead to a higher NPV, subsequently to a higher IRR and a shorter payback time. The O&M costs appear relatively high with approximately 4.5 % of the investment costs. This can be argued with the containment of very comprehensive costs as e.g. the one for direct marketing and insurance (see Section 4.4 for a more detailed elaboration). Hence, a change of the O&M costs has a clearly visible effect.

In comparison to the investment cost's sensitivity a reduction of -40 % of the O&M costs leads to a higher NPV of over 7 Mio. €, compared to just over 5 Mio. €. It can furthermore be seen that with a rise of 10 % the project is still profitable whereas with a rise of 20 % it already turns into a negative NPV. The variation of the O&M costs has a more important impact on the result than the alternation of the investment costs.

Overall, it can be stated that the used average costs set seem relatively high, in comparison to the Energy Catalogue from the Danish Energy Agency for instance, but these are primarily valid for Denmark. Moreover, a turbine model from Enercon is chosen, which is known as being more expensive than models from other companies. Therefore, higher investment costs may be accurate. Another aspect which leads to increased costs is the relatively high hub height of the chosen turbine model, which reflects as well in higher costs. Further the comprehensive O&M costs also include factors as direct marketing.

The investment and O&M costs should be seen in context with each other. Often wind turbine manufacturers link these together. This might for instance result in higher investment costs paired with lower O&M costs as the average values stated within this thesis. The base is hereby individual contracts and could not be included into the at hand project in which solely average values are used. All in all, the investment and O&M costs can be regarded as important inputs that have a quite significant impact on the result.

7.2.4 Discount rate

The selected discount rate can have a profound impact on the NPV, and with this, the perceived viability of the project. For the NPV calculation of this thesis, a real discount rate – disregarding inflation – of 4 % is assumed. As the nominal discount rate is including inflation, it is subsequently the real discount rate plus inflation. Even though for business-economic calculations a nominal discount may seem more appropriate, it only reflects in a higher rate and thus a variation of the real discount rate shows an analogue picture. Figure 48 demonstrates the variation of the real discount rate between the range of 0 % and 8 %.

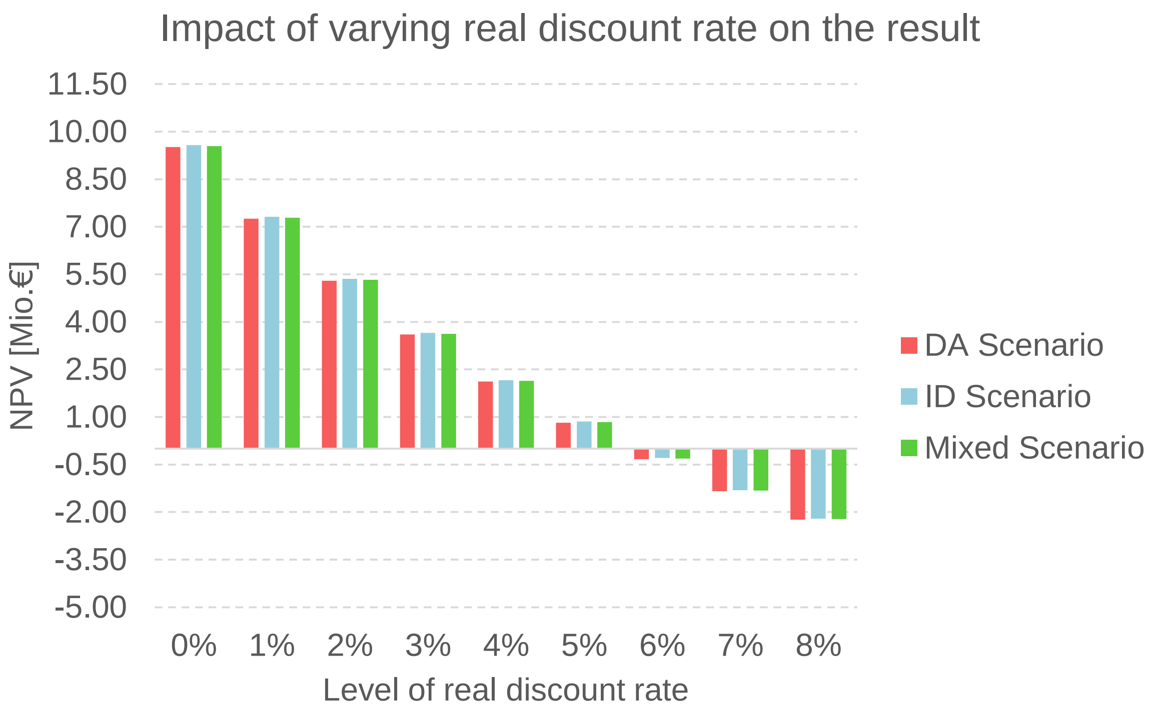


Figure 48: Sensitivity real discount rate (personal calculation)

Figure 48 shows that the NPV of all scenarios is highly sensitive to changes of the discount rate. By increasing the discount rate to 6 %, the project would not be feasible in any scenario. That corresponds with the IRR which is around 5.7%. An increase of the real discount rate to account for inflation by 2 % would therefore – under given modelling assumptions – lead to a negative NPV. A discount rate lower than the initial 4 % would let all scenarios gradually perform better.

The determination of an accurate discount rate is dependent on different factors as e.g. the liquidity and revenue expectations of a company, and therefore needs to be determined specifically. Some investors might want to choose a higher discount rate in order to prioritise the short-term revenues. Furthermore, if loans have to be paid back, the discount rate needs to be adopted higher accordingly.

7.2.5 Electricity prices

By receiving subsidies from the EEG, direct marketing is compulsory. Thus, a sensitivity analysis is conducted related to the electricity prices, as these must be seen in connection to the subsidies. In certain hours the day-ahead market price is higher than the subsidy, the investor only receives the market price. Thereby, the intraday promotion is dependent on the day-ahead prices, as these determine if a subsidy is paid for a certain hour at the intraday market as well (see also Section 6.4.2). Intraday trading is therefore linked to higher risks in regards of the EEG subsidies.

The more hours the market price is higher than the subsidy, the better for the investor. At present, the market prices are considerably low – the average yearly price in 2016 was 30 €/MWh on the day-ahead market – compared to the granted subsidy of 65.4 €/MWh. The sensitivity with varying electricity prices is illustrated in Figure 49. Hereby, the electricity prices are varied between a range of -40 % and +40 %.

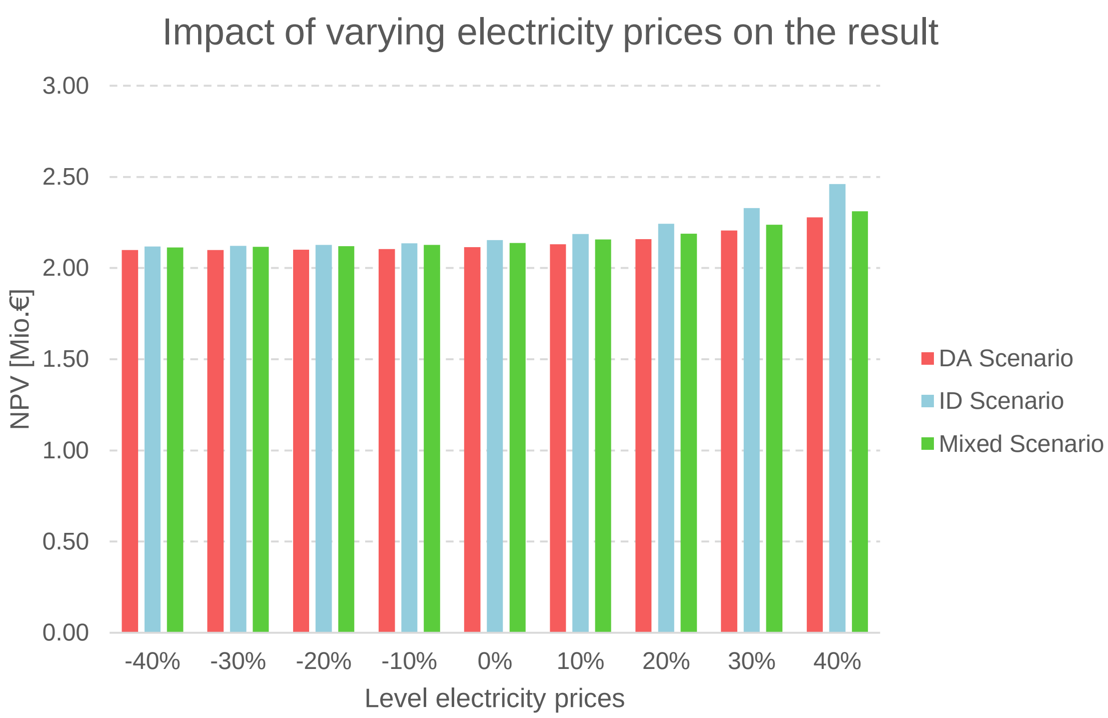


Figure 49: Sensitivity electricity prices (personal calculation)

In Figure 49 the effects of the market premium model are clearly visible: In case the day-ahead electricity prices drop below the granted subsidy in certain hours, the NPV stays stable since even with decreasing electricity prices the granted subsidy will be received, unless the market price is not higher than the subsidy in specific hours and the 6-hour rule does not apply. Therefore, the initial level (0 %) can be seen as the baseline. An increase of the electricity price leads further to a higher NPV due to the fact that an increment implies additional revenues. The highest impact can be observed by an increased price on the Intraday Scenario. Due to the determination of the subsidy payment in certain hours by the day-ahead price, the market price plays a more important role in the ID Scenario. It is more sensitive to price increases than the other scenarios.

