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The Effects of Battery Storage on Risk and Cost of Capital of Wind Park Investments

Lukas Erhard

Technische Universität München

Abstract

To reach the defined reduction goals for green house gas emissions, an increasing share of renewables and especially wind power is necessary. However, these generation technologies are intermittent and progressively exposed to market risks as a consequence of declining financial support in the future. To reduce revenue volatility, in this thesis, a wind farm is combined with a battery storage. The study emphasizes the battery's effect on the investment risk and the accompanying cost of capital. In order to assess this effect, I develop a deterministic optimization model based on historic wind farm and market price data in order to maximize cash flows. Monte Carlo scenarios are generated to evaluate the impact on risk by using the Value-at-Risk as risk criterion. I find that batteries can indeed reduce revenue risk in a case without subsidies. Furthermore, the link to cost of capital is made. The latter, as well as the battery prices, need to be reduced by a certain amount to make the application of a battery economically reasonable.

Keywords: Renewable energy, Energy markets, Battery storage, Wind investment, Energy investment risk

1. Introduction

The energy industry is undergoing a transformation. With negotiations on the Kyoto Protocol in 1997, climate change became more important in international politics, and leading economies around the world committed to reaching green house gas emission reduction goals.[1] The European Union (EU) has set ambitious goals that aim to reduce green house gas emissions. More precisely, by 2050 the aim is a reduction by at least 80 % compared to 1990 levels. Analyses have shown that this will only be achievable if the energy sector is close to zero carbon.[2] Furthermore, nuclear energy is being phased out in some countries like Germany.3[3] To meet these targets, the EU aims to reach a share of electricity from renewable energy sources (RES) which is at least 27 % in 2030.[4]

In order to achieve this share of RES in Europe, big investments are required. The EU Reference Scenario 2016 projects that wind power will cover 14.4 % of the total net electricity generation by 2020, whereas it projects 25 % in 2050.[5] This underlines the importance of future wind energy investment. Expressed in numbers, the estimated required investment volume for RES from 2011 to 2030 is 1.153 billion euros.[6]

A characteristic of RES is the intermittency of electricity production. This means that the energy produced is not continuously available and depends on external factors such as weather conditions.[7] Whereas tidal and solar power are rather predictable, accurate forecasts for wind energy are hardly feasible.[8] Operators of conventional power plants are able to control energy production according to current market prices to maximize profit. RES however are non- dispatchable which results in obligatory sale of electricity even if the current market prices are low. To avoid this, th possibility of affordably store energy is crucial.[9]

The funding for the investments in RES comes from different investors and equity providers, who want to be paid for bearing the risk of losing money. Because of this, a certain share will be demanded as interest, namely the cost of capital. The amount of cost of capital charged will, based on the assumption of risk-aversion, depend on the accompany-

[1]Cf. United Nations (2014); Oberthür and Ott (1999), p. 2.
[2]Cf. European Climate Foundation (2010).
[3]Cf. Wozabal et al. (2016), p. 688.
[4]Cf. European Commission (n.d.).
[5]Cf. European Commission (2016) p. 65.
[6]Cf. von Hirschhausen et al. (2014) p.32.
[7]Cf. Gersema and Wozabal (2016), p. 2.
[8]Cf. Hanania et al. (n.d.); Gersema and Wozabal (2016), p. 2.
[9]Cf. Gatzert and Kosub (2016) p.991.

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ing risk.

There are many different risks for this kind of investments but most studies are on the same page about the most pressing risk, namely the policy design or regulatory risk. The reason for this is that the policy design and accompanying support schemes account for predictable prices and therefore reduce the revenue risk.[10] The problem especially occurs to energy from RES as they are intermittent sources of energy and the electricity production cannot be controlled.

To make electricity from RES competitive, policies and accompanying support schemes have been introduced in Europe in recent years. This kind of subsidies promoted RES in the past and still continue to do so. For example, feed-in tariffs were used to provide stable revenues over the whole investment lifetime. Therefore, market risks are overturned.[11] Nevertheless, as RES technologies have matured and the efficiency in mastering the transformation of electricity production must be promoted, subsidies and other forms of support are intended to be cut and phased out in the future.[12]

With these curtailments of support, market risk becomes more pressing again. This leads to the necessity to cope with risk in combination with RES, especially in wind power, since the fluctuation of wind is much higher than the solar irradiation.[13] Among other possibilities, the operation of an energy storage is a way of dealing with this risk.

Since wind energy will play an important role for reaching the RES goals, the combination of a wind power plant with an energy storage in a virtual power plant (VPP) and its ability to influence the investment risk is analyzed in this thesis. Especially dropping prices make batteries an interesting choice as energy storage.[14] Most literature on this topic assesses the operation of VPPs in general from a risk-neutral and risk-averse perspective. Furthermore, the specific combination of a battery with a wind power plant is analyzed from a risk-neutral perspective only.

This thesis emphasizes the effect of a battery storage on investment risk. It will assess to which extent a battery can mitigate revenue risk coming from volatile electricity prices and stochastic generation patterns. Additionally, this impact on risk is linked to the cost of capital of wind farm investments. Consequently, the research question is the following: Can a battery storage reduce investment risk for wind farm projects, and if yes, would it be economically viable?

Section 2 of this thesis provides a review over recent relevant literature (2.1) and the definition of the research gap (2.2) this thesis is intended to fill. Subsequently, battery storage in renewable energy is introduced in chapter 3. Lead acid (3.1.1), Lithium Ion (3.1.2) and Redox-flow batteries (3.1.3) as major technologies are explained and the usage of second-life batteries for large scale energy storage is discussed (3.2). Closing up this chapter, section 3.3 demonstrates the provision of grid services and arbitrage trading as additional strategies to generate revenues. Section 4 introduces different RES policies, especially the support schemes which are crucial for understanding the importance of this thesis' topic. Section 5 captures the topic of risks in renewable energy investments starting with an overview of different risk categories (5.1). Thereafter (5.2), the market price risk is discussed. For this reason I elaborate on the market integration of, and resulting decrease of state-aid for RES (5.2.1), the market price dependence due to direct marketing (5.2.2) and the continued operation after the support period (5.2.3). In Section 6 the theoretical link of volatility in revenues, risk and cost of capital is clarified. Section 7 represents the core of the thesis, the developed model on the operation of a wind-battery-VPP and the influence on the investment risk in a case study. It starts with an introduction to the used methodology (7.1) followed by an overview of the underlying data set (7.2) and the presentation as well as interpretation of the results (7.3). Section 8 covers alternative instruments to stabilize revenues from RES and therefore reduce investment risk. First, risk transfer (8.1) like long-term contracts with large electricity consumers are addressed (8.1.1), financial instruments in terms of energy derivatives (8.1.2) and insurance products (8.1.3). 8.2 covers possible adjustments on the market framework for RES dominated markets. 8.3 explains diversification as a way to reduce risk for RES. Finally an overview of the thesis, including the main results, implications as well as limitations is given (chapter 9). Section 2 of this thesis provides a review over recent relevant literature (2.1) and the definition of the research gap (2.2) this thesis is intended to fill. Subsequently, battery storage in renewable energy is introduced in chapter 3. Lead acid (3.1.1), Lithium Ion (3.1.2) and Redox-flow batteries (3.1.3) as major technologies are explained and the usage of second-life batteries for large scale energy storage is discussed (3.2). Closing up this chapter, section 3.3 demonstrates the provision of grid services and arbitrage trading as additional strategies to generate revenues. Section 4 introduces different RES policies, especially the support schemes which are crucial for understanding the importance of this thesis' topic. Section 5 captures the topic of risks in renewable energy investments starting with an overview of different risk categories (5.1). Thereafter (5.2), the market price risk is discussed. For this reason I elaborate on the market integration of, and resulting decrease of state-aid for RES (5.2.1), the market price dependence due to direct marketing (5.2.2) and the continued operation after the support period (5.2.3). In Section 6 the theoretical link of volatility in revenues, risk and cost of capital is clarified. Section 7 represents the core of the thesis, the developed model on the operation of a wind- battery-VPP and the influence on the investment risk in a case study. It starts with an introduction to the used methodology (7.1) followed by an overview of the underlying data set (7.2) and the presentation as well as interpretation of the results (7.3). Section 8 covers alternative instruments to stabilize revenues from RES and therefore reduce investment risk. First, risk

[10] Cf. Noothout et al. (2016), pp. 22, 29 f.; Cleijne and Ruijgrok (2004) p. 50.

[11] Cf. Noothout et al. (2016), pp. 51-52.

[12] Cf. European Commission (2014), p. section 3.3.

[13] The year-on-year fluctuation of wind can be up to 25 % whereas solar irradiation is between 3 % and 5 %; Cf. Deign (2014).

[14] Cf. D'Aprile et al. (2016).

transfer (8.1) like long-term contracts with large electricity consumers are addressed (8.1.1), financial instruments in terms of energy derivatives (8.1.2) and insurance products (8.1.3). 8.2 covers possible adjustments on the market framework for RES dominated markets. 8.3 explains diversification as a way to reduce risk for RES. Finally an overview of the thesis, including the main results, implications as well as limitations is given (chapter 9).

2. Literature review and research gap

2.1. Literature review

Extensive literature exists focusing on risks in wind energy investments in general. Gatzert et al. for example identify the most pressing risks in wind energy investments.[15] There is a further study to be highlighted, namely the Dia-Core project by Noothout et al. They analyse risks in European countries in combination with a study on cost of capital in wind energy investments in these countries.[16] The main emphasis is on the relation between risk and the respective RES policies. The Green-X project by Cleijne et al. quantifies the risk in RES investments and can make the leap to the resulting weighted cost of capital (WACC) using the developed Green-X model.[17]

The majority of papers focuses on VPPs consisting of at least one intermittent energy source combined with another intermittent energy source or energy storage. Some of these papers e.g. Costa et al. conduct their analysis from a risk-neutral perspective and only attain the goal of maximizing profits. There also exists literature representing a risk-averse view that is based on accompanying key performance indicators for risk like the value at risk (VaR). This is due to the fact that investors will also consider risk since they are generally assumed to be risk-averse. However, the studies with risk-averse perspectives for VPPs consisting of a wind farm mainly focus on combinations with hydro power plants and consider the risk-aversion from the RES operator's perspective. Furthermore, they do not make a connection to cost of capital.[18] Table 1 provides an overview of studies on virtual power plants with wind power turbines and storage. This section introduces - making no claim to be exhaustive - the most important literature as a base for the present thesis.

Pinson et al. focus on the sizing of energy storages in VPPs to hedge imbalance penalties caused by wind power forecast uncertainty. Accordingly, they assume a market, where RES suppliers are responsible for caused imbalances due to forecast uncertainties. Their model aims to determine the optimal battery size in a dynamic way at every point in time. When applied to historic data, the model provides an optimal dynamic sizing schedule dependent on the operator's risk attitude. The dynamics are included in their model to reduce storage cost by under-utilization. Finally, they come up with the idea to introduce storage services as new independent entity in the electricity market. They consider offering storage as a service where RES producers can rent the necessary storage capacity on a daily basis.[19].

Gersema et al. elaborate on risk-diversification in terms of pooling different intermittent RES into a VPP. Their optimization model is based on two-stage stochastic programming. This study is not particularly emphasizing a combination of electricity storage and wind but of different RES. However, this paper has significant influence on this thesis since it takes risk preferences of risk-averse investors into account by applying the Conditional Value at Risk (CVaR). They aim to maximize utility through reducing revenue variability by selectively combining different intermittent RES. The two-stages in the stochastic optimization model represent the two decisions that must be made, and which are choosing the portfolio weights in the first stage and one year of trading decisions in the electricity market in the second stage. Gersema et al. apply the model in a case study to a market without any subsidies as well as to a market with a fixed feed-in tariff.[20]

Liu et al., go more into detail by focusing on VPPs consisting of wind power and hydro. They investigate the coordination of such VPPs from the generating companie's view in terms of bidding strategies. The study emphasizes the economic capital an electricity generating company needs to prepare to ensure continuing operation even if losses occur. It furthermore takes a risk-averse perspective by optimizing the risk adjusted return on capital (RAROC) which represents a measure that was established as an adjustment to the Return on Investment. The RAROC displays the compromise between profit and risk as it relates the expected return to the aforementioned economic capital. Five cases are carried out in total with different objectives or assumptions, namely RAROC maximization, risk-neutrality, risk-minimization, traditional risk aversion using the CVaR and the uncoordinated operation. [21]

A study comparable to Liu et al. was published by Moghaddam et al. who optimize the operation of a combined wind farm-cascade hydro system using the CVaR as risk-aversion criterion. Comparable with Gersema et al. a two-stage stochastic programming model is developed for profit maximization. The first stage decision contains the day-ahead bidding schedule. The second stage decision is related to the operation of the VPP in real time. As a result, Moghaddam et al. provide an optimal bidding strategy for the day-ahead market as well as for up- and down-regulation capacity. They find that the bidding strategy differs substantially conditional on imbalance penalty policies.[22]

In their study, Ekren et al. optimize a VPP consisting of photovoltaic (PV), wind energy and a battery storage with the main objective to reduce the system's cost. The study

[15] Cf. Gatzert and Kosub (2016).

[16] Cf. Noothout et al. (2016).

[17] Cf. Cleijne and Ruijgrok (2004).

[18] There exist studies which use usual hydro plants in VPPs or pumped hydroelectric storage. The latter represents also rather a storage.

[19] Cf. Pinson et al. (2009)

[20] Cf. Gersema and Wozabal (2016).

[21] Cf. Liu et al. (2015).

[22] Cf. Moghaddam et al. (2013).

provides a total system view approach trying to reduce the system's total cost by obtaining the optimal sizes of the VPP elements. The results indicate how investment costs should be distributed over PV, wind turbines, battery capacity and auxiliary energy sources at the optimum.[23]

Another study on wind power and battery storage is provided by Gönsch et al. who deal with the problem of time lagged commitments for RES. This study aims at providing a framework for maximizing profits under the condition of in-advance commitments. For modelling the problem of the decision when to sell and when to store energy as a Markov Decision Process, approximate dynamic programming is used. Calculations are applied for a case based on a community wind farm combined with a storage from the German supplier Bosch in northern Germany. Results show that even small battery storage with poor efficiency can increase profits substantially.[24]

A quite comprehensive study on grid integrated energy storages was published by Doetch et al. They distinguish between storages at producer level, at consumer level and storages in the grid as well as between three scenarios. At the producer level, they consider different purposes that storages can serve, namely marketing of electricity, mitigation of feed-in management, providing balancing energy and the EEG schedule. The scenarios represent different tariffs and a post-EEG scenario that relates to wind turbines older than 20 years for which generation companies do not get any tariff or premium anymore.[25] To assess the different applications of energy storages, the Generic Optimization Model for Energy Storage (GOMES) with a target function to maximize profit, is developed. The returns of the VPP applying the optimized storage is then compared with the reference returns of the operation without storage. Their model shows that in the post EEG scenario and the scenario with the low tariff, the returns with storage exceed the reference returns. These results are used to determine target investment costs for energy storage that show that for the post-EEG scenario, the storage is closest to economic efficiency.[26]

2.2. Research gap and starting point of the thesis

As shown in the previous section, extensive literature on the effect of energy storage in VPPs exists. There are existing studies with a risk-neutral as well as studies with a risk-averse perspective. Nevertheless, there is hardly any literature on the risk-averse operation of the specific combination of wind farms with batteries as energy storage. Furthermore, the studies mentioned do not include the investor's perspective by bringing together the optimized operation of the VPP with the effect on investment risk. This thesis addresses this research gap and make the leap to the cost of capital of wind farm investments. Unlike in the listed papers, no stochastic model will be developed. Instead, historical data from a wind farm and the electricity spot market are used to build a deterministic model. The objective of this model is to optimize the operation of the VPP, analyze the influence on the investment risk and make statements on the threshold values for cost of capital to cover the additional initial investment of the energy storage.

