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Article

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Mostafa, Mohamed; Rommel, Kai

Integration of wind power in the electricity market: A business case evaluation

Abstract

The legal and economic frameworks have passed through a set of development cycles in order to adjust market rules to the development of the share of renewables (RES) in the electricity generation. The latest version of the German Renewable Energy Law (EEG) requires the RES power to be introduced into the electricity market through the Transmission System Operator (TSO) – “indirect selling”, or to be sold directly into the market by the plant, instead of receiving the fixed feed-in tariff – “direct selling”. In this paper, these aspects of integrating RES legally, economically and its operation will be addressed more detailed. Direct selling of RES power on the electricity market has the major advantage of enabling the integration of the RES after the expiration of the feed-in periods of 20 years. Furthermore, it helps the electricity community to develop the required experience dealing with RES in a competitive market without relying on the feed-in umbrella. The electricity market setup and -rules were designed for planned fossil power plants and not for fluctuating generation like wind generators, therefore the realization of direct selling of wind power is expected to be challenging. One major challenge, beside its fluctuating nature, is the limited predictability of wind power generation. In this paper, a business case will be evaluated to investigate the economic feasibility of direct selling of wind power in the current market structure. The evaluation will rely on the newly issued Act EEG 2012 and the market data of the year 2010. With the use of a Monte Carlo Simulations we evaluate a medium sized wind park case and reveal differences in revenues between direct selling and feed-in tariffs. In most cases, direct selling provides comparably higher revenues. However, the use of sufficient measures to increase forecast quality represents a substantial precondition. Chapter 1 describes the legal framework for wind power trading. In chapter 2 we explain the business case evaluation, including the data preparation and the analysis of wind power without and with reserve capacity. Chapter 3 gives a summary and an outlook into the future.

1 Legal Framework for wind power trading

Renewable energy support schemes can be divided into price and quantity regimes. In quantity regimes, e.g. the Norwegian system, the regulator determines the quantity of renewables (Quo-

ta) that needs to be achieved and leaves it up to the market to determine the right price. In price regimes, e.g. Germany, the feed-in tariffs are determined by the EEG, leaving the quantity of renewables that will be generated up to the market. Another scheme, called the bonus model, can be considered as a modified version of the price models. The bonus model encourages the RES to enter the electricity market and to compensate the price differences by an extra payment. The risk of investing increases with the higher market integration.

Even though the price model, such as the EEG in Germany, has led to a faster development of the renewable energy share in the grid, it isolates the renewable sources from the electricity market. Therefore, the EEG 2009 started an **optional** mechanism for direct or indirect selling of RES power on the spot market. An advantage of direct selling is the greater integration of renewable energy plants, especially fluctuating resources such as wind, sun, and hydro power plants in the market. However, with current market prices, it is of high risk to the operator that the EEG plants will be in the money if they decided to directly sell their power on the electricity market. Therefore, the idea of an adaptive market participation bonus was introduced in the next amendment of the EEG 2012 (cf. RENEWABLE ENERGY LAW 2012).

The EEG 2012 added a special article that deals with direct selling. It shows that the German Government sets a high value to this topic. In the future, all system operators of renewable energy plants can – as of now, they do not have to – sell the generated electricity into the market themselves, either through Over the Counter (OTC) trading or on the power exchange. Besides the sales revenue, the operator receives a market premium from the grid operator, who can consider it in the calculation of the EEG surcharge. To limit the obligation risk of the plant owners, the EEG 2012 gives them the chance to decide monthly, which kind of power selling they want to consider, either direct selling or feed-in tariff. The market premium is calculated as the average difference between the respective EEG feed-in tariff and the average market price of electricity. The average price depends on the technology, i.e., solar power has a different market value than wind power. The differentiation in the EEG feed-in tariff is not based on costs but on market values. For instance, solar power is available during day time, when electricity prices are higher than during the night. Therefore solar power has a higher specific market value than wind power, which is not similarly correlated. The average market price mentioned here is a weighted average and calculated separately for each technology, according to the nationwide feed-in. Compared to the EEG-fixed feed-in tariffs, the operator should not have a financial disadvantage when they optimize their performance in the market. Having a direct selling model which includes a market premium, all renewable energy is introduced into the electricity market

and the operators has to adjust their operation to their rules, so that the renewable sources will become more important for the electricity supply in Germany.