Overall, due to the design of the EEG a change of the electricity prices mainly has an influence on the scenarios' revenues when these prices increase, as there is a set floor payment, represented by the granted subsidy. If the price in a certain hour is below that granted subsidy, the investor does not have to face any financial losses (as long as the 6-hour rule does not apply).

The sensitivity analysis presented in this chapter has elaborated the effect of different modelling inputs on the results. Thereby, it turned out that the outcomes are sensitive to certain inputs, namely the discount rate, the investment and O&M costs as well as the awarded subsidy. Thereof the awarded subsidy is regarded as the “most insecure” input, as this value is determined within a tendering procedure and strongly depends on the competition in this tendering. The investor does not know beforehand what extent of subsidy to expect. Even though a variation of the investment and O&M costs as well as the discount rate affect the results significantly, these inputs are easier to foresee than the awarded value. A variation of the yearly generation and the electricity prices on the other hand did not imply any crucial changes.

8. Wind turbines and German balancing markets

Next to the commercialisation of the generated electricity on the power exchange, there might be another option possible for wind turbines in the near future: the participation on the balancing markets, which is so far not an option for them in Germany. Within this chapter the TCR market is in focus, as the negative TCR market is likely to be opened for wind turbines within the next years. Due to the current organisation of the PCR and SCR markets, a participation of wind turbines is not likely in the close-by future. Thus, these are only touched upon shortly.

The following section elaborates the recent development related to the implementation of wind turbines on the German balancing markets and describes the Danish TCR market - in which the participation of wind power is already implemented - as best practise example. The very section will shed light on the second sub-question of the thesis and examine a way to make the German balancing markets accessible for wind turbines and clarify the expected potentials on that. Since a participation on these markets is not possible so far, the following section is, in order to gain knowledge, based on interviews conducted with the Danish TSO Energinet.dk and two of the German TSOs, namely TenneT and Amprion. Furthermore, since this way of commercialising wind turbines is not yet implemented, it is not included in the scenarios but solely discussed qualitatively in this section. All conducted interviews can be found in the **Appendix** and are – if necessary – summed up and translated to English.

The target of the German government in view of lowering the GHG emissions pursues a steady and further development of renewable energies. In 2016, the share of renewables in the domestic electricity generation has reached around 34 %. On specifically windy and sunny days, a high share of solar and wind power can push the penetration of renewables in certain hours to a significantly higher share of around 80 %. As these fluctuating power sources have grid feed-in priority, a rising expansion of them might lead to the conclusion of an increasing necessity to balance the grid. Wind energy furthermore causes imbalances during times with higher or lower wind power yield than forecasted. As already described in Section 3.5.6.4, the electricity system has to be kept in balance with little buffer around the frequency of 50 Hz, which is called dead band. There are different control reserves which will be activated to equal the imbalances in case of under- or overcapacity in the electricity system: namely PCR, SCR and TCR. PCR and SCR are procured weekly whereas TCR is procured daily on all weekdays. At the moment it is not possible for wind turbines to participate on any balancing market in Germany.

Wind power is due to its fluctuating character not seen as being reliable enough in predicting the generation in advance and hence it is excluded from attending. Additionally, long lead times do constrain their integration. However, there are intentions to include them into the negative TCR market in the future. Since fluctuating power sources are at a high risk of causing imbalances, it would be beneficial to include them in the balancing market and let them equal out the imbalance themselves. Furthermore, the idea is that these sources could contribute to increase the system security. In some other countries wind turbines are already successfully included in the balancing markets. Therefore, before examining the German market in more detail a small discourse to the Danish system will be displayed in the following paragraphs (RP-Energie-Lexikon n.d.).

8.1 Wind turbines on the Danish balancing markets

Denmark is one of the countries which already allows wind turbines to attend the TCR market. In 2012 the incentive for this was induced by the Danish Wind Power Association, an interest organisation supporting wind turbine owners, due to the fact that wind turbines cause imbalances which lead to negative downward regulating prices. The idea is that the wind turbines not only cause the imbalances but also help to remove them to some extent and hence contribute to maintain the system security. It started off with a low capacity level: in the beginning 200 MW out of 5,000 MW, of which 50 MW were onshore wind capacities, participated. Wind turbines are mostly seen as being suitable for negative TCR due to the fact they mainly run in times of high wind.

In the Danish system there is usually no performance price for bids in the negative TCR market and further no penalties as the system is voluntary. The turbine owners receive the money in case their turbines are used for regulation. Based on a forecast system the Danish TSO - Energinet.dk - calculates imbalances 1-2 hours ahead and activates bids by their merit-order. The lead time in which bids are made for the regulating market ends 45 min ahead of that period. The price constitution furthermore acts similar to the day-ahead market and uses a clearing price paid for all accepted bids. However, there is an exception in case of special balancing needs, such as grid bottlenecks caused by local congestion. Hereby, the pay-as-bid principle is used in order to match with the particular geographical location needed (Energinet.dk 2012, p.25) (Sorknæs 2015, p.45).

So far the résumé by Energinet.dk is the following: the amount of bids naturally depends on the meteorological conditions. At the moment, a maximum of 30 % of the installed wind capacity participates. Normally, wind turbine bids are activated around 200 to 300 hours a year. Currently, around 700 MW capacity onshore participate in the negative TCR market.

Since 2015 Energinet.dk furthermore helps to outbalance grid instabilities from the German gird on a daily basis, more specifically imbalances in the control area of TenneT. As this is in comparison an overwhelming amount, the participants for the negative TCR rose steadily and there are so far always more bids available than required to be activated. Especially in 2016 the capacity TenneT asked to be outbalanced by Energinet.dk grew significantly: almost all of the time the negative TCR volume needed was considerably higher (from half of the total volume up to around 20 times) than the one needed within the Danish system itself. Therefore, as the main drivers for the successful implementation are seen by Energinet.dk the agreement with Germany and extremely negative prices on the Nordic power market.

PCR is procured daily whereas SCR is procured on a monthly basis (Energinet.dk 2012, pp.5–9). Wind turbines are hereby not considered as being reliable enough for a participation. For the TCR the major weaknesses are considered by Energinet.dk concerning the operational issues: the forecasting, on which the decisions for system regulation are based, only includes data measurement of 30 % of all Danish wind turbines. When using wind turbines as negative TCR the TSO does not know the exact location of the shut-down turbines. Therefore, in times in which a lot of wind turbines are shut down, the forecasting model gets inaccurate as there are rising insecurities in the up-scaling of the model.

For the future Energinet.dk sees a potential for wind turbines to also participate as SCR, after the implementation of a common energy-only-market (EOM) with an appropriate design like the current TCR market for the Nordic area in about two years.

Overall, the example of the Danish TCR market shows that in windy hours it is successfully possible to include wind turbines as negative TCR. The main challenge lies within the design of the forecasting model. Among the reasons for the successful implementation are in particular the short lead times, the fact that the Danish system has no performance price for withholding the capacity and furthermore that there is no punishment in case of less or no delivery. However, as it is built on voluntary bids the risk of too less bids made maintains, even if so far it was never the case (Parbo 2017).