3. Battery storage in renewable energies

To reduce risk in investments there are different instruments. A transfer of risk is often possible via long-term electricity purchasing contracts. These kinds of contracts oblige one party to supply a predetermined amount of electricity at a predetermined price and the other party to buy this amount of electricity at the agreed upon price. This way both parties can protect themselves from electricity price volatility as well as the uncertainty about prices in the future and make their business more plannable. Another way of transferring risk in RES investments very similar to those in every business is insurance. Nevertheless, there are not a lot of specific insurances for uncertainties about future cash-flows. An insurance called "lack of wind cover" is offered by the Munich Re which covers a loss of profit in case of insufficient wind.[27] These risk transfer instruments are emphasized in section 8. Also support policies that provide certain revenues are a form of transferring risk from the electricity producer to the society as in most cases the electricity consumers are paying for the fixed tariff or the premium via levies.[28] The core idea of this thesis however is mitigating or at least reducing risk via combining wind turbines with energy storage as schematically shown in figure 1. A VPP consisting of a RES and an energy storage allows to store energy produced resulting in avoidance of mandatory electricity sales at the very time the energy is produced. Therefore, this combination provides more flexibility relating the point in time the energy is sold. Assuming sufficient storage capacities, the generation company can even decouple the supply profile entirely from the production.[29]

This section introduces and assesses different storage technologies for battery applications with RES. Subsequently, second-use batteries are emphasized and finally electricity arbitrage trading and the participation in the electricity balancing market as revenue generating strategies for grid-integrated batteries are analyzed.

3.1. Suitable battery technology

There are different types of energy storages and different ways to cluster them. One way to cluster them is by the way they store energy. Therefore, one could distinguish between mechanical, electrical, biological, electrochemical, thermal and chemical storages. An example for a mechanical storage is pumped hydroelectric energy storage, which

[23]Cf. Ekren and Ekren (2009).
[24]Cf. Gönsch and Hassler (2016).
[25]This however will be for post 2020. Details provided in section 5.2.3.
[26]Cf. Doetsch et al. (2011).
[27]Cf. Gatzert and Kosub (2016), p. 990.
[28]Cf. Noothout et al. (2016), p. 76.
[29]Cf. Rugolo and Aziz (2012), p. 7159.
[30]Own diagram based on Costa et al. (2008), p. 3.

Table 1: Literature on wind-battery virtual power plants; Source: Own table.

Author	Storage technology	Objective	Risk perspective
Pinson et al. (2009)	Not specified	Reduce imbalances, dynamic storage sizing to avoid under-utilization	risk-neutral
Gersema and Wozabal (2016)	None	Combination of RES for risk diversification	risk-averse
Liu et al. (2015)	Hydro	Optimize Hydro-Wind-VPP bidding strategy for generating companies	risk-averse
Moghaddam et al. (2013)	Hydro	Optimal profit-based risk-averse operation strategy for wind-hydro-VPP	risk-averse
Ekren and Ekren (2009)	Lead acid battery	Optimal sizing of wind-PV-battery-VPP components	risk-neutral
Gönsch and Hassler (2016)	Battery (not specified)	Profit-maximization considering time-lagged trading commitments	risk-neutral
Doetsch et al. (2011)	Battery (different technologies)	Multi-purpose grid integrated storage deployment (among others): Improve sales, provision of balancing power	risk-neutral
Costa et al. (2008)	Hydro	Increase profits and minimize imbalances of wind farms	risk-neutral
Barton et al. (2004)	Multiple, depending on strategy	Storage strategies to increase sales in limited grid connection conditions	risk-neutral

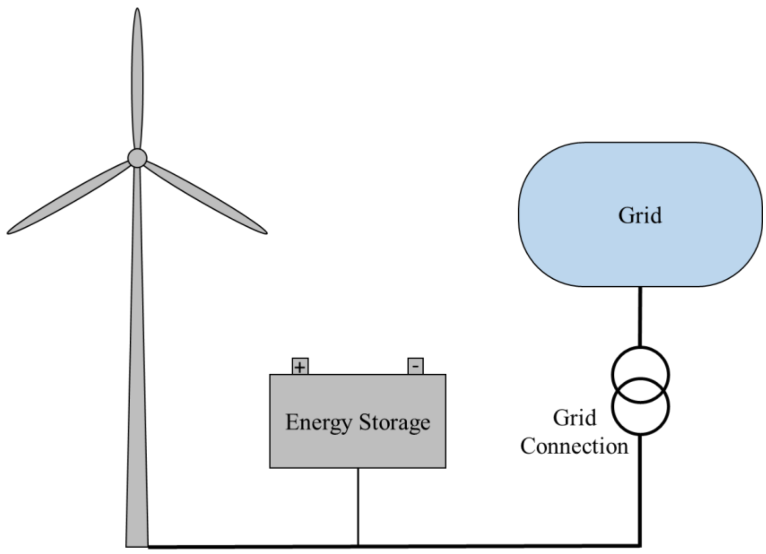

Figure 1: Combined wind-battery power plant [30]

is currently the by far most widely used grid integrated energy storage and already used in VPPs with RES nowadays.[31] Since some energy storages like e.g. pumped hydroelectric energy storage can only be realized in certain geographic conditions, electrochemical storage in the form of batteries is the chosen way to store energy used in this thesis.[32] A economic operation of big battery systems is still limited by high cost, scalability of the technologies and improvements are probably to result in a drop in costs for the future.[33]

Electrochemical storages in general consist of the actual chemical storage and an electrochemical converter which converts electric to chemical energy when charging and vice versa when discharging. Batteries can be distinguished between those with external and internal storage. The most

[31] Cf. Dunn et al. (2011), p. 928.
[32] Cf. Doetsch et al. (2011), p. 80.

[33] Cf. Dunn et al. (2011), p. 928.

commonly used batteries nowadays are systems with internal chemical storage like lead-acid, nickel-metal hydride (NiMH), lithium-ion or sodium-sulphur.[34] A increasingly arising technology with external chemical storages are redox-flow batteries which consist of two reservoirs with electrolyte solutions and a membrane between electrodes past which the fluids are pumped.[35]

In the following the main battery technologies will be introduced and respective advantages and disadvantages are addressed.

3.1.1. Lead acid batteries as a matured technology

Lead acid batteries consist of multiple cells which consist comparatively of a small number of components compared to other technologies. There is a spongy lead anode plate and cathode which is coated with lead dioxide and an insulating material used as separator in between the both electrodes. These components are placed within a plastic container which is flooded with an electrolyte consisting of a mixture of water and sulphuric acid. The separator allows the transport of the ions in the electrolyte between the electrodes and the accompanying conduction.

The biggest advantage of this technology is the high maturity level of this technology and the low-cost manufacturing. Lead acid battery capacity is the cheapest compared to other rechargeable cells. The technology is quite robust and tolerant to overcharging.

When it comes to disadvantages, the limited timespan in matters of cycles and the fact that these types of cells are not suitable for fast charging must be mentioned. Furthermore, there are some environmental issues with respect to the used materials like lead and acid.[36]

3.1.2. Characteristics of lithium ion batteries

Within a Lithium Ion battery the electrodes form host structures where the anode has a graphene structure and the cathode is a lithium-intercalation compound in a layer structure. By inserting or removing lithium ions in or from the electrodes' structure, the battery can be charged or discharged. When charging, lithium ions are removed from the layered intercalation compound and intercalated into the graphene structure and vice versa when discharging. An electrolyte which transports the lithium ions and separates the anode from the cathode is located in between the electrodes.[37]

A big advantage and the reason for its use in mobile applications is the high energy density and thus corresponding high specific energy and power.[38] Furthermore lithium ion batteries require relatively low maintenance and suffer significantly less from self-discharge compared to some other technologies. As a disadvantage the manufacturing of the cells still is expensive and the battery requires protection to ensure operation within safe limits as the technology is not as robust as comparable rechargeable technologies.[39] However, strongly decreasing prices are forecasted for this technology in the future.[40]

3.1.3. Introduction to redox-flow batteries

Flow batteries differ from other battery technologies as they do not have internal solid electrodes as energy storage. A redox-flow battery uses two electrolyte solutions which are stored in external tanks and pumped through the cell continuously. Inside the cell, an ion- selective membrane separates the two compartments where the two accordingly charged or discharged electrolyte solutions flow through. While redox-active ions undergo reduction or oxidation reactions when close to the electrode, non-reaction ions can still pass the membrane to ensures electrolyte balance.[41]

One big advantage of this technology is the independence between storage and converter when it comes to sizing. This is a difference to systems with an internal storage.[42] The modular structure allows smooth extensions of the storage capacity and is not limited in discharge depth like other technologies are. Furthermore, there is very little maintenance required.[43] Another advantage is the relatively simple electrode reaction compared to other batteries. Mentionable disadvantages are the necessity of pumps, reservoirs and sensors as well as the lack of technological maturity in comparison to other technologies.[44]

3.2. Potential of second-use electric vehicle batteries

Since the share of electric vehicles (EV) is increasing, multiple studies introduced the idea of using their integrated battery storages when connected to the grid.[45] Although using this service called vehicle-to-grid,for a VPP has advantages like a variable storage capacity and the mitigation of large initial investments, in this thesis stationary storing will be assessed due to simpler determination of storage cost.

Batteries suffer from slight capacity losses over time which is a major issue for application in EVs, since a high energy density is necessary. Nevertheless, these batteries are still suitable for stationary power storages as the mentioned capacity losses are not of major importance for this usage. A joint project of Daimler, the Mobility House, GETEC and REMONDIS shows the potential of second-use batteries. For this project 1,000 battery systems from used cars were retrofitted and combined to the worlds' largest second-use battery storage with a total capacity of 13 MWh. The task of this storage is to provide primary controlling power and the

[34] Cf. Doetsch et al. (2011), p. 64.
[35] Cf. Dunn et al. (2011), p. 933.
[36] Cf. Poole (2017a).
[37] Cf. Dunn et al. (2011) p. 930.
[38] Cf. Dunn et al. (2011) p. 930.
[39] Cf. Poole (2017b).
[40] Cf. D'Aprile et al. (2016).
[41] Cf. Dunn et al. (2011), p. 933.
[42] Cf. Doetsch et al. (2011), p. 64.
[43] Cf. Energiespeicher - Forschungsinitiative der Bundesregierung (2015).
[44] Cf. Dunn et al. (2011), p. 933.
[45] Cf. e.g. Kempton and Tomić (2005); Lassila et al. (2012); Vasirani et al. (2013).

batteries are estimated to be cost-efficient in this operation for at least ten years.[46]

3.3. Arbitrage trading and provision of grid services with battery storages

Energy arbitrage trading represents the strategy to make use of the spread between electricity prices at different times. Revenues are generated by charging the battery with bought energy at low prices and selling, which consequently equals discharging the storage in periods of high prices.[47] The time horizon for electricity arbitrage trading however is restricted due to technological characteristics and capacity. This means that high capacity storages like a large- scale pumped hydro may benefit from more long-term spreads such as the weekly load pattern. This spread is affected by the difference in demand between working days and weekends. However, batteries discharge over shorter time and are more applicable to time horizons in arbitrage trading within one single day. This implies revenue generation by taking advantage of the differences between on-peak and off-peak periods during the day.[48] The increasing market penetration of RES influences the electricity price spread. Whereas PV produces electricity during the day-time and consequently is lowering the peak prices, the wind power feed-in pattern is less systematic and is increasing the spread.[49] Nevertheless, the revenues generated by electricity arbitrage trading nowadays are too low to cover the cost of an appropriate battery storage.[50]

Furthermore, it is conceivable to generate revenues by providing services to the grid using a battery storage. Services that can be provided by energy storages include e.g. the provision of electric supply capacity, reserves or frequency regulation. Providing electric supply capacity aims at reducing system peaks by shifting electricity depending on demand. This can possibly replace specific plants which are solely operated to ensure power supply during peak hours. The supply of reserves covers generation and demand deviations to ensure grid stability.[51] This also includes fast-responsive capacities which must be available within ten minutes to compensate outages of generation or transmission facilities. Reserve that is available to sustain the system's frequency needs to respond within ten seconds.[52] By providing the listed services, revenue streams can be generated.[53]

These revenue generating strategies are just emphasized to point out that there are additional ways of operating grid integrated energy storages. However, the focus in this theses is the deployment in terms of a VPP to stabilize revenues and reduce risk.

[46]Cf. The Mobility House (2016).
[47]Cf. Salles et al. (2016), p. 1.
[48]Cf. Staffell and Rustomji (2016), pp. 213, 215.
[49]Cf. Staffell and Rustomji (2016), p. 2013.
[50]Cf. Staffell and Rustomji (2016), p. 224.
[51]Cf. Günter and Marinopoulos (2016), p. 227.
[52]Cf. Eyer and Corey (2010), p. 31.
[53]Cf. Günter and Marinopoulos (2016), p. 234.

4. Renewable energy policy and support schemes

As mentioned in the introduction, to reach defined green house gas emission goals, the share of RES in the energy market certainly has to increase significantly. Since the market mechanisms itself would fail to deliver the required share of RES, authorities need to intervene.[54] In Europe, the respective countries specify the applied support schemes with guidance by the European Commission.[55]

The principles of support schemes are generally distinguished between investment-based and generation-based support. For investment-based support schemes, investments are subsidized in the form of e.g. tax reductions or soft loans. Generation-based support instruments have the task to reduce price and quantity risk of RES.[56] The latter instruments are crucial for the market- integration of RES since they address the address the market risk. Consequently, it is not further elaborated on investment-focused support. Figure 2 provides an overview of the different support schemes and ranks them in order to the accompanying price risk. Additionally to the different support schemes, this section briefly covers the topic of balancing responsibility and curtailment.

The first group of support schemes shown in figure 2 are the feed-in tariffs (FIT). For the fixed price FIT, RES operators receive a fixed tariff that is independent of the market price movement. This leads to the lowest, theoretically nonexistent price risk. This ensures predictable, stable revenues since a constant tariff is usually provided over the project's predefined lifetime.[58] In some countries the tariff FIT is not completely fixed but varying with season or time of the day. However, weather dependent RES like wind are exempted from these constraints.[59]

The second group are premiums. The latter are more market-oriented compared to FIT since power producers participate in the market and receive a premium paid on top of the wholesale price. The allowance of market signals is a substantial advantage of premium systems since it gives incentives to feed in energy when prices and thus demand is high.[60] The height of the premiums can be fixed or sliding. However, the latter has the lower price risk since it smoothens the total remuneration compared to the volatility of the market prices whereas fixed premiums pass on the price profile.[61] For sliding feed-in premiums, the RES producer gets the difference between the spot price (for which the electricity is marketed) and a guaranteed price. This implies that the premium is zero when the market price equals or exceeds the strike price. Therefore, the price risk of a sliding feed-in premium is comparably low. Nevertheless, the electricity producer has to participate in the market. As a consequence,

[54]Cf. European Commission (2013), p. 3.
[55]Cf. European Commission (2017).
[56]Cf. Binda Zane et al. (2012), p. 79.
[57]Figure from Binda Zane et al. (2012), p. 79.
[58]Cf. Noothout et al. (2016), p. 51.
[59]Cf. Binda Zane et al. (2012), p. 81.
[60]Cf. Klessmann et al. (2008), p. 3656.
[61]Cf. Binda Zane et al. (2012), p. 81.