Figure 1 illustrates the basic concept of the market premium and its components. In this way an incentive is given to operate renewable energy plants according to the demand situation in the market. This is an important prerequisite for the operator to cooperate with e.g. smart storage, demand side management, such as cold stores, or gas-fired power plants to form a virtual power plant. This allows a better balance and integration of the fluctuating power generation from wind power and photovoltaic plants into the electricity system. With direct selling, new requirements came to the RES plants operators. The total actual power of a plant must be measured quarter-hourly and balanced in a balance group or sub-balance group with only similar kinds of power, i.e., the direct selling of RES power. The balance groups are used to physically and afterwards financially balance the actual power with the pre-submitted power profile.

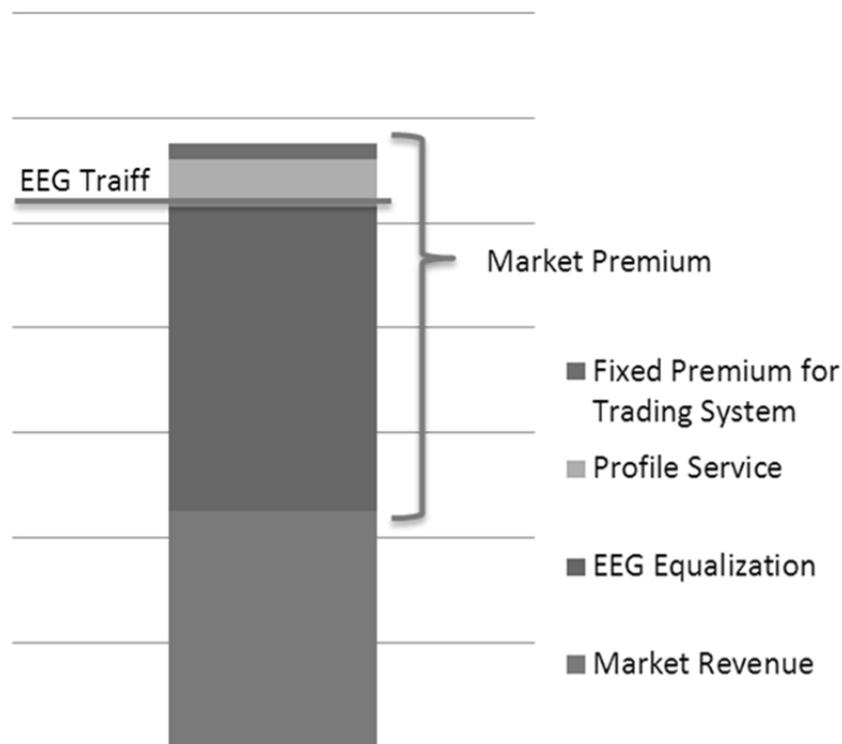


Figure 1: The concept of market premium; Source: on the basis of SENSFUSS/RAGWITZ 2011

The EEG § 33g states that “the amount of the market premium is calculated monthly. The calculation is retroactively based on the respective calendar month for the actually observed or calculated values on the basis of the value to be created pursuant to § 33h and in accordance with

the Appendix 4 to this Act” (cf. EEG 2012). Section § 33h sets the rules for calculating the value to be used for the market premium. It is based on the defined value of the feed-in tariff for each renewable source. As feed-in tariffs are calculated based on specific factors, they have to be calculated first, before calculating the market premium. The other important factor in the calculation is the monthly average of the market price for electricity. By coupling the feed-in tariff to the monthly average (Phelix Base) the risks of market price fluctuation will be eliminated. However, the incentive to respond to the hours of sharp price trend remains intact.

The market premium is expected to have the following benefits: a) shifting the maintenance work for RES power plants to lower-cost phases, b) reducing the production of RES power for negative price, c) improving mechanisms for power forecast and adherence to scheduled power, and d) promoting ideas for optimal performance through, for instance, pooling of plants, demand-side management with industry, and storage power plants. In the following business case evaluation we analyse the determinants of the market premium and the required quality of prediction models. The use of different simulations enables us to evaluate the conditions for revenue maximisation under the legal regime of the EEG 2012.