8.2 The German balancing power market development

After the outlook to the Danish system, which already successfully included wind turbines in the TCR market, the German status upon that will be examined further. As stated earlier, the participation of wind turbines in the balancing power markets is so far not possible. Germany has in comparison to other countries a high share of fluctuating renewables and hence one could conclude that steadily more balancing power is needed which brought up the discussion about the participation of wind turbines. However, the rising share of fluctuating renewables in

Germany did up to now not correspond with that trend, mainly due to changes in the power market organisation over the last years. Among them are the modification of the intraday market which now provides a greater flexibility accommodating with the predictability and profile of renewables. Shorter reaction and trading times promote the rise of participants. In 2011 the intraday market auction period was reduced from one hour to 15 min. Another development on the power market, which has to be taken into account is the fact, that a higher level of generating renewables causes a decline of the market prices and stimulates the exports to neighbouring markets. As these markets from other countries are most often interconnected, they are affected as well and might import electricity from Germany which thus leads to a smaller necessity of balancing power (Energiewende 2015).

In the German power system there is moreover occurring a paradox: since 2008 the balancing reserve capacity has overall declined by 15 %, whereas in the same time frame the capacity of solar and wind rose by 190 %. Furthermore, in that time period the costs for balancing power declined by 50 %, which can most likely be retraced to the cooperation of the TSOs on the balancing power market, which started in 2010, and the modification in the intraday market. At the same time the overall activations of balancing power declined as well (Hirth 2015, pp.1–28). This does however not necessarily imply that rising wind and solar capacities reduce the need of balancing reserves. The effect seems to come from other developments such as an improvement of weather and load forecasts.

Since the development might be unexpected it is worth to have a closer look, especially on the different balancing market segments. The overall revenues from balancing power prevailingly decreased since 2009: the financial balancing market volume shrunk by 60 % from 2009 to 2015 (Hirth 2015, p.4). In the same time the financial balancing market volume declined for positive as well as negative regulating power (Hirth 2015, p.5). Figure 50 displays the annual market size in monetary values of the different segments in the balancing power market. Both, the commodity and the performance price, are included in this calculation.

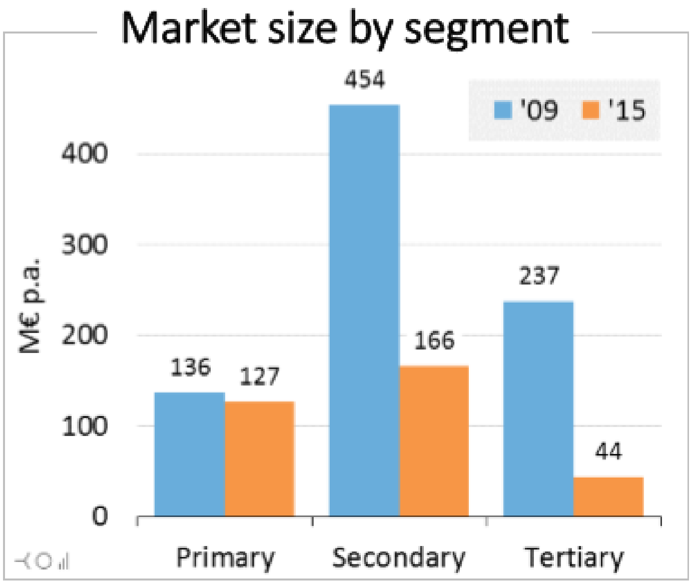


Figure 50: Market size of balancing power by segment (Hirth 2015, p.6)

Another interesting aspect in Figure 50 is furthermore that in 2009 the SCR held by far the highest share, whereas in 2015 it was still the highest but only with little deviation to the PCR. Apart from that, the price development is another remarkable factor as the prices have developed differently in the segments (Hirth 2015, pp.6–10).

An investigation of the last years has shown that SCR and TCR prices per MWh decreased clearly whereas for PCR the opposite occurred in the same time frame: the price per unit increased slightly. Concerning SCR, in 2013 the price was still higher than for PCR, whereas specifically in 2015, the situation was reversed (Hirth 2015, p.10). The prices for PCR stayed more stable than the prices in the other segments. This effect could be explained by looking at the price development in connection with the development of the prequalified suppliers. In terms of suppliers, there was a steady and significant increase, especially in the TCR and SCR segment, whereas the PCR did not rise that much in proportion. The only slight increase of suppliers in the PCR market keeps the prices on a more stable level and explains this effect (Hirth 2015, p.28).

Figure 51 below shows the performance price development for TCR, as this is the main field of interest. Hereby, the overall price decrease can be seen as well. It also applies to both, negative and positive balancing power.

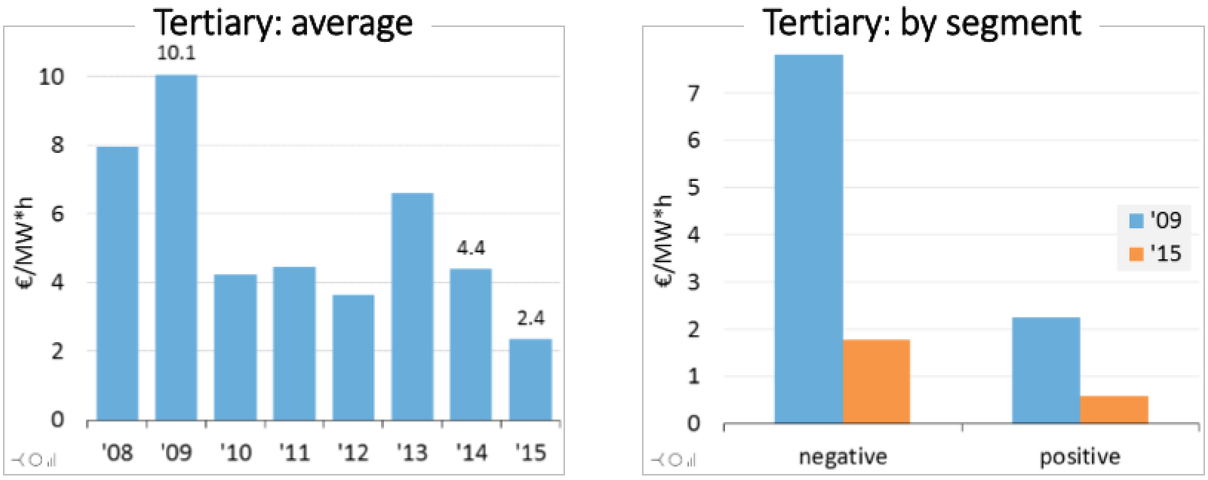


Figure 51: Performance price development TCR (Hirth 2015, p.14)

In Figure 51 it is depicted that negative balancing power has by far experienced a higher performance price decline than positive balancing power in the same time period. To get back to the paradox: the development has to be seen in relation with several factors that occurred at the same time. These are an improvement in wind but also load forecasts, less plant outages, the TSO cooperation regarding balancing reserves, a increased intraday liquidity and 15 min trading on power exchanges (Hirth & Ziegenhagen 2015, pp.11–12).

Regarding the possibility of wind turbines participating on the German negative TCR market, the current balancing power market design can be seen as the main obstacle that hinders their attendance. However, when looking at other countries there are different options to integrate wind turbines: for instance an adjustment of the market design or the introduction of an EOM, in which payments are solely based on the actual provided services. This is for instance the case in Denmark (Hirth & Ziegenhagen 2015, pp.20–21). Currently, in the German system there is a performance but also a differing commodity price in the TCR market, the contract duration for TCR is set to 4 hours.

The design of the market furthermore determines the participation of renewables on the balancing market (Hirth & Ziegenhagen 2015, pp.25–26).

8.3 German balancing power markets – steps for an implementation

Currently, there is a pilot phase going on in order to evaluate the participation of wind turbines on the negative TCR market in future. The pilot phase runs two years until the end of 2017. For economic reasons fluctuating renewables are especially considered to be used for downward regulation. This is due to the fact that wind turbines normally run on their maximum capacity whenever possible to gain the EEG subsidy granted for feed-in power. Hence, a reduction of their performance, in order to eventually participate on a positive balancing market, would diminish their revenue. Contrary, downward regulation is more attractive. Therefore, in a cooperation the four TSOs and Fraunhofer, a research institute, investigated within a study in 2014 the provision of negative TCR by wind power. The main focus lies on the certainty to generate an output based on probabilistic generation forecasts. Wind turbines are only allowed to participate in case it is possible for them to guarantee their performance to the same degree as adjustable power plants can. This criteria has to be fulfilled due to the performance price. The share of wind generation units that can participate will be determined by the required security level (probability) and the relative size of the forecast error. Hereby, certain aspects have to be considered: the size as well as the geographic distribution of the wind turbine pool, the contract duration and the forecast horizon. Overall, in order to promote the participation of wind turbines a larger pool, shorter contract duration and a shorter forecast horizon would be beneficial (Hirth & Ziegenhagen 2015, pp.18–19).