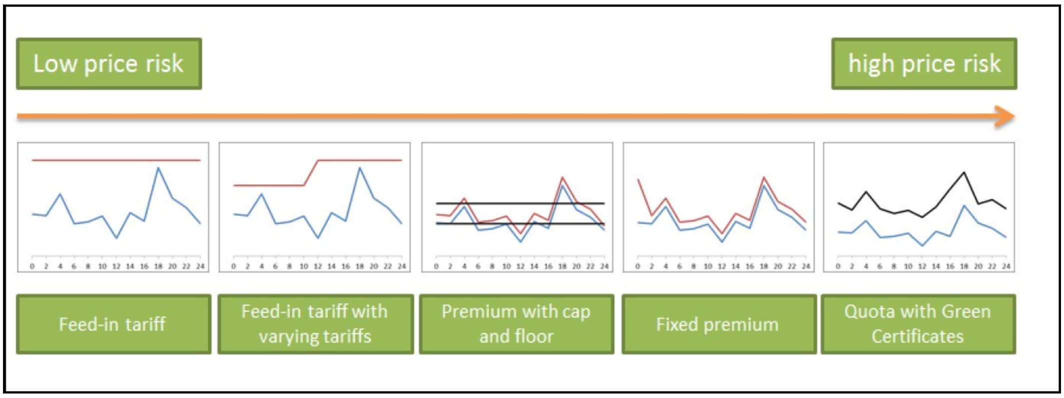

Figure 2: Support schemes with classification of the accompanying price risk[57]

other requirements like forecasting the feed-in quantity have to be met.[62]

Further forms of sliding premiums exist where e.g. no premium is paid when negative electricity market prices occur. This transmits the explicit market signal of supply surplus.[63] Another type of premium is the cap-and-floor premium shown in figure 2. This scheme has an increased price risk compared to regular sliding feed-in premiums since premiums are fixed for market prices within a certain range, limited by the cap and the floor. For the case that market prices rise to a level where the total remuneration, consisting of the market price plus the premium, would exceed the cap, the premium is decreased to limit the remuneration to the price cap. If the market price itself goes beyond this cap price, no premium at all is paid. However, the pre-defined floor price guarantees a certain minimum revenue.[64] This support strategy limits the price risk on the one hand but also profits on the other hand.[65]

Fixed premiums are independent from the market price and bear the highest price risk among the feed-in premium support schemes. They transmit fluctuations of market prices directly to revenues. The consequences are uncertain and unstable cash flows levels allowing for high profits or losses.[66]

Next to feed-in support schemes, quota regulations exist. The latter result from the definition of a certain minimum quota of RES an electricity supplier must have in its energy mix. These quotas can be technology specific to stimulate the expansion of particular technologies. In addition to the market price, RES producers receive renewable energy certificates for sold units which can be traded on a specific market. This leads to a total remuneration dependent to both, price fluctuations from the electricity market and the green certificate market. The comparatively high price risk results from the dependence on two independent market price risks.[67]

Some countries like Germany have a priority feed-in policy for electricity from RES. This leads to the fact that in a competitive market, renewable energy is preferred over electricity from other sources. As a result, producers of electricity from RES can be certain that their energy is bought.[68] Nonetheless, there are plans of the German government of partially eliminating the priority feed-in policy in Germany to level the playing field for all energy sources.[69] Other countries like Estonia or Finland do not even have this policy. Without priority dispatch, operators face uncertainty of finding a counterparty in the competitive market that buys the produced electricity. The risk of not being able to sell the output and be curtailed instead is called volume risk.[70]

Policies also specify the responsibilities for participating in the market. The two key types of energy markets are the spot market and the balancing market. Usually 12 - 48 hours in advance, supply and demand bids must be submitted in the spot market and by finding the equilibrium, the prices are determined for a whole day consisting of 24 hours. For the case that the forecasts, which the supply bids are based on are not met, the deviation between supply and demand must be regulated at the balancing market.[71] Since especially wind is intermittent, the balancing risk is another substantial risk for RES operators. This arises due to the obligation forecasting the amount of electricity that will be fed into the grid which equals the planned production. For deviations from the forecast, penalties apply or energy has to be bought from the balancing market. Plant operators often pass on the balancing responsibility to transmission system operators which charge a specific margin for underwriting this risk. However, in several countries, intermittent RES are exempt from the balancing responsibility.[72]

However, countries handle support schemes and exemptions differently. Sometimes, specific support schemes are only open to generators up to a certain size and support pe-

[62] Cf. Noothout et al. (2016), p. 52.
[63] Cf. Noothout et al. (2016), p. 51.
[64] Cf. Binda Zane et al. (2012), p. 82.
[65] Cf. Klessmann et al. (2008), p. 3656.
[66] Cf. Noothout et al. (2016), p. 52.
[67] Cf. Binda Zane et al. (2012), pp. 82-83; Klessmann et al. (2008), p. 3565.
[68] Cf. Binda Zane et al. (2012), p. 84.
[69] Cf. Becker (2016).
[70] Cf. Binda Zane et al. (2012), p. 84.
[71] Cf. Krohn et al. (2009), p. 93.
[72] Cf. Binda Zane et al. (2012), pp. 84-86.

riods can vary. Furthermore, countries exist, where generators can choose between different subsidy forms. The support schemes usually evolve and are adjusted after a while.[73]

The mentioned policies for RES reduce risks coming from market prices, volume or balancing substantially. However, RES technologies have matured and are getting more grid-competitive. To reach the aimed renewables' share in a cost-effective way, the mentioned exemptions and financial support schemes are planned to be phased out.[74] As a consequence, RES generators will be increasingly exposed to market risks in the future.

5. Risks in renewable energy investments

The following chapter firstly emphasizes risks in RES investments in general and outlines why exposure to the electricity market is crucial. The second part demonstrates circumstances which lead to advanced market volatility dependence.

5.1. Risk categories and ranking

In literature, there are some studies on risks in RES investments which cluster possible risks in categories as shown in table 1. The classifications and definitions of the categories are slightly different. Nevertheless, policy and regulatory risks seem to be among the most pressing concerns in these studies.

Policy design risk is very important as the height and the calculability of the projects' returns strongly depend on the support schemes provided from the government. Investors of RES projects rely on specific support schemes and policies like those introduced in the section above. The financial support usually is guaranteed over a predetermined timeframe which can e.g. be 20 years. The returns of an investment often are planned based on promised subsidies.

The situation in Spain showed the importance of this risk. Policies and support schemes were retrospectively changed. Consequently, the RES investments did not have the expected returns with which they calculated and which were considered as safe. These policy actions resulted in distrust about the politics which lead to defaulted wind energy funds. Furthermore, a period without any new investments in RES and a high cost of capital for investments occurred.[75]

A case like this is quite unlikely in countries like Germany, where the policy support schemes are anchored in law like the German Renewable Energy Sources Act (EEG). This beneficially influences the cost of capital which is consequently comparably low.[76]

The crucial about regulatory risk compared to e.g. technological risk is that there are hardly any internal measures to mitigate this risk. Only policy makers influence it.[77]

[73]Cf. Krohn et al. (2009), pp. 81-86.
[74]Cf. European Commission (2014), section 3.3.
[75]Cf. Noothout et al. (2016), p. 148 f.
[76]Cf. Noothout et al. (2016), p. 3.
[77]Cf. Gatzert and Kosub (2016), p. 996.

Changes in governments' priorities and accompanying changes in budgets can result in modifications of RES support. As these priorities are a political issue and may change over time, there is uncertainty about prospective support as well as retrospective adjustments like happened in Spain.[78]

The nature of policy design risk will probably change in the future as RES are expected to reach grid-competitiveness by 2030. To get a transition to a cost-effective energy delivery, RES must compete in the market and support schemes like feed-in tariffs or exemptions from balancing responsibilities have to be phased out.[79] With absence of support, intermittent RES have to be marketed directly, which leads to penalties for imbalances and deviations from the prediction. Furthermore, variable revenues occur due to price volatility. These changes of state-aid are of special relevance if no or not sufficient energy storage is available. This may lead to mandatory energy sales at low prices.[80]

Consequently, an energy storage cannot reduce the policy or regulatory risk itself. But these risks however are clearly related to the market or sales risk, which RES are more exposed to without or with instable support schemes. This means that a wind farm whose support scheme is abolished retrospectively thereafter is exposed to volatile market prices. Nevertheless, the market price volatility is not the only variability factor of the revenues of a wind farm. As the revenue consists of both, the quantity of electricity sold and the market price at this point in time, the wind speed fluctuations and the accompanying intermittency of output represent another variability in the revenues. Aside from short-term wind speed fluctuations there are also variabilities in the overall annual wind. The deviations of a single year wind yield from the long-term average can be substantial. Nevertheless, debt lenders and investors still demand their interests or returns, even in poor years regarding wind yield.[81] The mentioned price and output volatilities however, are not independent from each other but related. Since the share of wind energy increases, there is a strong supply surplus in windy areas or at windy times, resulting in depressed market prices.[82] There appears to be a tendency to negative correlation between market prices and available wind speeds which means low prices if there is a lot of electricity from wind to be marketed and vice versa.[83] Concluding it can be stated that the price variance is increasing for an increasing amount of RES installed.[84]

However, aside from the risk of increasing exposure to the market and output fluctuations due to policy changes, there are already nowadays application cases for storage capabilities. These cases are e.g. direct marketing under feed-in premiums, where higher revenues might be generated using a storage. Another case is post-support operation, which

[78]Cf. Gatzert and Kosub (2016), p. 995.
[79]Cf. European Commission (2014), p. section 3.3.1.
[80]Cf. Gatzert and Kosub (2016), p. 984.
[81]Cf. Rathmann et al. (2011), p. 75.
[82]Cf. Hirth (2015), p. 156.
[83]Cf. Sioshansi (2011), pp. 1-2.
[84]Cf. Wozabal et al. (2016), p. 705.

Table 2: Risk categorization; Source: Own table based on Noothout et al. (2016), p. 21; Gatzert and Kosub (2016), p. 984; Cleijne and Ruijgrok (2004), p. 15.

DiaCore	Gatzert	Green-X
Social acceptance risk	Strategic/business risk	Operational risk
Administrative risk	Transport/construction/completion	Product market risk
Financing Risk	Operation/maintenance	Input risk
Technical \& management risk	Liability/legal risk	Regulatory risk
Grid access risk	Market/sales risks	Financial risk
Policy design risk	Counterparty risk	
Market design \& regulatory risk	Political, policy, regulatory risks	
Sudden policy change risk		

means continued operation of wind turbines after the period of state aid.

5.2. Dependence on electricity market prices as a major risk

Being dependent on market prices implies variability in returns and consequently represents a pressing risk for both, RES operators and investors. The following section shows in which ways RES are increasingly exposed to market price fluctuations as a result of the targeted market integration of RES. Additionally, it is discussed, in which way an energy storage can offer a certain additional value to a wind farm.

5.2.1. Declining subsidies for renewable energy

To make RES more cost-effective, the European Commission wants subsidies in any form to be phased out in a degressive way in the future. Renewable energy is wanted to be integrated in the energy market as these sources of energy will be grid-competitive in the future.[85] To represent the maturing and learning of the technologies and to avoid overcompensation, there are predefined degression steps for the paid premiums or tariffs.[86] Furthermore, competitive bidding process as market instrument for market-premiums in direct marketing is introduced in Germany in the latest Act on the Development of Renewable Energy Sources for 2017. This means that only the RES operator with the lowest bid will get the market-premium.[87] Besides the goal of more cost-effective RES through more competition, competitive bidding helps for better plannability of capacity added. This is becoming more important as there are already sometimes bottlenecks in the power grid.[88] This application of tenders is one further step of phasing out the support provided by the government in form of feed-in premiums.

In the course of the market integration, there are also plans to cut the privilege of priority feed- in for RES.[89] A combination of a battery with a wind farm could be the technological advantage to operate a wind farm more efficiently compared to standalone plants and therefore enable operation with less financial support. Consequently, this can lead to being awarded for the state- aid under a tender scheme with competitive bidding.

The almost grid competitive RES will probably not get any subsidies in the more distant future. Additionally, operators will have to deal with trading their energy at the electricity market. When being completely exposed to the market, an energy storage likely can improve revenues of a plant by shifting the feeding in of produced electricity from a low-price period to a time with higher prices. The added value of a storage increases with more volatile market prices. This is due to the fact that the additional revenues represent the price spread multiplied with the given quantity and subtracted the losses due to storing.

5.2.2. Dependence on price volatility through direct marketing

One way of selling produced energy is e.g. the direct marketing in Germany according the section 34 of the RES Act.[90] Other than for FIT, direct marketing means that the energy producer sells energy directly and gets paid a market premium. The height of the market premium equals the difference of the average electricity price and a fixed feed-in tariff which is granted to older and small plants. The electricity price average is usually multiplied with a different profile factor for different RES.[91] Consequently, RES operators marketing their energy directly are supposed to have the same height of revenues in average as with fixed feed-in tariffs. Assuming, the operator would be able to store energy produced in low electricity price periods and sell it at a later point in time for a higher price, its average price at which sold its electricity is sold is higher than the markets' average price in the same month. Since the operator receives the

[85]Cf. European Commission (2014), p. section 3.3.1.
[86]Cf. Held et al. (2014), p. 5.
[87]Cf. Bundesministerium für Wirtschaft und Energie (2016), p. 6.
[88]Cf. Bundesministerium für Wirtschaft und Energie (2016), pp. 13, 14.
[89]Cf. Becker (2016).
[90]RES Act in Germany is the EEG.
[91]Cf. Nicola (2017a).

same market premium as other operators who do not have the possibility to store energy, higher revenues will be generated. Using this output controlling strategy, revenues can even exceed the fixed feed-in tariff level. Figure 3 illustrates, how a RES operator can increase its total remuneration at a premium that is fitted to the overall average market prices by increasing his average market price at which the electricity was sold. Of course, this approach is limited in some matter as the month' average electricity price which is used to determine the market premium will change if more RES operator use a storage strategy.

As mentioned in section 3, for receiving feed-in premiums, operators need to market their output. This usually is accompanied by balancing responsibility as every market participant must forecast the quantity feeding in and balance arising deviations. RES operators can transfer the balancing risk to direct marketers. This is done regularly as self-balancing is challenging for intermittent RES. The direct marketers assume the balancing responsibility e.g. by marketing electricity for a network consisting of multiple plants which leads to lower balancing needs. This third party, namely the direct marketers usually ask for a margin about 0.2 euro cents per kWh.[93] For the time between 2013 and 2015 the overall average electricity price at the day-ahead spot market was around 34 € .[94] Consequently, about 6 % of the electricity price in average represent the margin that has to be paid for marketing.[95] By using an energy storage, a wind farm is likely to be able to self-balance the output and therefore save some of these expenses.

5.2.3. Post support operation

Another scenario in which wind turbine operators are dependent on the market mechanisms is the post support operation. This describes the operation of a wind park after the period in which incentives or a sort of subsidies from the government are granted. As an example, the guaranteed duration of governmental support in Germany is 20 years.[96] Since the extension of wind energy took place in the nineties, the topic of post support operation will gain in importance in the upcoming years. In 2016, more than 7,000 wind power turbines in Germany reached an age between 15 and 20 years. This number will even increase and in 2019 there will be more than 10,000 reaching this age.[97] Due to the fact that the first EEG in Germany came into force in 2000 and all wind power turbines that already operated before this year were also guaranteed 20 years of state-aid from the year 2000 on, the financial support will expire for a significant number of plants in the end of 2020. This number is assumed to lie between 5,600 and 7,000 wind power turbines in Germany. Furthermore, there will be about 1,600 wind power turbines with support period expiring at each of the following years.[98]

For Germany, wind power plants are designed and planned to operate for 20 years. Although, plants which started operation before 2000 will get the promotion further on, there has to be a report which certifies that continuing operation is possible without any concern. Apart from this certification, there are further requirements to meet which result in additional cost.[99] As investments like RES are normally depreciated over a long span of time e.g. 15 years, older wind turbines can often draw from their full economic potential. Having a wind farm which is completely depreciated makes a continued operation even more attractive.[100] Fully depreciated plants can generate cheap electricity. Nonetheless, arising expenses for operation including lease, insurances, maintenance must be covered by the revenues. If this is the case, depends on the evolution of the electricity market prices in the first hand. For continuously low prices and imperfect circumstances of a project, an economically feasible operation after 2020 is probably not possible.[101]

Considering the deployment of an energy storage in combination with a post-support wind farm to shift produced energy to periods with sufficiently high prices can possibly make the continued operation reasonable.

6. Revenue volatility and its influence on cost of capital in theory

Projects in wind energy have a characteristic cash flow course which is displayed in figure 4. At the beginning of a project, the initial investment such as development expenditures and construction cost is required. During the operation, energy sales minus operational cost, interest, tax and the repayment rates represent the free cash flow. Finally, decommissioning expenses arise at the lifetime's end. This curve provides the baseline for a project's valuation.

Valuing projects as basis of decision-making is often based on the project's Net Present Value (NPV). This performance indicator is based on the concept of time value of money. The latter states that a certain amount of money today is worth more than the same amount in the future. This is due to losing the opportunity of earning interest for alternatively investing this money during the project's period.[103] The NPV can be calculated by using the Discounted Cash Flow (DCF) method. For this method, future cash flows are projected and discounted with a discount rate and offset with the initial investment of the project.[104] The difference between the

[92] Own figure.
[93] Cf. Wallasch et al. (2015), p. 19.
[94] Based on EPEX Spot Day-Ahead prices for 2013 – 2015.
[95] The real cost of marketing depend also on factors like park size, location, contract term (Cf. Wallasch et al. (2015), p. 19).
[96] Cf. Nicola (2017b).
[97] Cf. Wind-Turbine (2016a).
[98] Cf. Wallasch et al. (2015), pp. 1-2.
[99] Cf. Wallasch et al. (2015), pp. 6-9.
[100] Cf. Wind-Turbine (2016b).
[101] Cf. Wallasch et al. (2015), pp. 30-32.
[102] Figure from Noothout et al. (2016), p. 59; DEVEX stands for Development expenditures and equals the development cost; CAPEX, the capital expenditure, is the initial investment; OPEX are operational expenses that arise in relation to the operation.
[103] Cf. Welch (2009), p. 18.
[104] Cf. Wall Street Oasis (n.d.).

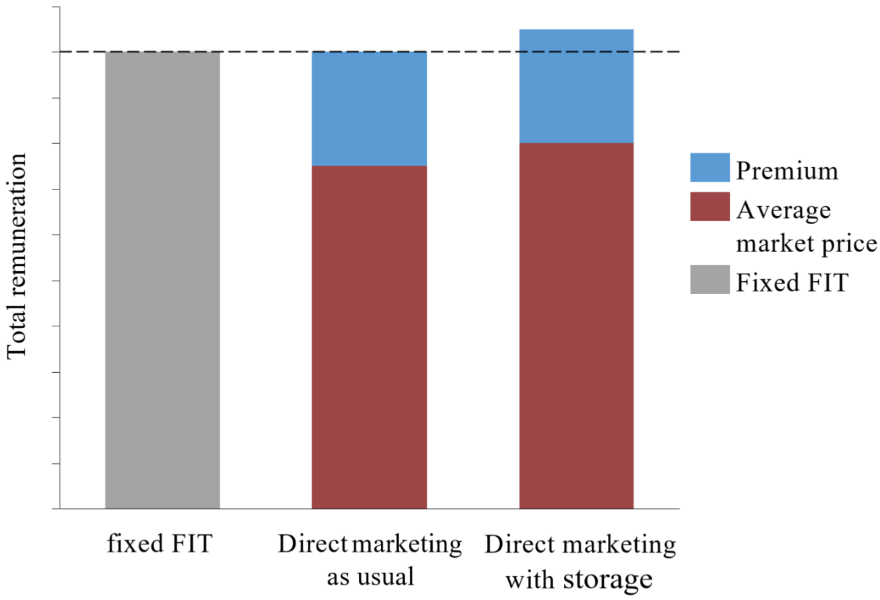

Figure 3: Comparison of total remuneration with and without storage[92]

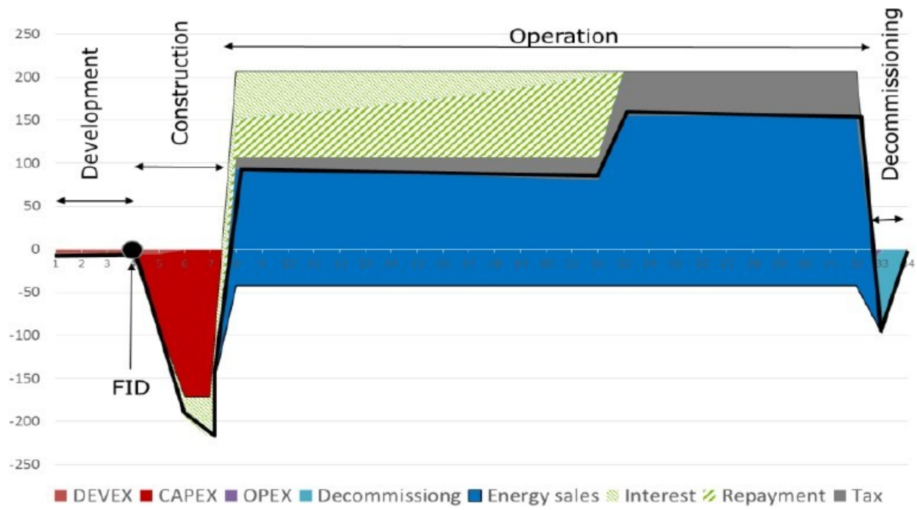

Figure 4: Characteristic cash flow of a wind energy project[102]

Present Value (PV) and the NPV only lies in the consideration of the initial investment for the NPV which usually is a negative upfront cash flow.[105] The NPV is calculated the following way[106]

$$NPV = C_0 + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} \tag{1}$$

C_0 represents the initial investment at $t = 0$, and is for this reason usually a negative figure. The sum of the discounted cash flows for the respective periods from $t = 1$ to the project's last period T is added to C_0. $(1 + r)^t$ is the applied discount factor and R is the discount rate which reflects the project's cost of capital. This implies that a project with lower cost of capital can result in a higher NPV than another project with the same cash flow projections. The commonly used method to determine the cost of capital is the WACC. The latter weights the cost of equity and cost of debt with a project's financing structure. A project often is financed both, by equity from investors and debt from banks or lenders. The following formula shows the calculation of the WACC[107]

$$WACC = (r_d * 1 - T)) * \frac{D}{D+E} * r_e * \frac{E}{E+D} \tag{2}$$

[105] Cf. Welch (2009), p. 35.
[106] Based on Welch (2009), p. 35.
[107] Based on Rosenbaum and Pearl (2013), p. 151.

where r_d = cost of debt

r_e = cost of equity

T = marginal tax rate

D = marketvalue of debt

E = marketvalue of equity

Expressed in words, the WACC is adding the components of cost of equity for the equity share and the cost of debt for the debt share. Therefore, $\frac{D}{D+E}$ represents the share of debt and $\frac{E}{D+E}$ the share of equity in the capital structure. These are the weights for averaging the cost of capital. Furthermore, the interest payment for debt r_d is considered as expense and consequently tax deductible which has a lowering effect on the WACC.[108] If a project is 100 % equity financed, the WACC consequently equals the cost of equity and vice versa for debt financed projects.

When calculating the WACC, the project's marginal tax rate as well as the capital structure are usually given. For new projects, an optimal target capital structure can be determined.[109] A study that analyzed debt-to-equity ratios across Europe found that countries with comparably low-risk environments allow for higher debt ratios. According to this study the ratios reach from 50/50 in eastern European countries like Romania and Bulgaria up to 80/20 in countries like France, Germany or Denmark.[110] Generally speaking debt is the cheaper form of capital compared to equity.[111] This is due to the fact that debt is paid off first in the case of financial distress when assets have to be liquidated.[112] The tax deductibility of cost of debt makes debt even more attractive. Therefore, a higher share of debt usually decreases the WACC. In theory, the WACC decreases with an increasing proportion of debt up to a threshold value where the optimal capital structure is reached. Beyond this critical ratio the debt share is so high that financial distress becomes more likely. Consequently, debt lenders as well as equity providers will likely demand for higher interest since risk increases.[113] Therefore, the risk assessment of projects determines which debt ratios are allowed at which interest rates. Knowing the fact that debt has lower cost compared to equity, high debt ratios like in Germany or Denmark are highly beneficial for financing RES projects.[114]

With a defined marginal tax rate and debt-to-equity ratio the cost of debt and the cost of equity must be determined in the next step. Since the cost of equity represents the investors risk perception, it can be used as investment risk proxy.[115] The height of these cost can vary across different investors even within the same project. Furthermore, it is implicit and therefore not observable like the interest rate for debt.[116] To determine the cost of equity, the Capital Asset Pricing Model (CAPM) is often used. For the latter, the cost of equity equals the expected return from the investors perspective. The calculation of the cost of equity r_e according the CAPM can be seen in (3)[117].

$$r_e = r_f + \beta(r_m - r_f) \tag{3}$$

where r_f = risk-free interest rate

β = Beta

r_m = expected market return

$(r_m - r_f)$ = market risk premium

The risk-free rate represents the expected payoff from an investment which is considered as risk-less. Usually defined as risk-free are investments where neither default risk nor uncertainty about reinvestment rates exist. An usually applied proxy for the risk-free rate are U.S. government bonds.[118] The market risk premium corresponds to the spread between the expected return on a market portfolio and the risk-free rate. Since investors usually are risk averse, higher returns are expected when investing in the market compared to the risk-free rate. The expected market return can be deduced from surveys, historical data or current market data.[119] Widely applied for the market return are stock market indexes like the Dow Jones' Standard & Poor's 500 for the U.S.[120]

The last missing and in literature most frequently discussed parameter for calculating the cost of equity is the beta. It provides information about the project's risk compared to the market portfolio's risk, also called systematic risk. A straightforward way of calculating beta starts with computing the covariance of the returns of a project i with the market portfolio m, Cov_{im}. In the next step this covariance is divided by the variance of the market portfolio σ_m^2 as displayed in (4).[121]

$$\beta_i = \frac{Cov_{im}}{\sigma_m^2} \tag{4}$$

Another way of calculating beta is by a linear regression. When regressing the asset's returns against the market portfolio's returns, beta represents the slope of linear regression.[122] The resulting beta will be higher than one for assets that are riskier, and below one for assets that are less risky than the market portfolio average. This implies that a project with a beta of one bears the same risk as the market portfolio and that a risk-less asset has a beta of zero.[123] However, this way of calculating beta uses historical returns which are not publicly available for private companies.

[108]Cf. Damodaran (2006), p. 52.
[109]Cf. Rosenbaum and Pearl (2013), p. 152.
[110]Cf. Noothout et al. (2016), pp. 41-42.
[111]Cf. Modigliani and Miller (1958), pp. 295-296.
[112]Cf. Damodaran (2006), p. 612.
[113]Cf. Rosenbaum and Pearl (2013), p. 152.
[114] Cf. Noothout et al. (2016), p. 41.
[115]Cf. Noothout et al. (2016), p. 23.
[116]Cf. Damodaran (2006), p. 28.
[117]Based on Fama and French (2004) and Rosenbaum and Pearl (2013), p. 154.
[118]Cf. Damodaran (2006), p. 35.
[119]Cf. Damodaran (2006), p. 38.
[120]Cf. Rosenbaum and Pearl (2013), p. 155.
[121]Cf. Damodaran (2006), p. 32.
[122]Cf. Damodaran (2006), p. 48.
[123]Cf. Rosenbaum and Pearl (2013), p. 156.

The fact that this calculation of beta only takes the volatility of the returns into account has led to further research on methods for determining the cost of equity. As an example, the Fama- French three-factor-model incorporates the market capitalization and the book-to-market ratio to the stock's or in this case project's returns.[124] Nevertheless, for this thesis it is not necessary to dig deeper into calculation methods for cost of equity as the introduced theory already provides clear evidence that they are significantly influenced by volatile revenues. The level of cost of equity for onshore wind projects differs substantially across Europe from very low rates between 6 % and 9 % in Germany up to 16 % to 18 % in Romania or 15 % to 20 % in Estonia.[125]

The other share of the WACC apart from the cost of equity is the cost of debt. The latter quantifies the interest rate banks or private lenders demand for borrowing money. As abovementioned, debt is the cheaper type of financing compared to equity since debt lenders are served first in the case of financial failure.[126] For calculating the cost of debt, there is no commonly used method like the CAPM. In general, the cost of debt depends on a company's default risk. The latter is determined by the height of the project's generated cash flows in relation to its obligations and the stability of these cash flows. This implies that companies with high financial obligations and low but volatile cash flows end up having a high default risk. Due to this fact, high stability and predictability of the business a corporation operates in influence the default risk in a positive way. The default risk can be measured most easily if the company has outstanding bonds that are rated by independent rating agencies.[127] In general, the cost of debt is the sum of the risk-free rate and a credit risk rate representing a default premium.[128] Often the cost of debt and therefore the height of the interest the lender asks for is assessed qualitatively by consulting debt capital market specialists.[129] Investors name three main influencing factors on cost of debt, namely the investment risk for the specific industry, general country risk and the degree of competition between debtors.[130] Another factor significantly influencing the cost of debt is the competition between potential creditors for particularly attractive projects. This can e.g. be a RES project in a country like Germany. The cost of debt for the example of onshore wind investments varies substantially within Europe from countries like Greece where lenders demand between 8.5 % and 12.5 % to Germany where very low interest rates from 1.8 % to 3.2 % prevail.[131]

However, the introduced RES support schemes like FITs tend to lever out market risk almost completely leading to the perception of RES projects as secure long-term investments.[132] Nevertheless, with elimination or reduction of governmental support the exposure to volatile electricity prices increases. In combination with the intermittency of the output, proper predictions on future returns probably become almost unmanageable. The resulting volatility of the expected cash flows represents an investment risk. According to the above introduced factors influencing the cost of capital, this volatility and uncertainty of revenues is reflected by a higher cost of capital.

7. Economic feasibility case study

In this section, a case study is conducted to analyze the influence an energy storage has on the investment risk for wind energy projects. The following model is developed to investigate the application of an energy storage for a case where no subsidies for RES are provided. This would correspond to a post support scenario. The aim is to test if the hypothesis that a battery can reduce the investment risk of a wind park holds true for the chosen case. Furthermore, threshold values that allow an economically feasible operation of such an VPP are identified.

7.1. Methodology

For the task of this analysis, a stochastic or a deterministic model can be used. For deterministic models, the future is predictable and the result is reproducible due to predetermined input values. Stochastic models however are based on probability theory. Statistics build the input values and the results are distributions, consequently not reproducible.[133] The following base model is implemented in a deterministic way since this makes it easier to understand compared to a stochastic model. Hence, this model is more likely to gain wider acceptance, especially for practical application.[134] As a consequence of its complexity, stochastic modeling requires increased computational effort, therefore advanced software. Nevertheless, Scenario testing in combination with the deterministic model includes uncertainties, provides a distribution instead of an absolute value as a result and thus will allow risk assessment.

The present model consists of the four steps displayed in figure 5. At first, the operation of a wind-battery VPP is optimized regarding cash flows. Secondly, Monte Carlo scenarios are generated and evaluated. Subsequently, risk figures of the operation with and without a storage are compared. In the fourth and final step, the sensitivities are checked and critical values are identified at which the operation of such an VPP would become profitable.

To go into detail, in the first step, the operation of the VPP is optimized in a risk-neutral way. The optimization aims at maximizing the cash flows. For this purpose, constraints like

[124] Cf. Fama and French (1992), p. 451.
[125] Cf. Noothout et al. (2016), p. 44.
[126] Cf. Damodaran (2006), p. 612.
[127] Cf. Damodaran (2006), p. 64.
[128] Cf. Bishop and Officer (2013), p. 5.
[129] Cf. Rosenbaum and Pearl (2013), pp. 153-154.
[130] Cf. Noothout et al. (2016), p. 3.
[131] Cf. Noothout et al. (2016), pp. 40, 43.
[132] Cf. Noothout et al. (2016), p. 43.
[133] Cf. Rottmann et al. (n.d.).
[134] Cf. Cummins et al. (1999), p. 424.
[135] Own figure.

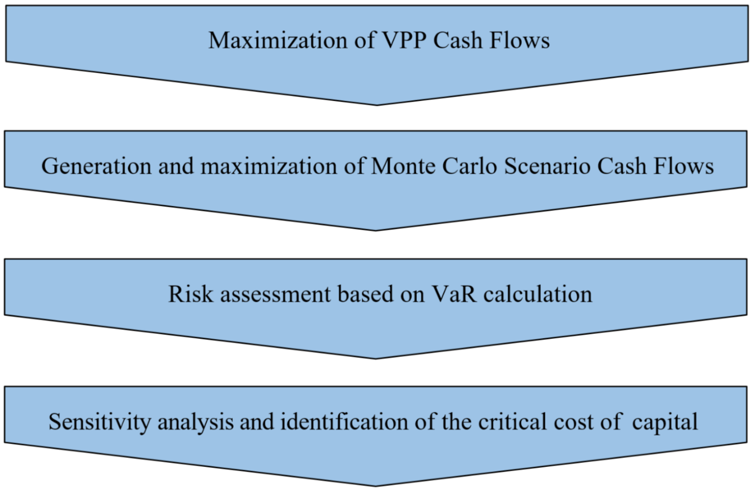

Figure 5: Steps of the developed model[135]

capacity, power and efficiency degree of the battery must be defined. The model uses wind park output and electricity price data to develop a strategy, when to store and when to sell the produced energy directly. In order to optimize the operation of the VPP, a time horizon must be set. Fluctuations in prices and wind yield between different times of the day, workdays and weekends, different seasons and even between years exist. However, strategies for long time horizons like smoothening seasonal price and wind yield fluctuations would require huge capacities. This tends to be a case for large long-term storage capabilities like large hydro storages. As this thesis analyzes the impact of a battery storage in combination with wind, one day in terms of 24 hours was chosen as time horizon. This is due to the characteristics of battery technologies that include full power durations in this application below 24 hours.[136]

The objective function of this optimization is stated in (5). P_d is the power which is directly sold, when produced, whereas P_{st} is the power sold from the storage. p_{Spot} represents the spot price at the current time t. The objective is to maximize the sum of this function over 24 hours.

$$\sum_{t=0}(P_d(t)+P_{st}(t))*p_{Spot}(t)\overset{!}{\rightarrow} max \tag{5}$$

For the objective function certain restrictions apply. Obviously, the amount of energy taken from the battery cannot be bigger than the amount already stored up to this time. Furthermore, P_{st} is restricted by the battery characteristics like capacity and power. Applying these restrictions, the model still remains idealized. However, the lifespan of a battery is subject to the number of charging cycles. Furthermore, losses occur when charging and discharging the battery. Consequently, imputed costs arise when using the storage. To de-idealize the operation of the storage and to consider the aforementioned losses, the model includes a degree of efficiency for the battery. The side condition (6) holds true for every point in time. The maximum amount of energy that can be sold from the storage P_{st} equals the amount of energy stored at that time. This obviously cannot be higher than the difference of the wind turbine's output P and the amount of directly sold energy. This difference is multiplied with the degree of efficiency η. The level of the latter depends on the applied battery technology.

$$P_{st} \leq (P-P_d)*\eta \tag{6}$$

If the price difference is not big enough to compensate the $1-\eta$ loss due to storing energy, the decision not to store energy at low prices and sell it at higher prices should be taken.