The study was initiated as it was unsure how the participation of wind power in the negative TCR market is possible as it is afflicted with uncertainties concerning the verification. Therefore, the study aimed to determine and choose a detection method. This mainly concerns the technical details and will not be further examined in detail in the thesis (BMUB & Fraunhofer IWES 2014, p.15).

For TenneT wind farms are a possible option in wind intense hours for offering negative TCR at favourable costs. Furthermore, it is seen as a way to introduce the wind power plant operators to a regulated operation mode – especially in view of the time the subsidy period has ended. The German EEG grants subsidies for a time period of 20 years. However, concerns are hereby the inaccuracy of day-ahead forecasts and moreover the exact determination of the outer and inner wake effects of a wind park. In the German system sanctions take place in case of non-fulfilment of the awarded balancing power, applying to the performance price and the shortfalls over the commodity price. Currently, due to economic reasons, which were already described earlier in this section, primarily negative TCR is of interest. TenneT however assumes that negative SCR could be attractive in the future but not at present due to the high requirements and the current lead times. One of the possible options would be a shortening of the lead times on the balancing market. According to TenneT there are right now preparations by the BNetzA to do so in future. Therefore, TenneT sees wind turbines as having a significant role in special windy times at the negative TCR market (Neubauer 2017).

With the participation of wind turbines on the negative TCR market another German TSO, Amprion, expects a range of different changes to come into effect: for the TSOs with the attendance of wind turbines the traded volume and the diversity of actors is expected to rise and hence the performance price to decline in the TCR market. Furthermore, for Amprion it is seen as a chance to gain experience with new technologies but also methods on the balancing market which could in the future be adapted to other types of technologies and balancing types, such as PCR and SCR. For wind turbine operators it offers the participation in a new market. Overall, it is expected to contribute to the security of supply and the economic efficiency (Speckmann 2017).

Challenges are seen according to Amprion in the currently low prices for TCR which might hinder or complicate a refinancing of the required investments for participation as control reserve and the running costs. Wind power will most likely stay behind most technologies regarding the commodity price as the market premium has to be compensated and no fuels can be saved by downward regulation. Furthermore, it relies on challenging determination methods for the possible feed-in, namely probabilistic prediction. Penalties are a part of the German balancing market design and are regulated within the framework contract of the TCR. Attending wind turbines are seen as a way to gain experience with new technologies as it is beneficial for the system security that various technologies provide balancing power (Speckmann 2017).

Amprion does not see the attendance of wind turbines at the very moment as attractive for turbine operators as the performance price is relatively low and furthermore the TCR is not frequently activated. In addition, not a high revenue from the commodity price can be expected especially when receiving steady and solid subsidies under the EEG. It might however be seen as an opportunity for those who were not able to get awarded in the EEG auctions. Concerning the lead times, no further changes are expected from Amprion. The TCR market is already tendered daily. After the closing of the pilot phase and the implementation of wind power in the TCR market it is most likely that there will be considerations to include wind power furthermore in the PCR and SCR markets. In case of collaborations with other countries, wind turbines are, as soon as they are part of the national balancing markets, instantly integrated in the cross-border markets. Generally, both, TenneT and Amprion, see a larger and more distributed portfolio as an advantage as it can balance out uncertainties in itself (Speckmann 2017).

In regards of the lead times and the balancing market design, there might be changes expected in the future based on guidelines from the EU. The EU adopts certain guidelines which are binding for the member states. Of special interest in regards of this thesis is hereby the current draft concerning the establishment of a Guideline on Electricity Balancing. Aim is hereby to create an efficient and open European market based on the framework for cross-border markets (European Commission 2017e). However, certain aspects can already be concluded which might have an effect on the design for the German balancing market: Within this guideline it is stated, that the TSO should perform an analysis in order to minimise the costs for providing reserve capacity. Hereby,

> "*the volume of non-contracted balancing energy bids which are expected to be available both within their control area and within the European platforms taking into account the available cross-zonal capacity*" (European Commission 2017d, p.40)

should be considered within the analysis. Every TSO should define itself the rules for the procurement of balancing energy however the EC sets up some principles to which the rules of procurement shall align. These are inter alia:

> "*the procurement method shall be market-based for at least the frequency restoration* (SCR and TCR) *reserves and the replacement reserves*" and "*the procurement process shall be performed on a short-term basis to the extent possible and where economically efficient*" (European Commission 2017d, p.40).

Based on these rules it can be concluded that further changes might be expected within the German balancing market design especially in regards of the lead times and price determination. The design might shift in direction of the Danish system, in order to participate in the cross-border European market without hurdles and disadvantages for the German power plants and aligning to the guideline. These alignments are necessary for a further development of the vision of a common European balancing market.

In view of answering the second sub-question of the at hand thesis this section aims to give an overview of the accessibility for wind turbines on the German balancing markets, currently the negative TCR is in focus, as well as their potentials on it. The section has shown that in the future the integration of wind turbines on the negative TCR market is likely. This balancing market is hereby, next to day-ahead and intraday trading, another potential market place. The main challenges are the lead times, the load predictions based on forecasts and the punishment in case of non-fulfilment. There is currently a pilot phase running with the participation of wind turbines on the negative TCR market in Germany. In contrast, there are countries which already have successfully included wind turbines into one of their balancing markets, such as Denmark. The successful implementation in Denmark is mainly based on the following aspects: voluntary bids, short lead times, no performance price and furthermore no punishment for non-fulfilment of the agreed volume. Due to the success of the Danish model it could be used as a role model for the design of the German TCR market. Overall, there could be an adaption between the different European countries expected due to the intention of the

European Commission to harmonise the market, stated in the Guideline on Electricity Balancing.

The TSOs consider the negative TCR market as a moderately interesting market for wind turbines operators in Germany in the near future. It has to be furthermore stated at this point that the market volume on the balancing markets is much smaller (around 1,500 MW for negative TCR in 2016) (Haendel & Klobasa 2016, p.15) than on, for instance, the EPEX day-ahead market (usually at least a few hundred GWh daily). Main concerns in regards of the participation of wind turbines lie hereby on the following factors: in times of participating on the balancing power market no subsidies are granted and furthermore wind turbines cannot save fuel costs with downward regulation as other power plants can. Furthermore, the activation is not occurring frequently.

The present low costs for negative TCR, and their decrease in the last years, bring at the moment also low incentives to participate. Besides the modification of the intraday trading, shorter lead times as well as the merit-order effect in combination with the interconnection of the neighbouring countries have an influence on the attractiveness of the market. Nevertheless, with the participation on the balancing markets wind turbines could contribute to the system security and help to equal the imbalances they caused themselves to some extent. This is especially interesting due to the feature of wind turbines to operate very short-term. To pick up on another aspect concerning the attractiveness of the German balancing market, the earlier stated agreement between Energinet.dk and TenneT is of interest: as shown, quite a high amount of capacity is regulated downwards by Energinet.dk in the last years for the German TSO TenneT, which especially makes the market interesting for Danish wind turbine operators. This leads to the assumption that although the German market volume is at the moment relatively small the potential is much higher, especially when having to outbalance the overcapacities in the north of the country itself without making use of other neighbouring balancing markets. The agreement with the Danish TSO furthermore shows that there is a prospective bigger market volume and the need for a new organisation of the domestic market.

In conclusion when focussing on the more technical aspects it is evident that a bigger pooling of turbines, both numerical and area-wise, is beneficial for an increased forecast accuracy paired with the possibility of compensating unforeseen deviations from the stated forecast within the turbine pool itself. Currently, negative TCR is the main focus of interest whereas in the future it is most likely that wind turbines might also be integrated in the PCR and SCR market. The negative SCR market may however be more attractive due to the currently higher prices offered and the more frequent activation than the TCR.

To sum up, the balancing market, at first the negative TCR market, can be considered of interest in the future as another option to commercialise wind power generation on the market. Especially, with the aligning process to the European guidelines more changes are expected which might foster furthermore a participation of wind turbines also on the SCR and PCR market.

9. Discussion

The thesis sheds light on the business-economic feasibility of the Sernow wind park, in regards of its' electricity promotion and the EEG subsidy. Within the following paragraphs, certain additional aspects of the EEG and the EEG's impacts regarding the enforcement of the set political goals, certain delimitations, the different relations of the project to electricity markets and offshore wind power will be looked at and discussed more closely.

On a politic level, several targets regarding climate change were set. The GHG reduction of 95 %, compared to 1990 levels, is aimed to be achieved by 2050 with an increment of renewable energies. For instance should renewables have a share of 40-45 % until 2025 and a share of 55-60 % until 2035 in the gross electricity consumption. Whether the in the law stated deployment corridors for renewable energies are enough to reach these expansion targets strongly depends on the future progress concerning the energy efficiency and the development of the electricity consumption. According to a study by Agora, a German think tank, the targets in the heat and mobility sector as well as the ones concerning renewables for 2035 would not be reached in a business-as-usual case, combined with a small increase of the energy efficiency and with a slight electrification of services. For the 2025 targets, this is not the case: they could be reached in a business-as-usual scenario. However, in a combination with an increased electricity demand, the attainment would not be possible anymore (Argyropoulos et al. 2016, pp.33–35).

Further, it is expected that the climate targets until 2020, namely a 40 % reduction of the GHG emissions compared to the level of 1990, will not be reached in case no further actions are taken. Especially, the high share of coal power plants would have to be reduced. Therefore, in order to reach the middle and long term climate goals set by the German state, a much faster reduction of the CO_2 emissions is needed in the electricity sector (Argyropoulos et al. 2016, pp.33–35).

In order to fulfil the climate targets, the EEG was adapted to boost the development of renewable energies in a controlled way. As can be seen in the results of the at hand thesis, see Section 7.1, due to the low power prices on the power exchange a support scheme for renewables is needed in order to make it possible for them to successfully compete on the market. For renewable power plant operators the EEG is a great opportunity as it guarantees a stable income for a time span of 20 years. Therefore, it can be stated that the EEG stimulates the development of renewable energies as it gives the incentive to invest in them. However, with the switch from a fixed feed-in to an auction system more risks are included. Within the new design subsidies will be determined by an auction with a pay-as-bid principle. Hence, an operator does not necessarily receive any subsidies. Every plant operator has to evaluate for which amount the bid can be made. A low bid would guarantee getting awarded whereas one should consider that at least the electricity generation costs should be covered. Furthermore, it can be discussed, if an extension cap for renewable energies (2,800 MW-2,900 MW for onshore wind turbines), is constraining the increment. Thereby, the extension is “artificially limited” even though more facilities may be implemented in regards of achieving the set political goals, what would – on the other hand – require more state aid.

This is done within certain development corridors which only allow the installation of a certain yearly amount of capacity in order to align to the grid development. Overall, the EEG can be seen as a successful instrument to boost renewable energies.

The new scheme based on auctions seems to be chancier. It might further have an effect on the diversity of the actors. So far, the main actors of the German energy transition were private owners, especially regarding wind onshore. This might be about to change with the modification in the EEG design. The auction system is not only risky in terms of being awarded, it furthermore requires, in order to attend the tendering, security payments and the approval under the Federal Immission Control Act. This might be an obstacle for private land owners, communities and smaller project developers with less liquidity. Especially, the approval is not only time-consuming but also costly. Hence, it can be concluded that bigger companies with a larger portfolio and a higher liquidity have advantages.

The German state included an exemption in the law in order to guarantee the actor’s diversification: citizens’ energy companies. For this type of actors specific rules are accepted, however bound to a maximum capacity of 18 MW with 6 installations in total and a specific ownership structure defined by the law. If these factors apply, the law permits this actor a lower security payment beforehand, a prolonged realisation period and the participation in the tender without having the approval under the Federal Immission Control Act beforehand. Furthermore, instead of a pay-as-bid system this type of actor is assured to get a uniform pricing system, meaning in case a bid from a citizens’ wind farm gets awarded, instead of the bid made this actor would get the same as the highest bid which was still awarded in this very auction round (Watson Farley & Williams 2016, p.6). With this exemption the law aims to retain the diversity of the ownership structure. The very small players will benefit from that, however there are concerns that especially medium-sized companies could have troubles within the new EEG scheme. Partnerships between these medium-sized companies and bigger ones seem most likely to compensate the risks. One example for this is the cooperation between ABO Wind AG and Vattenfall A/S, concluded in 2017. Vattenfall will help ABO Wind AG to bear the risk and help to boost the expansion of onshore wind turbines. ABO Wind AG performs at a local level whereas Vattenfall A/S supports mainly financially (Dahl 2017). For Vattenfall A/S it is mainly seen as an investment to rise their share of renewables and to expand their onshore wind portfolio in Germany with the support of local players. Regarding the ownership structure and the diversity of actors there are changes expected within the future. It seems that in the future there might be mainly big players and very small ones. The medium-sized companies might vanish due to the increased risks associated with a needed higher liquidity.

Another flaw of the EEG design might be the not realised capacity. In case a project won the tender and is delayed in the construction or finally the project cannot be realised, the capacity is not added up to the next auction round. The capacity is furthermore lost. However, the development corridors and their fulfilment is needed in order to achieve the targets set in view of GHG emission reduction.

An additional aspect that needs further discussion is the re-examination of the quality factor every five years. These re-examinations as well as the original examination has to be paid by the investor. In case of deviations of more than 2 %, the operator will be reimbursed or has to make additional payments. The prior definition of the site's quality factor, which is linked to the granted subsidy, poses an additional risk on the operator or planner. To avoid over- and underpayments the quality factor should be determined over five years and not be solely based on single years. The effects of this in the at hand case are already outlined in Section 7.2.1. The quality factor should be determined based on the expected power yield it will re-examined after five years based on the actual generation of the last five years. There could be the case that these were very weak years concerning wind speeds. Nevertheless, the quality factor gets adapted and reimbursement payments are granted. After the next five years there is another re-examination which could turn out that the last five years were exactly the opposite from those five before. Five very weak wind years are followed by five very strong ones and vice versa. This reflects in very different cash flows for the investor in this time intervals. In any case this situation even if seeming unlikely might occur and is posing an additional risk on the wind turbine operator as the investment is calculated based on static assumptions concerning the granted subsidy. If the above described case occurs, the previously projected financial reflows alter. This might lead to problems concerning the liquidity of the plant operator and the refunding of loans for instance. Therefore, these five years re-examinations might have an influence on the planning companies and thus on the expansion of renewables.

As described in Section 2.3, the at hand thesis is linked to different delimitations that border the analysis and may change the outcome of the thesis. The project investigated the business-economic feasibility of the Sernow wind park. Hence, only effects which are considered as being important for investors are included. When lifting the scope to a more comprehensive one, other effects have to be considered. For example could the effects on the added value be included. The chosen Enercon turbines are manufactured by a German company. Such investments may stimulate the economic performance of the company and furthermore enhance the employment situation.

In addition, the modelling year and its market prices may have an impact on the results, if market prices would rise again. The result must be seen specifically in connection to the modelling year, as the subsidy cannot be seen separately from the market prices. A clear price increase on the electricity markets – which would be necessary to have a significant effect on the result – seems however unlikely at the present German power market and in the near future.

Zoning regulations and environmental restrictions can have an enormous impact on the feasibility of a project. While some natural impacts may be financially compensated, others cannot. In such a case, even a fully developed project cannot be implemented due to the conflicts with restrictions. Even though this risk was not considered in the at hand thesis, it certainly plays a key role for an investor in reality. As these spatial regulations can hardly be influenced by the investor, this risk can be an imminent threat for a wind power project developer.

A factor not considered in the thesis was financing parts of the wind park by loans. Enough financial liquidity to cover all expenses was presumed. In reality projects might be financed by loans to a certain extent. In this case, the revenues need to be accordingly higher, as a yearly loan payback needs to be considered.

The research group's investigations have shown, that receiving subsidies by the EEG the participation of wind turbines on the negative TCR market would not be a very attractive business due to the subsidy losses during downward regulation and the non-frequent activation. Furthermore, wind turbines cannot save any fuels by regulated operation. The participation of wind turbines could however be more attractive if the subsidy is still paid to them even though turbines are in regulated operation. Thereby, wind turbines would keep the subsidy for certain hours and could still contribute to the grid stability.

A very crucial point to discuss is the price development on the electricity markets in regards of subsidies for technologies, such as for wind power. Subsidies are paid to technologies in order to make them competitive on the market until they can compete without any financial aid. Even though some technologies are expected to have a significant reduction in costs, the market price development must correspond with this trend in order to let them be a feasible investment without financial support. The LCOE of different technologies in 2013 and their predicted cost development can be obtained from Figure 52.