The wind turbine loads the battery when the current spot price is low. Consequently, the storage is discharged at a time with high electricity prices. This leads to a shift of the feed-in profile of the wind farm. Therefore, higher revenues result without increasing the total amount of energy produced. For the practical implementation of this optimization, Microsoft Excel Solver is used.[137]

The cash flows of this VPP will then be compared to those of the standalone wind farm that must sell the energy at time and current price when produced. Another constraint is the specification that the load of the battery must be zero at the end of the day. This makes the implementation of the model easier since the daily operation schedule of the VPP is optimized. In this way, different days in terms of scenarios are more comparable.

In a second step uncertainty in terms of volatile output, fluctuating market prices and forecast errors is included into

[136] Cf. Barton et al. (2004), p. 442.

[137] Microsoft Excel Solver is an Excel add-in which can use different algorithms to find optimal solutions. In this application, the Generalized Reduced Gradient (GRG) non-linear algorithm is used. This is since some of the restrictions in the model do not meet the conditions for linearity, hence the Simplex algorithm could not be used (Cf. Frontline Systems, Inc. (2017)).

the model via scenario testing. Accordingly, spot price and wind scenarios are simulated using Monte Carlo method. Historical data used only projects and therefore estimates an expected value. The Monte Carlo simulation generates a range of possible outcomes.[138] Appropriate random numbers which are generated by using Monte Carlo simulation, serve as input values. For generating these random numbers, the forecast error for wind and spot prices is considered. The distributions of the latter are assumed to be normally distributed with zero mean.[139] To implement the Monte Carlo simulation RiskAMP was used.[140] Apart from the type of distribution, the mean and the standard deviation are required to generate a Monte Carlo scenario. For generating the scenarios for the energy output of the wind farm, the wind forecast error was used as the distribution's standard deviation. The forecast error δ_t in (7) is calculated as a function of the forecasted power P_f and the maximum output of the wind farm P_{max}.[141]

$$\delta_t = \frac{P_f}{5} + \frac{P_{max}}{50} \tag{7}$$

Similar to the wind forecast, the error for the price forecast depends on the forecast technique used. For the according scenarios, a deviation of 5 % of the estimated value is assumed.[142] The simulated scenarios are also used as input data for the VPP optimization model like it is done with the real data in the first step of the model. The resulting yearly cash flow scenarios show a distribution for each, the VPP and the sole wind farm. They are used to assess the risk and a comparison of the operation with and without a battery.

The risk assessment represents step three of the model. To determine if there is an influence of using a battery storage in combination with a wind farm on the investment risk, different risk measures can be used. A nowadays commonly applied measure is the VaR. It provides information about the maximum loss that will not be exceeded in a certain time horizon at a defined confidence level. This equals the relevant distribution's quantile in terms of statistics.[143]

In this application of the VaR, I do not investigate the maximum loss that could occur. Instead, it is applied to determine the minimum cash flow that will be realized with the specific probability in each period. The VaR is calculated at the 99 %, the 95 % and the 90 % confidence level. Consistency in the results for all three confidence intervals will increase the results' validity. If the VPP achieves a higher minimum cash flow relatively to the expected value compared to the standalone wind farm, the use of a battery is likely to have a positive effect on the investment risk. An improved VaR corresponds with a reduction of uncertainty coming from different price and output scenarios. This implies a narrower distribution of the cash flows for the VPP compared to the cash flows of the standalone wind farm for the same scenarios.

Given that the VaR analysis states a lower risk for the VPP compared to the standalone wind farm, the fourth step follows. It is assumed that with a reduced risk, the WACC of the investment decreases. This complies with the assumption that uncertainty and volatility in revenues influences both, the cost of debt and the cost of equity. Section 5 elaborates on this topic. Consequently, the WACC is used as total cost of capital. A further assumption is that the innovation character of combining a wind power plant with a battery storage in a VPP is not influencing the investment risk and the cost of capital. The implementation of the fourth step starts with the calculation of the wind farm project's NPV by using the DCF method. Therefore, a reasonable duration of operation and WACC have to be determined. The resulting NPV is compared to the NPV of the VPP for which the initial investment of the battery must be considered. The price of the battery storage depends on its capacity on the one hand and the price per kWh for the chosen technology on the other hand. The initial investment of the wind farm itself is not taken into consideration as the VPP is compared to the standalone wind farm. Consequently, when taking this investment into account, results remain unchanged. For the wind power plant without a battery, no initial investment at all is included into the NPV. Subsequently, the critical WACC for the VPP is determined. The latter corresponds to the discount rate, at which the NPV of the VPP matches the NPV of the standalone wind farm. The calculation is also conducted by using the Excel Solver which is capable of performing this computation by applying what-if analyses. Since the cash flows are optimized and consequently set, the height of the critical WACC depends on the investment cost of the battery and the defined timeframe. For investigation of these dependencies, sensitivity analyses with battery price and number of periods as varying inputs are conducted. In this context, the threshold battery price, for which the NPVs would be equal for the VPP and the standalone wind farm is identified, assuming the same WACC.

7.2. Data set

For the study, the output pattern of an existing representative 50 MW wind farm in northern Germany is considered. As data basis, the output data for the years 2013 – 2015 is available. This selected data sample is favorable for the study as 2013 was a poor, 2014 a medium and 2015 a good year in Germany when it comes to overall wind yields.[144] Hence, bias coming from the choice of a specific year is mitigated. The plant's wind yield data is provided as quarter- hourly values. These outputs are consolidated to hourly values to match the time interval of the available price data. As a next step, the data is pre-processed to eliminate irregularities and make it easier to handle via generating typical profile days.

[138] Cf. Structured Data LLC. (n.d.).
[139] Cf. Liu et al. (2015), p. 785.
[140] RiskAMP is an add-in for Microsoft Excel which provides a Monte Carlo simulation engine (Cf. Structured Data, LLC. (2017)).
[141] Cf. Liu et al. (2015), p. 785.
[142] Cf. Conejo et al. (2005), p. 1039 f.
[143] Cf. Jorion (2006), p. 17.
[144] Cf. IWR (2014); IWR (2015); IWR (2016).

This consolidation of data is common practice in research and simplifies the handling of bulk data.[145] Therefore, an average day is generated for each month of a year. This is done as wind levels are not constant over the year. The result as can be seen in figure 6, shows that the output in winter months is much higher than in summer. For example, the average output on a December day is more than 390 MWh whereas on an average august day only around 103 MWh are produced.

For electricity price data, the European Power Exchange (EPEX) spot prices for Germany are used. The prices which were available on an hourly basis over the same three years are also broken down to typical daily patterns. This is necessary as the prices vary between months. However, for electricity prices it is insufficient to only distinguish between months. The key influence on the height of the prices over the day, and thus on how the load profile of a day looks like, is the fact if it is a working day or weekend.[147] Daily load profiles of weekends are very different to those of working days as can be seen in figure 7. In detail, typical price trends of January working days and weekends are compared. Figure 8 displays the average prices per MWh for the two categories of weekdays over the year.

A major role in creating the introduced VPP is the battery capacity as well as the maximum power of the storage. For the first step of the analysis, the cash flow maximization, an endlessly big storage would be the best, as all the generated electricity could be sold at the time with the highest price and investment costs would be not considered in this part of the model. Nevertheless, investment cost is a substantial issue and choosing the right capacity and power is crucial for maximizing the benefit. The topic of optimal sizing of batteries for VPP is an issue that makes up an own field of research. For this thesis, the size of the storage is determined in a pragmatic way. As the storage is used to maximize the daily profit, the average daily output of the wind farm is the first step of figuring out an appropriate capacity. The daily average output over the years 2013 until 2015 is about 198 MWh, whereas the hourly average output is 8.3 MWh.

For this application, the battery has to shift the output within one day. Therefore, the load change has to be quite fast and high power has to be provided. Furthermore, the used battery should have a long lifespan. For this case a lithium ion battery is chosen. To use a storage with half of the days average output would result in a battery system with almost 100 MWh. This nearly equals the size of the currently installed world's largest lithium ion battery storage in California that has a capacity of 120 MWh.[150] The ratio between capacity and wind farm output in practical applications differs significantly. The Notrees[151] MW wind farm in Texas for instance was equipped with a 24 MWh and 36 MW battery which results in a capacity to wind power ratio of around 0.16.153 Another VPP project in Braderup in northern Germany consists of an 18 MW wind farm and a 3.3 MWh Battery.[152] In a study on a VPP consisting of wind power and Vehicle-to-grid energy storing, storage capacities from 19 to 50 MWh are analyzed for a 13 MW wind farm.[153] The relation of storage size to wind farm output varies for different applications as well. It makes a difference, if the objective of the storage is to maximize revenues, to stabilize outputs or to participate in the balancing energy market.[154]

For this study, a 25 MWh lithium ion battery system was chosen. On the one hand, this is a storage for today's conditions. On the other hand, the fact that this model is developed for the operation without financial support which is rather a case for after 2020, battery prices are likely to be lower. Therefore, this is assumed to be a realistic dimension. For the power of the battery 25 MW is chosen. As battery prices are usually provided in € or $ per MWh, the maximum power as price factor is neglected. For this model, it is assumed, that the lithium ion cells are available as units with a capacity that allows one hour of discharging with the maximum power and hence a ratio of power to capacity of 1. This is assumed be a good starting point, when considering the application of second-use electric vehicles batteries since these usually have rather high power. To make a statement about the influence of the battery size, the study is additionally conducted with a 15 MWh and a 35 MWh battery. This can provide information about additional potential of risk reduction and about an increase in profitability through variations in battery capacity.

As degree of efficiency for the battery 90 % are used.[155] Degrees of efficiency can be better nowadays and might, because of further research and development in this field, be even better for the time, when the assumed circumstances of the model exist.[156] This may be from the year 2020 onwards. Nevertheless, 90 % are used as this also considers the cost of wear and tear by charging and discharging the battery in this study. Furthermore, the degree of efficiency probably will be lower for the application of second-life electric vehicle batteries.

To create the Monte Carlo Scenarios random values are generated using the RiskAMP Excel Add-In. As abovementioned, the prediction errors for both, the wind and the spot prices are assumed to be normally distributed with zero mean. In total, 10 scenarios for each typical day are generated and the daily revenues are maximized for each of them. This number of scenarios was chosen to keep computational and manual effort manageable. Figure 9 shows the Monte Carlos price scenarios for working days in January. The red line which represents the typical day derived from the real

[145] Cf. Hippert et al. (2001), p. 49.
[146] Own figure based on wind park data 2013-2015.
[147] Cf. Hippert et al. (2001), p. 49.
[148] Own figure; based on the EPEX Spot Day-Ahead prices for 2013 – 2015.
[149] Own figure; based on the EPEX Spot Day-Ahead prices for 2013 – 2015.
[150] Cf. Overton (2017).
[151] Cf. Better World Solutions (2015); Younicos (2016).
[152] Cf. Gillhuber (2014).
[153] Cf. Vasirani et al. (2013), p. 1320.
[154] Cf. Doetsch et al. (2011), p. 100.
[155] Cf. Statista (n.d.).
[156] Cf. Leuthner (2013), p. 16.

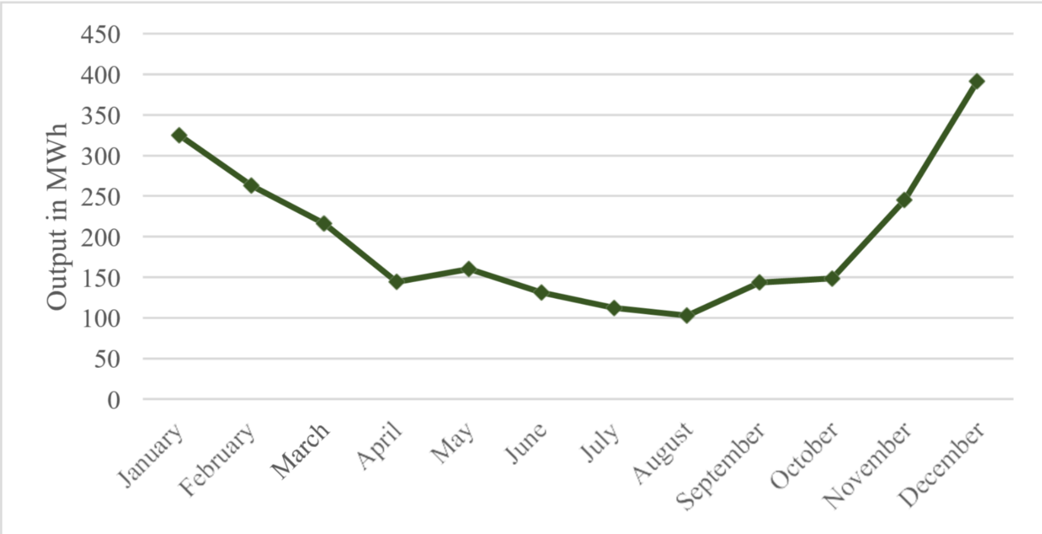

Figure 6: Average daily wind farm output[146]

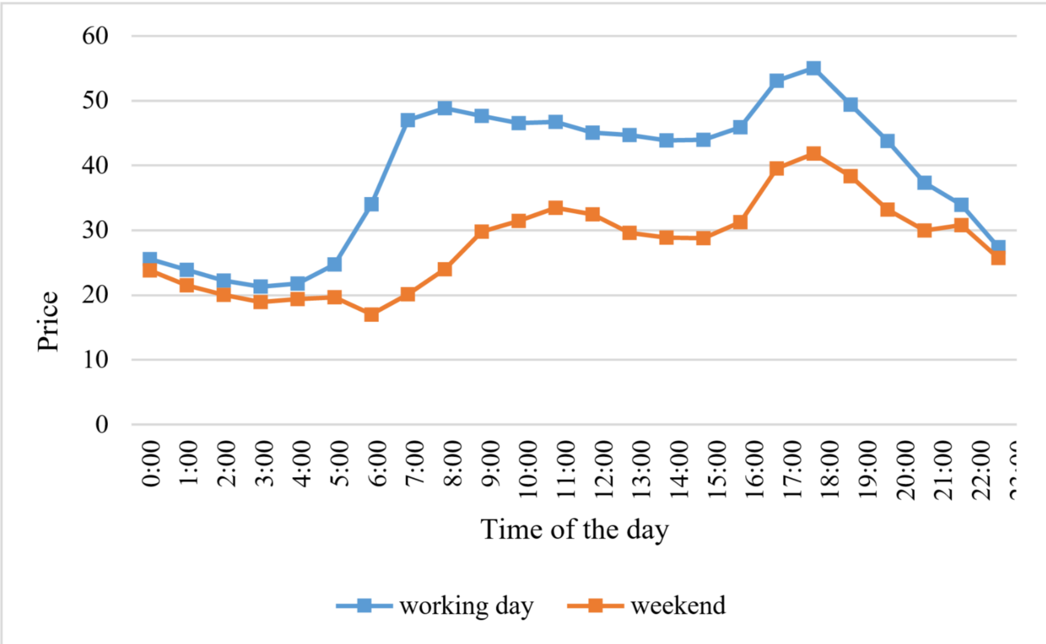

Figure 7: Typical daily price profile for January[148]

price data therefore equals the blue line in figure 7. Figure 10 includes the output scenarios of the wind farm in a structure analogous to figure 9. Worth mentioning is the fact that the output pattern over a day usually will not be as smooth as the red line as this line represents a typical day calculated as average.

For the calculation of the VaR a bigger number of scenarios is needed, since e.g. the 99 % VaR equals the 1 % quantile. For only 10 values this requires an interpolation and might end in an unprecise estimation. The operation for the generated Monte Carlo scenarios is optimized for each of the 10 cases. The accompanying monthly revenues are independent of each other. This independency is used to create a bigger sample by combining the monthly outcomes of the optimization of the scenarios to new scenario years. This is done since the VaR will be calculated for the yearly cash flows. If every month would be combined with each other, this would result in 1012 combinations. This number of scenarios however would exceed the capabilities of Excel. To enlarge the sample by choosing some scenario combinations without getting a biased selection of combinations, 500 random combi-

[157] Own diagram.
[158] Own diagram.

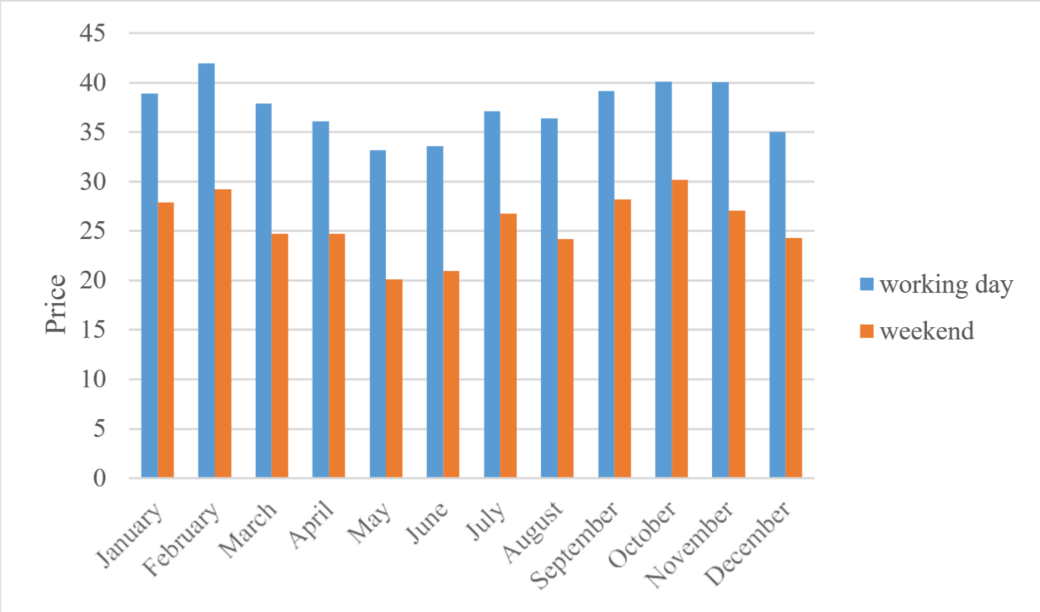

Figure 8: Average electricity price on typical days[149]

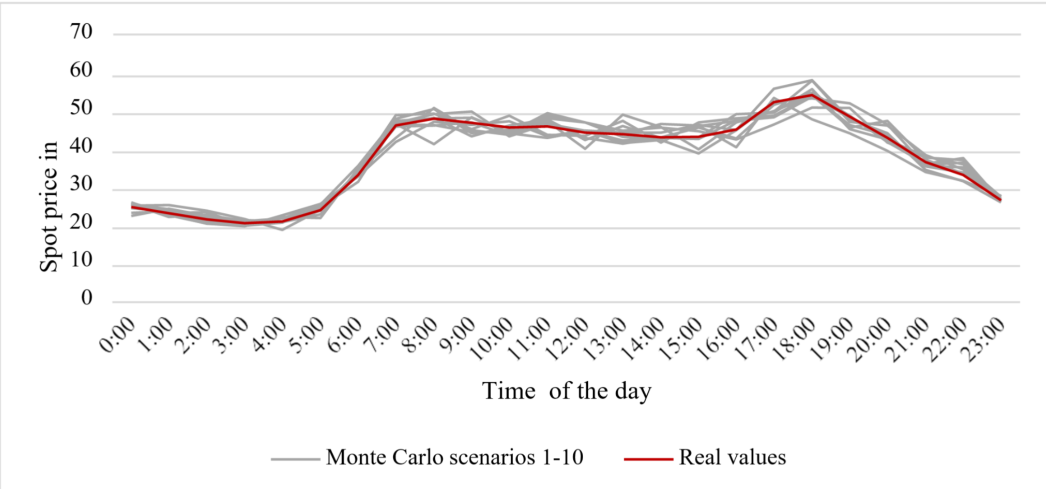

Figure 9: Price scenarios for a working day in January[157]

nations are generated. For conducting the VaR calculation, confidence levels of 90 %, 95 % and 99 % on the annual cash flows are chosen. Due to the fact that the VaR is calculated on the revenue distribution over the different scenarios, the implication from this study is not the influence a battery has on daily volatility, but on how it can reduce deviations from the expected value for different scenarios. As in this case the VPP consisting of this plant and a battery is compared with the standalone wind farm, the investment cost of the wind turbines is of secondary importance, whereas the investment cost of the battery storage unit is of greater importance.

Since the case considers a post support scenario, it will take place e.g. from 2020 onwards for the case of Germany. This implies that prices for lithium ion batteries will considerably differ to today's prices because prices tend to be falling for this technology. Studies estimate that prices in 2020 will decrease to 200 € per kWh and evolve to prices of around 160 € per kWh in 2025.[159] Primarily, the mass production as a consequence of a higher demand for EVs is the reason for this forecasted price decline. Cases with both, 200 € and 160 € are assessed.

The increasing share of EVs also leads to a growing availability of second use batteries as mentioned in section 2.4. The prices of the latter might be even lower and would possibly increase the project's profitability.

To calculate the NPV of the project, a WACC is needed as discount rate. In order to figure out an appropriate WACC,

[159] 200 $/KWh was cleared with the up-to-date exchange rate (1 USD = 0.9421 €) (Cf. D'Aprile et al. (2016)).

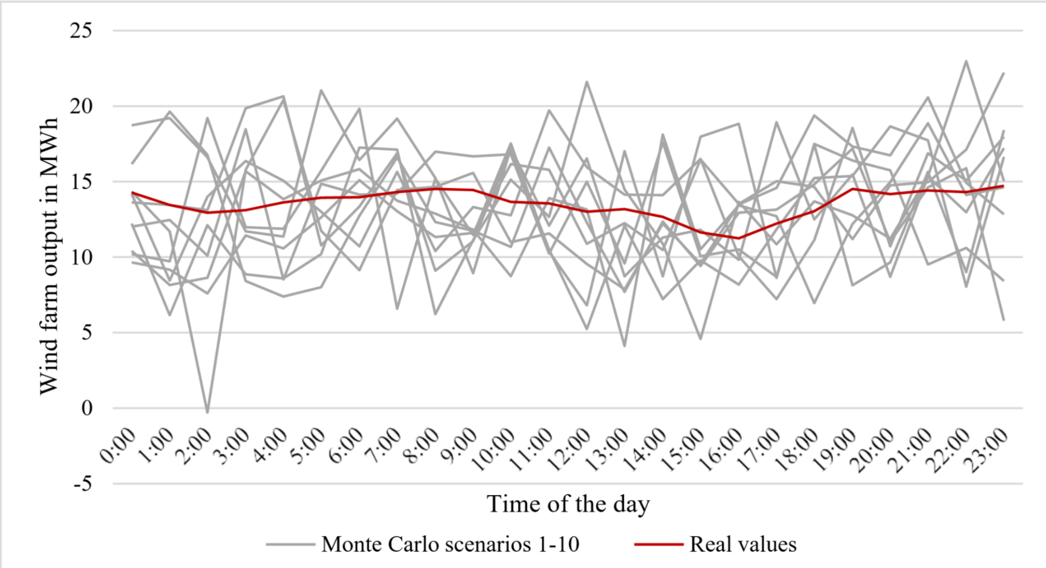

Figure 10: Output scenarios for a day in January[158]

the DiaCore project is used. For Germany, which is the considered country as the wind farm is located there, the model value of the study is 5.6 %, whereas the estimations from the interviewees indicate a WACC in a range from 3.4 % to 4.5 %.[160] Within the scope of the initial investment, 5 % are used and for sensitivity testing, the NPV is recalculated with 3.5 % and 6.5 %. Another required input for the NPV calculation is the number of periods. For the project's time horizon, a 20-year timeframe is chosen. For sensitivity-testing, the calculation is conducted with a 15- and a 10-year horizon as well. The critical storage cost where the NPVs with the same timeframe and WACC match for the standalone wind farm and the VPP was calculated for the mentioned horizons and discount rates reaching from 3 % to 7 %.

7.3. Results

The results of the first step of the analysis match the expectations as a storage is for the VPP used which generates additional revenues by shifting outputs to high price times. Still, the investment cost of this storage unit is not yet included in this part. Figure 11 shows the average over the monthly revenues of the real data and the generated Monte Carlos simulations for the standalone wind farm and for the optimized operation of the VPP with a 15 MWh battery. The fact that the revenues of the VPP are higher is as expected. The profitability of the battery depends on the financing parameters like initial investment cost and the cost of capital which partly depends on the risk of the investment.

The VaR of the standalone wind farm and the VPP that is calculated by using the 500 generated random combinations of the scenarios are shown for the different battery capacities in table 3.

The absolute number can be interpreted as a minimum yearly revenue with a certain probability. Thus, with a 90 % probability the yearly revenue of the VPP with the 25 MWh will not be below 2,672,830 € whereas it will not fall below 2,394,245 € for the standalone wind farm for the same wind and price scenarios. The relative shortfall from the expected value that equals -2.29 % for the VPP is smaller than for operation without a battery which equals -2.50 %. To conclude, the VaR calculation states for the 90 %, the 95 % and the 99 % confidence level that the operation of the VPP is less risky than operating the equivalent wind farm without the possibility of storing energy. The calculation with all three confidence levels increases the validity of the analysis.

Especially interesting in the VaR analysis is the influence of the battery size on the risk. Obviously, the absolute numbers for the VaR of the 35 MWh battery in terms of the quantiles are higher because the whole distribution of the revenues is on a higher level compared to smaller batteries. Nevertheless, the relative shortfall from the mean is bigger than for the 25 MWh battery for all three confidence levels. A possible reason for this phenomenon is the fact that in seasons with a low wind yield, the capacity remains partly unused due to the large- scale of the storage. The conclusion from this assessment and the highlighted cells in table 3 is that the 25 MWh battery could reduce risk better than a 15 MWh and 35 MWh battery.

The reduction of the risk of wind farm investments in terms of lower volatility of future cash flows is assumed to cause a reduction of the WACC. The following table 4 illustrates the critical values for the WACC. The latter must lower for the VPP to this value to achieve the same NPV as the standalone wind farm does. For example, when there is a WACC of 5 % for wind power investments, a battery price of 200 € /kWh and a project duration of 20 years is assumed, a WACC of 4.46 % and therefore a reduction by 0.54 per-

[160] Cf. Noothout et al. (2016), p. 112.
[161] Own figure.

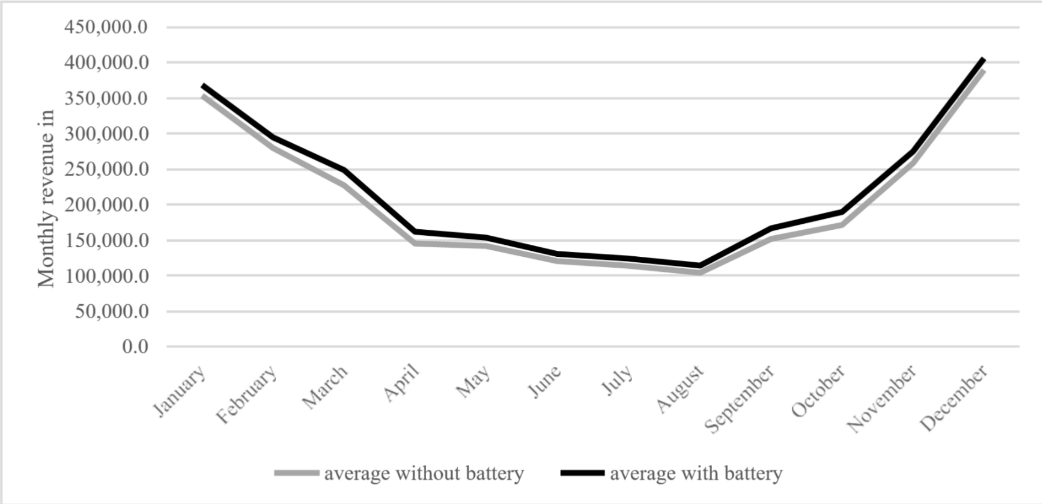

Figure 11: Average monthly revenues with and without battery storage[161]

Table 3: Value-at-Risk results based on yearly revenues; Source: Based on own calculations.

	Standalone wind farm		VPP 15 MWh		VPP 25 MWh		VPP 35 MWh	
VaR	Relative	Absolute number	Relative	Absolute number	Relative	Absolute number	Relative	Absolute number
90 %	-2.50 %	2,394,245 €	-2.38 %	2,570,291 €	-2.29 %	2,672,830 €	-2.30 %	2,749,306 €
95 %	-3.38 %	2,372,719 €	-3.18 %	2,549,210 €	-3.03 %	2,652,676 €	-3.06 %	2,727,944 €
99 %	-4.75 %	2,339,055 €	-4.37 %	2,517,781 €	-4.12 %	2,622,987 €	-4.15 %	2,697,407 €

centage points is necessary for the 25 MWh battery VPP a as threshold value to match the NPV of the windfarm without battery. In case of a cost of capital rate below this critical value, the VPP has a higher NPV than the plant without energy storage. For a WACC of 3.5 % with a project's timeframe of 20 years and a battery price of 160 € /kWh, which is reasonable for 2025, the VPP would already be almost competitive since the cost of capital would only have to fall to 3.46 %.[162] Striking is that shortening the project's lifetime from 20 to 15 years for a 160 € /kWh battery nearly has the same influence for the analyzed rates of cost of capital as raising battery prices from 160 € /kWh to 200 € /kWh. Also noticeable is that the shorter the time horizon is the bigger is the influence of higher battery prices. This seems reasonable as there are less years with higher cash flows

for the VPP compared to the sole wind farm which contribute to cover the initial battery investment. The 40 € /kWh difference in battery price sum up to a significant difference of 1 million € for the initial investment for the 25 MWh energy storage. As concluded from the VaR calculations, the 25 MWh battery can reduce risk by more than the 15 MWh and the 35 MWh battery. And since the 35 MWh battery would have to reduce the cost of capital more than the other configurations, this tends to be not an interesting option. However, since the initial investment is lower, the 15 MWh would only require a smaller reduction of the WACC to match the NPV of the standalone wind farm. For the 15 MWh battery, there is even the case where the additional revenues would completely cover the initial investment of the storage. This underlies the assumption that the most favorable of the assessed combinations occurs, with the battery price being 160 € /kWh, the project's period 20 years and the WACC for wind projects 3.5 %. Consequently, the NPVs of the standalone wind farm and the VPP would match without the necessity to lower the WACC for the VPP. However, there is evidence, that this is mainly caused by the favorable conditions since the WACC would only have to be reduced from 3.50 % to 3.46 % for the 25 MWh battery. As for this study there was merely the assumption that a better VaR reduces the WACC, it would be an interesting extension for future research to quantify the impact a certain change in the VaR has on the cost of capital.

The results of the calculations about the critical battery prices which directly can be projected to the critical initial investment, can be seen in figure 12. The previous calculation of the critical WACC obviously indicates that a longer project‘s life allows higher prices. As an example, the critical energy storage price for a 25 MWh battery at which the NPVs for the VPP and the standalone plant are equal, at a WACC of 5 %, is 136 € /kWh for a 20-year, 113 € /kWh for

[162] Cf. D'Aprile et al. (2016).