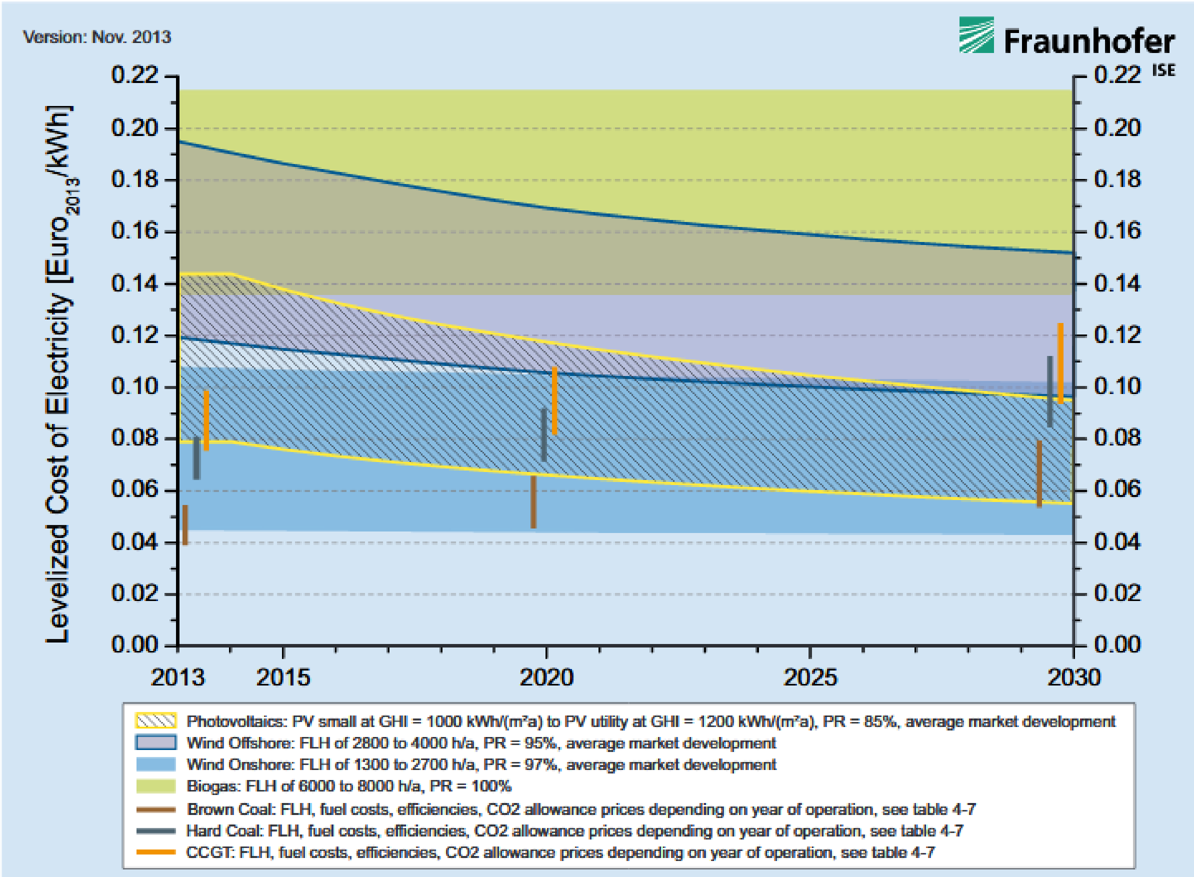


Figure 52: LCOE of different technologies (Kost et al. 2013)

Figure 52 outlines, that big potentials for cost degression are especially seen for offshore wind turbines and PV in future. Small changes are expected for the onshore wind turbines. An increment in terms of costs is assumed for conventional fossil fuel plants due to increased costs for CO_2-quotas. All LCOE for different technologies underlie certain ranges. As calculated in Section 6.3, the Sernow wind park has LCOE of 5.9 ct/kWh.

When linking this information now to the electricity wholesale market prices, an interesting development can be observed: None of the investigated technologies from Figure 52 can compete on the power market, even though adjustable units may benefit from high prices in certain hours. In 2016, the average day-ahead price was around 2.9 ct/kWh and the intraday price averaged in 3 ct/kWh. The technology subsidy is paid by a payment every German consumer has to dispense: the EEG surcharge. This money is then reallocated (in form of subsidies) to turn energy projects into viable investments for investors to achieve the politically set extension goals. At the same time, especially renewables, put a downwards pressure on the market prices due to their merit-order effect. So to speak, this is causing a circular effect.

While on the one hand subsidies are paid with the intention of making technologies competitive on the market, on the other hand these technologies are a driver that lets the market prices sink. This is maintaining (or even increasing) the need of subsidising technologies further as competition becomes harder by that development and may be in contradiction to the political goal of security of supply.

A characteristic of German renewable energy politics was the latest shift of focus within the wind power segment towards offshore by the EEG 2014. For onshore wind power the yearly development is limited to a capacity of 2,800 MW in 2017. As already mentioned in Section 2.1 installed capacity was higher in the last years. With the amendment 2014 the German government decided to put a special focus on the offshore technology. The target, primarily stated in the EEG 2014, decreases with the 2017 amendment and aims for a total installed offshore capacity of 15,000 MW by 2030, instead of 25 GW due to grid connection and transmission problems. Hereby, the technology is financially supported to a higher extent than onshore (Deutscher Bundestag 2016, p.5). Due to the long lead times concerning the construction and the grid connection it is stated in the law that until 2024, in which there are two yearly auction rounds, only wind farms which are already planned (year 2017) and approved can participate. For these farms an interim rule is implemented. For 2017 and 2018 the yearly volume is set to 1,550 MW. The securities for offshore wind project are also much higher than for onshore ones (Bundesregierung 2016, p.2)(PWC 2016).

However, the concentration on offshore seems to be in contrast to the grid bottleneck problematic in the north of Germany concerning the high generation of wind power in the north of Germany and the energy-intense industry in the south of the country. Rather the opposite: an intense development of electricity generated by offshore wind farms might put additional stress on that situation. The German government seems to counteract this issue with only letting already planned and approved wind farms participate until 2024. Further, the about to be build transmission line between Germany and Norway, called NordLink, might ease the situation. By 2018 the transmission line is supposed to be build which has a capacity of 1,400 MW. The high capacity level of hydro storage in the Nordic countries seem to be an approach to balance the electricity (Zakeri et al. 2015, p.2). Besides the gird bottleneck issue, another interesting feature occurred lately regarding the generation costs of offshore wind energy. The first offshore auction of 2017 already took place. In this auction round very low awarded subsidies were determined: on average 0.44 ct/kWh. The lowest bids getting awarded were 0.00 ct/kWh, whereas the highest winning one was 6.00 ct/kWh. The 0.00 ct/kWh signifies that the project developer will operate the wind farm without receiving subsidies. There is quite a high competition in the field as around 6,000 to 7,000 MW capacity of wind farms are already planned. Additionally to the awarded subsidy of the auction round, even if no subsidy at all is granted, comes as well the claim for grid connection and the option to operate the wind farm for 25 years. The grid connection is financed by the end consumer via the network charges (Neue Energien 2017). The low average price in the first offshore auction was quite a surprise. Already in late 2016 Vattenfall A/S won an auction round in the Danish system for their wind farm Kriegers Flak with an awarded sum for 4.99 ct/kWh. This was at that point already considered as very low, since the electricity generation costs are expected to be around 12 ct/kWh (Vattenfall 2016). The low prices show the cost reduction potentials and the cost competitiveness of offshore wind energy. Reasons for the cost reduction are stated as technological progress, low financing costs, the growing size of offshore wind farms, the growing experience with planning, construction and the running of the offshore wind farms. Especially the size of the farms is used to lower the costs (Preuß 2016).

To fall back to the German auction round, there were three projects which bid with 0.00 ct/kWh: one is from EnBW and two from the Danish energy company DONG Energy. To emphasise on the example of DONG Energy: within that auction round DONG Energy won with three projects of which two do not receive any subsidy at all and one is awarded for 6 ct/kWh. DONG Energy states that the projects without support are feasible due to the high wind potential at the very spots, the location itself nearby other wind farms which would reduce the O&M costs and the granted extended lifetime to up to 30 years (Wehrmann 2017).

Additionally, in 2016 DONG already won an auction for two wind farms within the Dutch subsidy scheme: both for 7.27 ct/kWh. It should be stated that the different subsidy schemes are differently designed and hence support the technology differently in view of the time and the capacity. But still in 2012 DONG Energy stated to aim for LCOE of 10 ct/kWh in 2020, including the grid infrastructure (Windkraft-Journal 2016). However, the different values the company bid on, even in one auction round, raise the question whether a support is needed at all when obviously it is already possible to operate the wind farms without financial support. Or furthermore why a company would bid for the lowest value, when it could get subsidies and thereby maximises its' profit. Also the different values DONG Energy achieved for their wind farms in the auctions could conclude some kind of cross-subsidising in the company: letting some parks finance others whereas the 0.00 ct/kWh bids are used to simply get the capacities approved.