Table 4: Critical WACC for the VPP; Source: Own table; An overview of the calculations and results for one battery configuration (25 MWh) is provided in appendix 1.

	Battery price					
	160 € / kWh			200 € / kWh		
	Timeframe					
	10 years	15 years	20 years	10 years	15 years	20 years
Battery capacity						
	Reference WACC = 3.5 %					
15 MWh	2.63 %	3.30 %	3.50 %	2.13 %	3.03 %	3.33 %
25 MWh	2.07 %	3.12 %	3.46 %	1.31 %	2.70 %	3.19 %
35 MWh	1.37 %	2.82 %	3.31 %	0.39 %	2.27 %	2.94 %
	Reference WACC = 5.0 %					
15 MWh	3.94 %	4.66 %	4.90 %	3.39 %	4.35 %	4.69 %
25 MWh	3.26 %	4.41 %	4.79 %	2.43 %	3.93 %	4.46 %
35 MWh	2.47 %	4.03 %	4.58 %	1.41 %	3.40 %	4.14 %
	Reference WACC = 6.5 %					
15 MWh	5.23 %	6.01 %	6.27 %	4.62 %	5.65 %	6.02 %
25 MWh	4.44 %	5.66 %	6.09 %	3.53 %	5.12 %	5.70 %
35 MWh	3.54 %	5.20 %	5.80 %	2.40 %	4.50 %	5.30 %

a 15-year and 84 € /kWh for a 10-year time horizon. This is due to the fact that the additionally generated revenue by deploying the battery needs to cover its initial investment. With a higher number of years in which these additional revenues occur, more overall cash flows cumulate. However, the figures that are further away in the future contribute less to covering of the cost than the early returns due to discounting.

In figure 12, it is noticeable that the lines seem to be flatter for shorter project periods. Consequently, the critical battery prices for a 10-year project are obviously lower than for longer projects but the influence of higher cost of capital also seems to be lower. Furthermore, the difference in threshold values for batteries is bigger between 25 MWh and 35 MWh than between 15 MWh and 25 MWh.

All in all, it can be stated that for projects with 15 to 20 years, the application of a battery storage in a VPP can be competitive to a standalone wind farm. This assumes that in the future battery prices will be significantly lower than today or where second-use storages from electric vehicles can be used. Notably, this holds for a scenario without any support scheme for renewables. Furthermore, it depends on the development of the WACC for RES investments. Even if there is a degree of efficiency for the battery in the model, this still would not be sufficient to represent a real, non-idealized battery. Including more parameters like a lower partial load limit, operating cost and cycle stability would result in changes of the optimal operation schedule and the economic performance.[164] Additionally, the assumption that the standalone wind farm is self- balancing and sells the energy produced without a third-party wholesaler results in higher cash flows. When considering a direct marketer charging a predefined share from the standalone wind farm operator, the difference between the revenues compared to the VPP clearly will increase.

8. Alternative instruments for revenue stabilization

Even though this thesis emphasizes the combination of RES with energy storage to deal with the challenges of the electricity market in a post-2020 scenario, there are other instruments to successfully integrate RES into the market. Figure 13 shows the classification of alternative risk stabilizing instruments covered in this chapter. Firstly, there is the possibility of transferring the risk of volatile electricity market prices and intermittent output by directly selling electricity to consumers in terms of power purchase agreements (PPA), using energy derivatives or by using insurances. Besides transferring the risk, the possibility of adjustments on the market framework for RES dominated markets exist. Finally, geographic diversification as instrument to reduce output volatility is assessed.

8.1. Risk transfer

8.1.1. Corporate power purchase agreements

While average households buy power from utilities, some companies purchase directly from generators by long-term contracts called PPAs. These kind of contracts have been used almost exclusively for conventional power sources for

[163] Own figure.
[164] Cf. Doetsch et al. (2011), p. 89.

[165] Own figure.

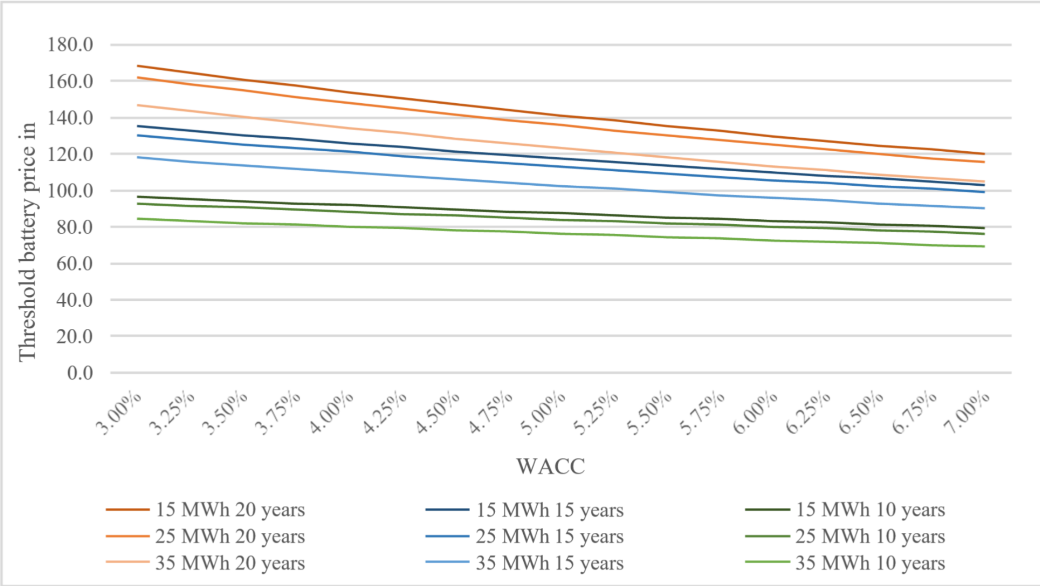

Figure 12: Critical battery prices dependent on WACC and timespan[163]

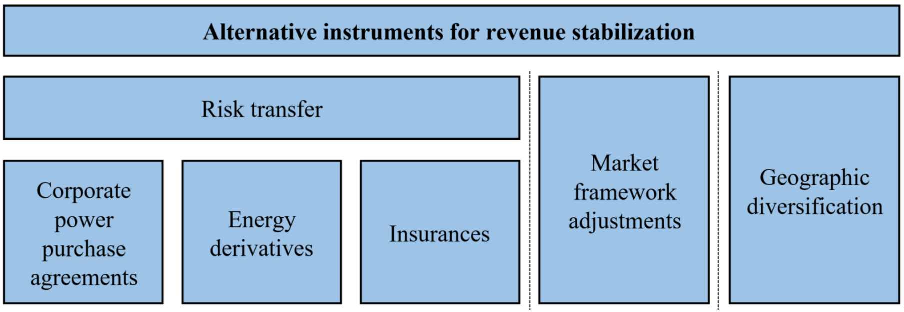

Figure 13: Structure of the section on alternative risk stabilizing instrument[165]

a long time.[166] It is common practice that banks ask for a PPA as a prerequisite for providing debt.[167] PPAs are usually at least ten year term contracts between a company as electricity consumer and a renewable energy generator. The consumer usually commits to take all the produced energy of the plant for a fixed price per kWh. The delivery of the electricity can either be physical or virtual.[168]

For physical PPAs the generated electricity purchased is delivered directly from the seller to the purchaser meaning the consumer is receiving the actually bought electricity.[169] Businesses with big data centers or other facilities that have a concentrated heavy load are common companies in physical PPAs. Usually in a physical PPA, the seller is responsible for providing the electricity at a particular delivery point, whereas the purchaser has the duty to transfer the electricity to its load. This service is often taken over by external service providers.[170]

[166]Cf. Baker & McKenzie (2015), p. 2.
[167]Cf. Green Rhino Energy (2013).
[168]Cf. DLA Piper (2016), p. 6.
[169]Cf. Baker & McKenzie (2015), p. 11.
[170]Cf. Penndorf (2016).

Virtual PPAs can be structured in different ways and are closer to a financial contract or an option than an actual contract for power. Virtual PPAs are hedging instruments to reduce the risk coming from volatile electricity prices. A common form of this kind of contract is the contract for difference (CFD). For a CFD the buyer and the seller agree on a fixed strike price for the electricity. Therefore, there is a guaranteed price for both parties regardless of the actual volatile market price. In a first step, the generator sells the energy to the market and receives the market price. The consuming business obtains the electricity from the utility as usual and pays the market price. For a market price exceeding the settled strike price of the CFD, the seller pays the difference to the buyer and vice versa. Using this kind of PPA no adaptions regarding the process of how consumers purchase the energy from the utility have to be made.[171] Another advantage of virtual PPAs is the simplicity for logistics and the fact that the consuming business can virtually power more than one subsidiary by one plant.[172]

[171]Cf. Baker & McKenzie (2015), p. 11; Penndorf (2016).
[172]Cf. Baker & McKenzie (2015), p. 11.

For consumers this form of purchasing electricity is a hedge against price uncertainty, can help them to put emphasis on their sustainability agendas by reducing their carbon footprint and improves its public recognition of being an environmentally-friendly.[173] There is also an initiative of big businesses from all over the world called RE100 which committed themselves to 100 % renewable energy. At this moment, 89 big Corporations and electricity consumers like IKEA, BMW, Coca Cola, General Motors, Google, Procter & Gamble and many more are part of this initiative.[174] The advantage of PPAs for the plant operators is the fact that the fixed electricity price provides predictable and stable revenues which gives certainty and mitigates market risks like the volatile spot price. Besides the operator, the investors of the plant benefit from this market risk reduction. This possibility of removing market risk leads to new implemented projects in RES.[175]

The amount of electricity purchased directly by companies via PPAs has significantly increased over the last years. Bloomberg New Energy Finance analyzes recent PPA deals frequently and lists the biggest corporate off-takers. For 2016 e.g. this was Amazon with 650 MW, followed by other big companies like Google, Microsoft, Facebook, Dow Chemical or Walmart. During this year, the amount of electricity purchased via PPAs tremendously rose compared to prior years.[176]

Companies as consumers have capability to further push additional conduct of RES projects via PPAs as they are responsible for a large share of electricity. Nevertheless, corporate PPAs alone are not perceived to be able to initiate sufficient investments in order to reach the 2030 renewable energy targets.[177]

8.1.2. Energy derivatives

Apart from corporate PPAs there are other derivatives to hedge market risk. A reason why derivatives as financial tools can be advantageous compared to PPAs is the fact that PPAs often come along with discounts resulting in lower prices compared to forward prices.[178] A special characteristic about trading electricity is the fact that there are restrictions on storage and transportation in contrast to other commodities.

A common derivative and primary instrument in electricity price risk hedging is the forward. Electricity forwards are bilateral contracts which preliminary are traded in the Over-the- Counter (OTC) market. A forward is an individual contract which consists of the obligation to sell or buy a specific underlying at a certain time in the future at an predetermined price. For electricity, the aforementioned underlying is a fixed amount of electricity. Consequently, electricity forwards are a type of supply contract which obliges the seller to deliver and the buyer to take the electricity. Electricity forwards' maturities are in a range from a few hours to several years. Nevertheless, maturities longer than two years are unusual.

What differentiates electricity forwards from other commodity forwards is the distinction of different delivery times at a day. Consequently, electricity is a dissimilar commodity at different day-times. There is on-peak and off-peak electricity which is traded separately and delivered at different times of the day. Therefore, the average electricity price over the relevant time interval at maturity is typically used for calculating the settlement price. Usually, the electricity producer or plant operator is the seller in this type of contract, whereas a utility or a consuming company represents the buyer. Per definition the seller of the underlying holds the short position and the buyer the long position.

Aside from the deviating calculation of the settlement price, the general calculation of the payoff of an electricity forward is equal to other financial or commodity forwards. This is shown in (8)[179], where S_T represents the spot price at maturity T and F the pre-specified contract price.

$$ForwardPayoff = (S_T - F) \tag{8}$$

The forward payoff results in a profit for the buyer and a loss for the seller if the spot price at maturity exceeds the forward price and vice versa. One example for financially settled electricity forward contracts is the abovementioned CFD.[180]

With the same structure as forward contracts, future contracts represent the highly standardized and exchange traded equivalent. While forwards are usually OTC traded and individualized, futures are standardized in several specifications like settlement procedures and trading locations. The traded delivery electricity quantity is usually substantially smaller for electricity futures than for forwards. Futures are only traded on organized exchanges unlike forwards. The result is higher transparency compared to forward prices and a reduced risk of default of contracts counterparty. The major drawback of electricity futures can be the limitation when it comes to transaction quantities.[181]

Another widely used derivative is the swap. A swap represents a contract for the exchange of financial instruments between two parties. The interest rate swap is the most applied form of a swap. It allows the exchange of a floating interest rate for a fixed income rate between two parties where one party holds a contract with a floating interest rate and the other party with a fixed interest rate. For specific reasons, like hedging against interest rate uncertainty or speculating in a specific change of floating interest rates, these parties can enter a swap contract.[182]

The electricity swap represents an application in the electricity market. It allows the holder to exchange a floating

[173] Cf. WindEurope (2017), p. 15; DLA Piper (2016), p. 5.
[174] Cf. RE100 (n.d.).
[175] Cf. Baker & McKenzie (2015), p. 6; WindEurope (2017), p. 15.
[176] Cf. Bloomberg New Energy Finance (2016), p. 4.
[177] Cf. WindEurope (2017), p. 16.
[178] Cf. Aydin et al. (2017), p. 2.
[179] Cf. Deng and Oren (2006), pp. 942-943.
[180] Cf. Deng and Oren (2006), pp. 942-943.
[181] Cf. Deng and Oren (2006), pp. 943-944.
[182] Cf. Investopedia (2017).

electricity price for a fixed price over the contracted period. Typically, the contract is defined for a fixed quantity of energy and the floating price is referenced to a spot price. Theoretically, swaps are a strip consisting of multiple forward contracts with a constant forward price for each of the multiple settlement dates.[183]

Aydin et al. suggest a basic hedge structure based on forwards for wind plants exposed to market price risk.[184] The basic idea is exchanging volatile prices with a fixed price by selling forward contracts at expected wind output levels. The difficulty in this strategy is the uncertainty of the output forecasts. This means that in case of a too small share of the forecasted output is sold as forwards, a long position is left, while for selling too much, a short position is left exposed to market spot prices. To determine the required number of forward contracts needed, the plant operator should estimate the wind farm output pattern in hourly steps for one MW of electricity over a predefined period. Then, this output should be valued by weighting the electricity spot prices with the expected volume which results in an expected revenue per MW for this period. This revenue is divided by the cost of a forward contract for one MWh to determine the right number of forwards needed. An adjustment for wind output that is correlated with the market prices can be made. For a negative correlation, which means that prices are lower when a lot of wind energy is produced, the plant operator should reduce the hedge quantities in order to reduce revenue dearth.[185]

As abovementioned, forward contracts usually are not traded for maturities longer than two years. For longer-term hedging, Aydin et al. suggest natural gas swaps since gas contracts are often available for longer maturities.[186] For this hedging strategy, spot gas is bought for settling against fixed gas forward purchase. In order to buy the gas, the spot market revenues of the wind farm are used. The amount of gas is scaled by the expected market heat rate. The latter represents the cost for the amount of gas needed to produce the appropriate quantity of electricity from the gas.[187] Gas is the chosen commodity for hedging as the prices of gas and electricity strongly correlate.[188]

As an example, a wind farm with a 100 MW peak power and a 35 % capacity factor for the on- peak period[189] for a specific month is assumed. Furthermore, the average spot price for the on- peak hours in this month is assumed to be 40 € /MWh as well as a forward price of 70 € /MWh. The hedging strategy would then be hedging 20 % which equals 0.2 MW per produced MW.[190] For a gas forward for the same month, the price is presumed to be 4 € /MMBtu which implies a market heat rate of 23.3 MMBtu/MWh. The hedging strategy for these parameters would be hedging 4.7 MMBtus for each wind MW by using gas swaps.[191] A side fact that should be considered is that the market heat rate is not fixed and there might be errors in forecasting. This is based on the fact that gas and electricity prices are not perfectly correlated and the degree of correlation is dependent on the penetration of these commodities as well as the electricity generating technologies in the specific market. Therefore, as Aydin et al. state, a probability- weighted market heat rate should be used.[192]

Aside from derivatives hedging commodity price risk, there are weather and even more specific wind derivatives. Weather derivatives are contracts whose underlying can neither be held nor produced. These contracts are therefore financial tools that can be used to hedge against risk associated with specific weather conditions. They are financial market products and can to some extent also be classified as insurance products. Wind derivatives are traded at the Chicago Mercantile Exchange and OTC. As a major industry, dependent on weather conditions, energy companies are principal investors in the weather market.[193]

Another type of weather derivatives are temperature contracts. The characteristic of the latter is the link to temperature as weather index too. The weather derivative market is growing faster compared to the market for wind derivatives. This is due to the fact that it is very difficult to model wind accurately and to value these contracts appropriately.[194]

Wind derivatives are usually standardized products, dependent on the daily average wind speed. This underlying average wind speed is measured over a specified period by a predefined station. Nevertheless, the modeled average wind speeds can only hedge a part of the weather risk as wind sensitivities and power curves vary for different turbines with some plants even requiring a specific duration of a wind speed level. This wind duration factor can be included as underlying weather index in an additional risk hedging strategy to take this requirement into account.[195] The traded volume of contracts on wind conditions is increasing yearly.[196]

8.1.3. Insurances

Besides financial instruments like options, there are also insurances which can reduce the risk of volatile revenues. However, common insurance products focus on weather conditions like fluctuating wind and not volatile market prices.

One example is the "lack of wind cover" by Munich Re. This product ensures specified minimum revenues to operators for periods with wind speeds that fall far below expectations. That way, operators meet the financing and operation costs and the return targets. Plant operators are covered

[183] Cf. Deng and Oren (2006), p. 944.
[184] Cf. Aydin et al. (2017), p. 5.
[185] Cf. Aydin et al. (2017), pp. 5, 20.
[186] Cf. Aydin et al. (2017), p. 11.
[187] Cf. Aydin et al. (2017), p. 11.
[188] Cf. Pschick (2014), p. 40.
[189] This usually is during the day time, when demand for electricity is the highest.
[190] This ratio is the result of the calculation $\frac{40€\ /MWh}{70€\ MWh} * 35\%$
[191] Cf. Aydin et al. (2017), p. 13; This results from multiplying the 20 % hedge ratio with the market heat rate $0.2 * 23.3 = 4.7$.
[192] Cf. Aydin et al. (2017), pp. 21-22.
[193] Cf. Aïd (2015), p. 86; Alexandridis and Zapranis (2013), p. 300.
[194] Cf. Alexandridis and Zapranis (2013), p. 300.
[195] Cf. Alexandridis and Zapranis (2013), pp. 300-301.
[196] Cf. Alexandridis and Zapranis (2013), p. 319.

against revenue shortfalls caused by poor wind conditions. In order to set up the specifications of the insurance contract, historical weather data for the location is combined with the turbine specific power-curve and multiplied with the number of turbines to calculate the annual energy yield of the wind farm. If the actual turnover is – as a result of a lack of wind - below the modeled yearly turnover which results from the energy yield multiplied with a fixed price per MWh from a feed-in tariff or an PPA, a certain range will be covered by the insurance.[197] Consequently, this insurance product limits the risk coming from the intermittency of the output, not from volatile market prices. Nevertheless, the variable output is one factor of the hardly predictable revenues.

Another insurance product which covers lost revenues caused by weather in general is the KLIMArisk by the insurance company HDI Global. The contract can be specified to cover shortfalls caused by different weather events like too strong or too weak wind, strong waves or temperature or precipitation extremes. A fixed sum is paid by the insurance company when the abovementioned parametric weather index hits a certain threshold.[198] Even if this kind of insurance is not specifically designed for wind farm operators to hedge against a lack of wind, it can be used for this purpose.

This chapter provides just a brief overview of insurance products on turnover shortfalls due to fluctuating wind. There is probably a variety of comparable products offered on the market such as the weather resource protection product by Allianz that covers electricity generation shortcomings caused by fluctuating wind.[199] As a result, it can be stated, that existing insurances focus on the wind farms energy yield dependent on the wind speed and not on revenues dependent volatile market prices. This might be due to the fact, that at this moment, there are almost predefined prices for electricity in most markets ensured by support schemes.

8.2. Adjustment of the framework for renewables-dominated electricity markets

The increasing share of RES influences the electricity market substantially. It led to lower and more volatile market prices. The reason for this phenomenon are very low marginal cost of electricity from RES on the one hand and the presence of support schemes suppressing market signals on the other hand. Some of the latter still occur by giving incentives for feeding-in energy even if there is already a surplus in supply, characterized by negative prices.[200]

The financial support schemes introduced in section 3 incentivized investments in RES and contributed significantly to the rapidly growing share of RES in the past. However, they intervene in the market via levering out mechanisms and signals to a certain extent. The expeditious market penetration of renewable energy resulted in low and volatile market prices which led to difficulties for conventional electricity producers when it comes to covering expenses. With a high share of intermittent renewables, general market design adjustments are inevitable.[201] Morch et al. formulate key features of a successful design for RES dominated markets which are shown in figure 14, namely faster and larger markets, smaller products, efficient pricing and a level playing field for all market players.[202]

For RES, generation conditions are intermittent and change fast due to weather. These circumstances should be reflected in markets that are RES dominated by allowing for shorter lead times to establish faster markets. Plant operators must provide a generation schedule in advance to the transmission system operator. With shorter lead times, the gate closure for submitting the bids or updating the forecasts moves towards the delivery hour. RES operators would likely be able to self-balance deviations for the variable generation due to more accurate short term forecasts if the gate closure was as close as possible to real time. Consequently, less balancing capacity would be needed.[204]

Furthermore, larger markets in geographical terms would benefit from smoother and less intermittent output from RES. The phenomenon of reduced overall fluctuations via geographically diversified markets would be taken advantage of. By using a common European grid model, the present infrastructure could probably be exploited best. The enlargement of markets also induces a growing interconnection between regions and cross-border competition.[205] Thus, the aggregation of energy markets could result in a more economic integration of intermittent RES.[206]

The key feature of smaller products refers to the timeframe of contracts. Usually there are one- hour long power contracts traded.[207] However, smaller products in terms of shorter timespans makes trading, especially for wind energy, easier. The reason for that is the higher accuracy of output predictions for short time frames. Smaller products also allow adjustments of bids closer to real time. Nonetheless, smaller products should be introduced in combination with larger products as well. This is essential for balancing out liquidity in the markets and implementation cost. A first step towards smaller products that occurred was the implementation of a 15-minute product at the German intraday market.[208]

Furthermore, pricing in the electricity wholesale market should be efficient. This implies transparent pricing and allowing for volatile prices and spikes that signal scarcity instead of artificially influencing them. This is expedient as transparent prices reflect market signals like the need for

[197] Cf. Munich Re (2015).
[198] Cf. Gatzert and Kosub (2016), pp. 989-990; HDI Global SE. (n.d.).
[199] Cf. Allianz (2015).
[200] Cf. Morch and Wolfang (2016), p. 12.

[201] Cf. Morch and Wolfang (2016), p. 18.
[202] Cf. Morch and Wolfang (2016), p. 21.
[203] Own figure based on Morch and Wolfang (2016), p. 21.
[204] Cf. Krohn et al. (2009), p. 94; Morch and Wolfang (2016), p. 22.
[205] Cf. Morch and Wolfang (2016), p. 22.
[206] Cf. Krohn et al. (2009), p. 94.
[207] Cf. Krohn et al. (2009), p. 96.
[208] Cf. Morch and Wolfang (2016), p. 23.

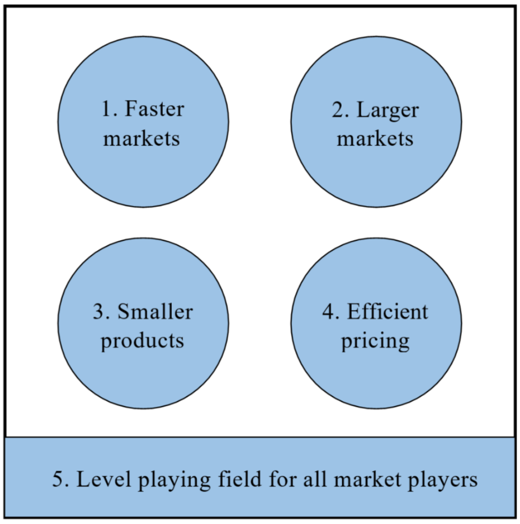

Figure 14: Crucial market characteristics for a successful market integration of RES[203]

additional investments. The transparency of prices also includes direct relation to marginal costs of electricity production.[209]

For all of the mentioned market features, the playing field within the electricity market must be leveled. Firstly, this includes that balancing responsibilities apply to everyone. This becomes more feasible for RES operators with the abovementioned faster markets which allow short gate-closure time. Secondly, the priority feed-in compared to conventional energy existing in some countries must be eliminated to achieve a level playing field. Thirdly, a polluter pays principle should be introduced as the cost of pollution is calculated to low. This results in cheap conventional electricity and artificially uphold competitiveness with respect to RES. And finally, the subsidies for conventional energy sources must be adapted to the support for RES. The high level of subsidies paid to conventional electricity generation must be adjusted analogously to the state aid guidelines for RES.[210]

RES operators would especially benefit from the market features of shorter lead times and smaller products as this would reduce balancing risk and help to stabilize revenues. Nevertheless, for the introduced market framework, the support policy must be adjusted as well. Therefore, the support schemes should stabilize the revenues of RES but also allow for market signals. The subsidies should be allocated using an adequate mechanism like a tender. Furthermore, the paid premiums should be based on produced energy and not on capacity which would bring profits to a generator even without generating. To benefit from a wide portfolio of generating technologies in the long run, supports should be technology-specific. Consequently, further development and cost-reduction for specific technologies can be stimulated. Finally, as well as for the market features, a level playing field for all market players should be established.[211]

8.3. Diversification as an instrument to reduce output volatility

The weather is responsible for the intermittent output of wind power turbines. As the weather deviates at different places at the same time, geographical diversification is an instrument to reduce weather-related output volatility. The basic principle of geographic dispersion is the following. The wind speed and direction is not the same at every place and the correlation of wind speeds decreases for wider distances between wind farms. Small or negative correlations are beneficial in this case as it can be used to smoothen the output fluctuations.[212] Furthermore, wind forecasts are more precise for large areas like whole countries compared to smaller regions.[213] Thus, the overall forecast for a geographically dispersed portfolio of wind farms would be more accurate than the forecast for a single wind farm.

A further step of geographic diversification would be to diversify a portfolio of wind farms over multiple regulatory regimes. Aside from the reduction of the output variability, this also mitigates policy or regulatory risk as the total portfolio revenues are not dependent on the regulatory framework of one single country.[214]

Obviously, the introduced geographic diversification is applicable for portfolios of wind farms only, not single ones. Therefore, this kind of diversification solely constitutes an option for companies with a sufficiently big scale.

9. Conclusion

The objective of this thesis was to analyze the influence a battery storage has on investment risk for wind farm

[209] Cf. Morch and Wolfang (2016), p. 23.
[210] Cf. Morch and Wolfang (2016), pp. 23-24.
[211] Cf. Montoro and Corbetta (2016), pp. 25-27.
[212] Cf. Drake and Hubacek (2007), p. 4001.
[213] Cf. Holttinen (2005), p. 2057.
[214] Cf. Watts (2011), p. 17.

projects. With progressive market integration of RES, wind farm projects are increasingly exposed to electricity market risks accompanied by uncertainty in future revenues. Existing Literature is extensively addressing the topic of market integration of RES and the forthcoming challenges coming from accelerating exposure to market risks. Similarly, literature on VPPs in general as well as VPPs consisting of wind power and a battery storage exists. However, these studies mostly focus on optimal operation strategies from a risk-neutral point of view. This thesis enlarges the current field of research by pointing out possibilities to reduce investment risk coming from uncertain and volatile revenues. This is necessary to incentivize further investments in RES which is a prerequisite to meet the defined targets on green house gas emissions. The main contribution of this thesis is the analysis of the influence of battery storage on risk coming from revenue volatility in a business case without support schemes and making the leap to cost of capital. Based on the assumption that investors are risk averse and that the WACC declines with lowering risk, the study provides evidence that a battery storage can indeed reduce the overall financial risk.

The results of the study show that deploying a battery in the proposed way benefits both, RES investors and operators. For the latter, stable and plannable revenues as a consequence of energy storage opportunity lead to risk reduction. Investors probably can maintain wind farm projects as low-risk long-term investment options in the future. This furthermore results in low financing cost for operators.

The analysis is based on wind farm and electricity market data from Germany. Results state that for reaching the same NPV, the cost of capital for a VPP has to be reduced compared to an usual wind park investment. The scale of the required WACC reduction reaches from less than 0.5 up to more than 4.0 percentage points depending on input data assumptions about size and price of the battery, the project's timeframe and reference rate for cost of capital. Since the operation of an VPP like the constellation introduced in the case study will be most reasonable post 2020, the assumptions made represent the main limitation of the model. Therefore, assumptions on battery prices are made based on predictions. Moreover, the technological characteristics of the chosen battery such as partial load limit, operating cost or cycle stability could be included more detailed to map the operation more realistically. In addition, it is questionable how required returns from RES investments and consequently cost of capital will evolve during times when no certainty by state-aid is provided. As e.g. Doetsch et al. point out, the determination of the actual level of cost of capital by investors and banks is to a certain extent subjective and influenced by qualitative measures like political stability as well.[215] Furthermore, the volatility and height of the prices used for the study might not be representative for the post 2020 era. The reason for this is the increasing share of intermittent energy sources whose low marginal cost and stochastic generation cause not only lower but also more volatile market prices.[216]

An extension of the model would be to add generality by formulating it in a stochastic way. The objective function could then be formulated not in order to maximize the revenue and assess the influence on the risk afterwards but to optimize the impact on the investment risk. This kind of modelling was implemented in literature for general VPPs in terms of VaR maximization. Furthermore, the battery size could be included as a variable to identify optimum battery parameters. However, this would add further complexity. Thus, a deterministic model was chosen for this thesis to increase clarity of the results which is likely to result in wider acceptance for practical use.[217]

Circumstances for grid integrated storage deployment will probably change in the future. This is due to the abovementioned lower electricity prices and increasing price volatility as well as the ceasing of state-aid. However, especially the falling prices and ongoing development of batteries will probably be game-changing for stationary electricity storage. With a larger scale of installed electricity storage capacity and lower cost of storing energy, the trading of electricity changes as it becomes an affordably storable commodity. Assuming sufficient installed storage capacity, a wind farm can decouple its supply profile from the actual electricity production curve.[218] With more affordable batteries, storages can also be used as multi- application devices aside from the VPP function. Additional revenues may be generated via arbitrage trading, providing services like reserve supply or frequency stabilization, or by offering balancing capacity. Consequently, revenues can be generated by different tasks to make battery systems more valuable. A further business case for using storages was introduced by Pinson et al., namely offering electricity storage capacity as a service in the form of an independent electricity market entity. This would enable RES operators to rent capacity for reducing tied-up capital and determining the required storage size dynamically in order to avoid under-utilization in low wind times.[219]

Furthermore, the deployment of a second-use storage by Daimler and The Mobility House provides strong evidence that the application in stationary storages is an economically viable lifetime extension for EV batteries.[220] With an increasing share of EVs, more used batteries will be available in the market. This provides inexpensive storage capacity on the one hand, and improves the batteries' eco-balance on the other hand. The mentioned technological evolution and further innovation on smart grids makes the issue of storing electricity in large scales even more tangible. This is however crucial to make RES dispatchable and therefore competitive in the market. Combined with revenue-stabilizing instruments, RES are likely to remain attractive investments in the future.

[215] Cf. Doetsch et al. (2011), p. 3.

[216] Cf. Ketterer (2012), p. 35.

[217] Cf. Cummins et al. (1999), p. 424.

[218] Cf. Rugolo and Aziz (2012), p. 7159.

[219] Cf. Pinson et al. (2009), p. 7.

[220] Cf. The Mobility House (2016).

Dealing with this topic becomes increasingly important to reach the defined target shares of RES in the market. This is indispensable for cutting the carbon emissions, counteracting climate change and contributing to a sustainable future.

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