10. Conclusion

Germany has appointed different political goals related to GHG reduction and the extension of renewable energies. Germany aims for a GHG reduction of 95 % until 2050, compared to the level of 1990, whereas the share of renewable energies in the final gross energy consumption should add up to 60 % for the same time horizon. An important goal related to power targets is a 55-60 % share of renewable power in the gross electricity consumption until 2035. Thereby, onshore wind power plays a crucial role in achieving this target: a yearly capacity increase of 2,800 MW between 2017 and 2020 and a further increment of 2,900 MW after 2020 is planned. The share of wind power in the whole German electricity generation added up to 14 % in 2016. Besides the desired political extension of onshore wind power, an opposing trend can be observed on the electricity markets: German wholesale prices – and thus the recoverable revenues for power plants as wind turbines – are steadily decreasing since 2011. In order to support the competitiveness of renewable energies, the EEG was invented in 2000. Since then, the EEG had different amendments, the most recent one in 2017. This amendment brought a crucial change in the way how renewable energy technologies are subsidised: in contradiction to the previously executed scheme of fixed feed-in tariffs, the new system prescribes a tendering procedure to receive an individually determined subsidy. Subsidies – paid as market premium – are granted to the operators asking for the least financial support per kWh based on bids the operators make. Thereby, the cheapest bids from operators are aggregated until the desired capacity level is reached in a merit-order pay-as-bid principle, in which too expensive bids do not get awarded. In addition to the subsidies, all generated electricity has to be promoted via direct marketing. Wind parks with weaker wind conditions receive a higher subsidy and vice versa.

The latest development on the power markets, the political goals related to renewable energies and wind power as well as the new amendment of the EEG in 2017 have raised the following research question and sub-questions:

What are the options to promote wind turbines in Sernow on the German power market in regards of the EEG 2017 amendment in a business-economic feasible way?

- *Which form of direct marketing lets the wind turbines in Sernow perform business economically the most feasible when receiving support by the EEG?*
- *How can balancing markets be made accessible for wind turbines and what market potentials can be expected?*

The above stated questions were examined along the case of the Sernow wind park in Germany from an investors view. The first sub-question was answered by modelling the wind park in the simulation software windPRO followed by an investigation, how and if the generated electricity can be promoted business economically feasible on the power markets when receiving financial support granted by the EEG. An answer to the second sub-question was found by conducting different interviews and literature research, as the German balancing markets are not accessible for wind turbines yet. From the research conducted within the at hand thesis the below standing can be concluded along the example of the Sernow wind park:

Regardless of the way of promotion, all scenarios, representing the different ways of promotion, achieve a very similar result. The main assumptions for the results are a given period of 20 years, a real discount rate of 4 %, an awarded subsidy of 6 ct/kWh and a granted subsidy of 6.54 ct/kWh. Under these modelling assumptions, the ID Scenario performs best yielding in a NPV of 2.15 Mio. €, while the DA Scenario performs slightly worse with a NPV of 2.11 Mio. €. The Mixed Scenario adds up to a NPV of 2.14 Mio. €. All Scenarios have a simple payback time of 12 years and an IRR of around 5.7 %.

By varying the wind parks' yearly generation within realistic ranges, the sensitivity analysis shows, that the results stay very stable. Only large increases or decreases lead to significant changes of the results, which can be traced back to the subsidy scheme design (see also Section 7.2.1). Derived from the at hand analysis the subsidy scheme does not favour a stronger or weaker wind site, within realistic ranges. Overall, it can be expected that investments into new onshore facilities may take place in sites with very different wind conditions. Certain risks included in the subsidy scheme need to be considered by the investor. The testing of the quality factor every five years – which has to be financed by the investor – may cause financial problems as e.g. money has to be paid back if too many subsidies were granted. Such a situation may occur due to weak wind years. Thereby, risks are mainly expected within the first five years, after an adoption these risks seem to be very unlikely. To reduce the risk of over- and underpayments, the quality factor has to be assessed long-term. An inexact quality factor does not have a large effect on the overall revenues but may change the temporal distribution of the payments.

To other input factors, the results for the Sernow wind park seems to be clearly sensitive. Varying investment and O&M costs as well as the awarded subsidy and the discount rate have a visible impact on the result. The impact of an electricity price variation can be regarded minor at the at hand thesis. This however changes with a lower granted subsidy and higher electricity prices. The subsidy always needs to be seen in relation to the electricity prices, as it is paid only if the electricity price is lower than the granted subsidy and the 6-hour rule does not apply.

Even though the German balancing markets are not accessible yet for wind turbines, a possible participation as negative TCR is very likely in future. The main constrains for the participation of wind turbines are the long lead times and their fluctuating generation character. The present market design is an obstacle for the participation of wind turbines. Denmark can be taken as a best practise example for integrating wind turbines as balancing capacity, as it introduced a market design allowing their attendance. At present, the German TSOs are running a pilot phase investigating the provision of balancing power by wind parks. Experiences from this pilot phase should help to make the negative TCR market accessible for wind turbines.

This market is not expected to be very attractive for wind turbines that receive subsidies by the EEG. By regulated operation, the turbines would receive less subsidy and furthermore no fuel can be saved by such an operation mode but the wind turbines would have the possibility to remove imbalances from the system and to contribute to a higher level of security of supply. The analysis shows however, that Germany has a high demand for a flexible negative TCR market, which can be derived from the “special agreement” between Energinet.dk and TenneT. TenneT is currently paying a lot of Danish wind turbine operators for downward regulation in times of an overproduction in Germany. This regulation of wind turbines is not possible at the moment in Germany itself due to the different market organisation compared to Denmark. Hence it can be concluded, that there is a demand for a new organisation of the national balancing markets. The recoverable prices at the negative TCR market are expected to be relatively moderate by the German TSOs Amprion and TenneT, since over the last years the negative TCR market has faced a strong price decrease and the negative TCR is not activated frequently. Amprion and TenneT see further potential to integrate wind turbines in the SCR and PCR markets. An alignment of European balancing markets may also have a positive impact on the inclusion of wind turbines as the market volume increases and more expensive units might be replaced.

Overall it can be stated in relation to the EEG subsidy scheme that for the Sernow wind park the awarded subsidy plays a crucial role, while the (corrected) granted subsidy is of less interest. When getting awarded for receiving 7 ct/kWh, the wind park can be regarded as a secure investment while with an awarded subsidy of 6 ct/kWh the investor has to face higher financial insecurities. By not knowing what extent of subsidy can be expected for a project, especially investors with a higher liquidity, that are able to overtake higher financial risks, may have an advantage. Due to the onshore wind power extension cap, competitors can be pushed out of an auction by such companies.

Even though special rules apply for citizens’ cooperatives, it is arguable if these special rules really encourage them. With the new tendering procedure, the investor landscape might undergo a big structural change. A central question is if the EEG amendment 2017 has the expected effects and who is benefiting from it. Even though this subsidy scheme may require less financial state aid and helps Germany to achieve its goals, “weaker” financial player with less liquidity might be pushed out of the market, leading to less diversity and a shift of market power.

The way of how electricity from the Sernow wind park can be promoted business economically feasible in Germany regarding the EEG subsidy can be answered clearly: even though the ID Scenario achieved the best result for the Sernow wind park, the differences between the scenarios are minor. These differences however become bigger with increasing market prices. It can be concluded, that the way of promotion does hardly matter in the at hand thesis. The balancing markets will most likely be accessible for wind turbines in the near future. A new market design, similar to the Danish one, would surely enhance their accessibility to the negative TCR market. While the market potential for wind turbines is given, the recoverable price expectations for investors are moderate. Nonetheless, wind turbines can actively contribute to the security of supply on the long run, which plays an increasing role with a further increment of wind turbines.

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Appendix

Interview Amprion (Markus Speckmann)

- What changes do you expect for the TSOs and plant operators by the participation of wind turbines on the balancing market? From your point of view – where do you see advantages?

    - Changes TSO:
        - The liquidity on the balancing markets will rise whereby the performance price is expected to decline.
        - We will gain experience with a new technology and a new method (possible feed-in, probabilistic prediction) and then adapt these if applicable to other types of balancing power (PCR and SCR) as well as other technologies.
    - Changes plant operator (wind energy):
      They will get to know a new market (TCR) as well as new methods (possible feed-in, probabilistic prediction)
    - Advantages:
      Integration of a new technology in the balancing market. This contributes to the economic efficiency and security of supply.

- In your opinion where are the main challenges for the integration of wind turbines in the balancing market?

    - The currently very low prices for TCR on the market will complicate the refinancing of the required investments for the participation as well as the running costs.
    - Regarding the commodity price wind energy will stay behind most of the technologies as first of all no fuels can be saved (in the negative TCR) and secondly the cancelled EEG market premium has to be compensated.
    - The challenging methods (determination of the possible feed-in, probabilistic prediction).

- Which penalties are planned for plant operators in case of non-fulfillment of the awarded balancing power? From your point of view are there concerns regarding the grid stability?

    - Penalties: These are regulated in the framework contract of the TCR. It can be seen on regelleistung.net
    - Concerns: As the participation is limited to only one type of balancing power, which is not regularly used, we can gather experiences without endangering the system security. Therefore, we have no concerns. Furthermore, it is beneficial for the system security that the balancing power supply is offered through different technologies.

- Do you see an advantage due of the economies of scale for plant operators with a broad wind power portfolio by the performance of balancing power, which have furthermore the possibility to pool wind turbines with adjustable units?
  - Yes, there are advantages due to the economies of scale. The larger the portfolio, especially with a wide geographical distribution, the greater will be the balancing effects and the more balancing power per installed MW can be offered.
  - The pooling of adjustable units has a positive impact and furthermore the balancing effects can be used as well.

- Do you estimate the provision of negative TCR as a potential attractive market for wind turbine operators?
  - At the moment not due to the fact that the performance price is relatively low. Furthermore, the TCR is not activated frequently. Therefore, a high revenue from the commodity price is not expected.

- Shortened lead times on the balancing market and within the intraday business would facilitate the participation of wind turbines. Do you consider changes in this direction as realistic in the near future?
  - The TCR is already tendered daily (exceptions are weekends and holidays). There are no further shortenings to be expected.

- Which potential do you see in the integration of wind turbines in the remaining national as well as cross-border balancing market?
  - After the closing of the pilot phase for TCR there will surely be considerations how wind turbines could be integrated in the PCR and SCR. At some point wind turbines will provide PCR and SCR.
  - As soon as wind turbines are integrated in the national balancing markets they are automatically integrated in the cross-border ones as far as there are collaborations.

Interview Energinet.dk (Henning Parbo)

- What was the main idea of integrating wind turbines in the Danish balancing market? What were the major challenges of the implementation?
  - The main driver was a request from the Danish wind power association, which is an interest organisation for wind turbines. Wind turbines cause imbalances and negative downward regulating prices.
  - 2012 implementation
  - The design was chosen in order to reduce the risks for wind turbine owners in times of an electricity overload.
  - Started with 200 MW out of 5000 MW to create a reasonable limit.
  - Only one challenge: define information which goes back and forth from plant operator to system operator (Energinet.dk) → solution: Information from wind turbines activated in power market and hence time series of how many MW of wind turbines are closed down

- How does Energinet.dk deal with insecure balancing power from wind turbines? What happens if wind turbines fail their performance of balancing power?
  - Pro-active system: Control centre forecasts imbalances 1-2 hours ahead (+ online measurement towards Germany) → activates bids. In case of persistent imbalances: activate more or deactivate. A 100 % performance is not required.
  - Bid made → immediately money will be received. Afterwards measured. Imbalances will be compensated, the price is hereby the same. Idea behind: wind turbine owner doesn’t earn money for not delivered energy. No penalty payments in Denmark due to the fact that wind turbine owners would otherwise not participate with a 100 % guarantee.

- Denmark is currently admitting wind turbines as negative tertiary control reserve. How is their balancing capacity procured?
  - No procurement. Deliver bids for regulating market 45 min ahead, no capacity payments. When competitive in merit-order wind turbines are taken. 100 % voluntary. No exclusion.

- How many wind turbines participate as negative tertiary control reserve (in % of negative tertiary control reserve volume and the actual wind turbine capacity in MW)? How did the wind turbine balancing capacity and the negative tertiary control reserve volume develop since the implementation?
  - Amount of bids depend on the meteorological condition. Max is 1400 MW at the moment, 30 % of total turbines in DK. Due to subsidies: needs to pay off, therefore power price minus subsidy. All prices are negative.
  - Activated: 200-300 hours per year. TCR is activated under special circumstances.
  - Special request from TenneT to take the surplus power from Germany, on daily basis. Agreement approved by BNetzA.
  - Wind offshore participates entirely: 700 MW
  - Onshore: 700 MW
  - Started very small but especially due to the agreement with Germany (2 years ago), more and more turbines participate.
  - Started: 50 MW onshore

  - Main driver 2012 extremely negative prices and main driver at the moment: arrangement with Germany.

- What is the current ownership structure of wind turbines providing negative tertiary control reserve and how did it develop? Do you see an advantage for operators with a big wind park portfolio?
  - Privately owned onshore.
  - Yes, most certainly scale effect.
  - Average size is 2 MW of wind turbine. No individual bids. The centrally organized organization pools (Danmarks vindenergi)

- Wind turbines are only allowed to participate in the balancing market when being pooled with adjustable units. How does the TSO make sure the wind power capacity is backed-up?
  - There is no back-up as there are many voluntary bids/reserves. Therefore, no back- ups need to be bought. No capacity payment for Danish negative TCR.
  - Wind turbines are not allowed in the PCR and SCR as they are not considered as secure enough. No stand-by payments/capacity payments for wind turbines.

- Can the Danish negative tertiary control market be considered as a lucrative business for wind turbine operators?
  - Yes, in some hours. Mainly due to the arrangement with Germany. Otherwise, the hours are very low (300 per year maximum).

- What is your current resume about admitting wind turbines for negative tertiary control reserve? Did the desired effects occur?
  - One challenge: more an operational problem instead of an implementation one, caused by the special arrangement with Germany. Energinet.dk does not know which turbines exactly are shut down (location). Only the capacity is known. The forecasting which is 2 hours ahead is based on an online measurement of 30 % of the wind turbines (including meteorological data and mathematical models). The forecasting model gets inaccurate in case a lot of wind turbines are shut down. Insecurities in the up-scaling.

- Do you see potentials to integrate wind turbines in the residual national and cross-border balancing markets?
  - Yes, however not at the moment.
  - At the moment SCR is traded on a monthly base. But an EOM for the whole Nordic area will be set up (secondary market). One for TCR already exists. With the implementation of the SCR EOM in 2 years, wind turbines will most likely participate.

Interview TenneT (Arndt Neubauer)

- What changes do you expect for the TSOs and plant operators by the participation of wind turbines on the balancing market? From your point of view – where do you see advantages?

    - In the negative TCR wind farms can, in times of strong wind, provide relative large amounts of TCR to favorable costs. The grid consumers benefit from these cheap costs. Additionally, that way the EEG-operators are slowly introduced to a regulated operation mode- which can be important after the end of the granted subsidy period.

- In your opinion where are the main challenges for the integration of wind turbines in the balancing market?

    - The tender preparation: A day-ahead wind forecast could be too inaccurate.
    - The determination of the possible feed-in: the wake effects – on the inside (affecting one's own wind park) and on the outside (surrounding wind parks with wake effects), depending on the wind direction, and the wind velocity are the main obstacles for the determination of the possible feed-in.

- Which penalties are planned for plant operators in case of non-fulfillment of the awarded balancing power? From your point of view are there concerns regarding the grid stability?

    - These sanctions apply currently to the performance price (see framework contracts TCR) as well as the costs for shortfalls over the balance energy price. In case of repeated shortfalls a withdrawal of the pre-qualification can occur.
    - No, not in case the rules of the TSOs are fulfilled.

- Do you see an advantage due of the economies of scale for plant operators with a broad wind power portfolio by the performance of balancing power, which have furthermore the possibility to pool wind turbines with adjustable units?

    - Yes, pooling is a clear advantage for tendering. If hypothetically a wind farm of 100 MW can bid on 20 MW, a pool of two of these parks on different geographical locations could bid out of 200 MW for 50 MW with the same reliability.

- Do you estimate the provision of negative TCR as a potential attractive market for wind turbine operators?

- Negative TCR is more attractive than positive TCR, due to the fact that the positive TCR requires a permanently reduced operation. The support for this amount of energy would be cancelled and would have to be compensated by a high performance price (a few hundred Euros per MW).
- Negative SCR could be more attractive, however the requirements are currently too high for wind energy.

- Shortened lead times on the balancing market and within the intraday trading would facilitate the participation of wind turbines. Do you consider changes in this direction as realistic in the near future?

  - At the moment there are preparations from the BNetzA for a new determination process in Germany. The German TSOs expect far-reaching consequences in this area within the next months and years.

- Which potential do you see in the integration of wind turbines in the remaining national as well as cross-border balancing market?

  - In the future wind turbines could play a significant role in certain times of the year on the negative TCR market.