2 A business case evaluation

In order to decide whether to receive the fixed feed-in tariff or directly respectively indirectly sell the wind energy to the market in order to receive the market premium, a business case should be evaluated to understand the economic feasibility of both options. In the following, a single, relatively small, 100 MW wind park will be evaluated with the following key assumption: **entering the market with this power will not have an impact on the market clearing price.** This assumption is so far valid considering that the normal generator sizes of conventional power station are in the range of 500 MW to 1,500 MW. With these assumptions the spot market price history can be used for the evaluation for the selected year. The process shown in Figure 2 will be used for the calculations. It can be described in the following steps:

1. The day ahead forecast will generate a time series of wind power. This power will be sold in the day-ahead market.
2. The shortest-term forecast is run hourly to correct the yesterday’s forecast. The difference between the day-ahead and the shortest-term forecast can be corrected by trading activities on the intraday market.
3. The remaining forecast errors have to be compensated either by balancing energy market or by holding own operated reserve capacity or a combination of both.

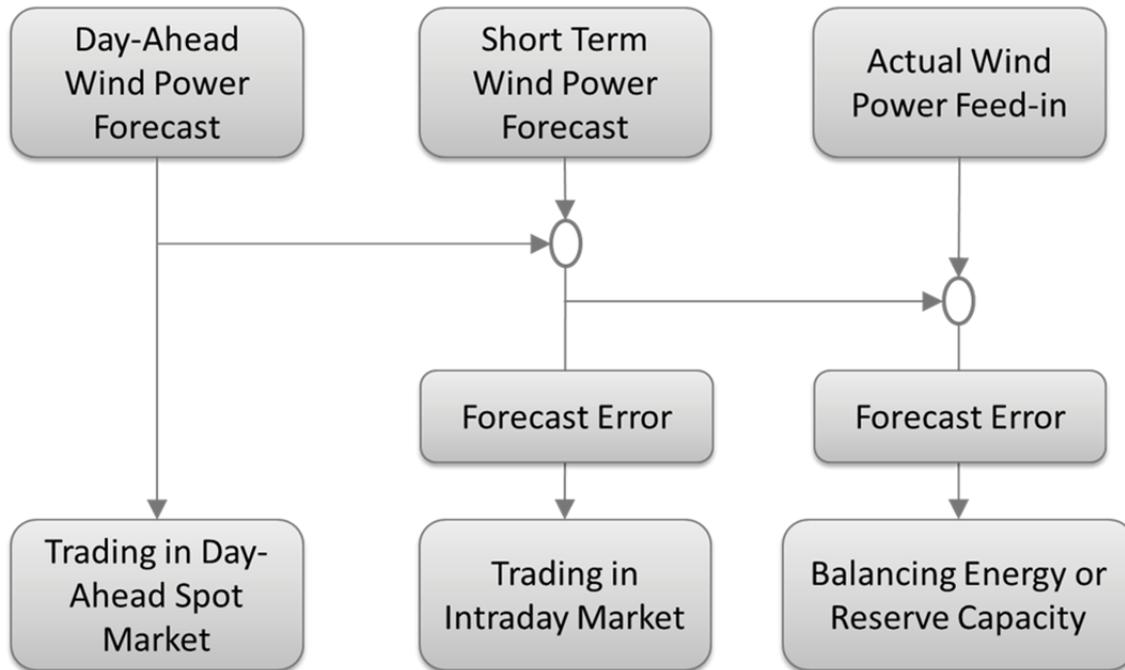


Figure 2: Trading process of wind power; Source: own research

The subsequent sections cover the following steps of the evaluation. Section 3.1 describes the data preparation needed for the calculation, e.g., wind power forecasts and the spot prices. Section 3.2 and 3.3 describe the evaluation of the direct selling model as illustrated in EEG 2012 without and with reserve capacity. In section 3.4 the results are discussed.

2.1 Data

Wind power data for single wind parks

According to reports of the German TSOs, nowadays day-ahead wind power forecast systems are an essential tool for grid integration of wind energy, especially for trading activities on electricity spot markets. The accuracy of the forecast is an important factor, as forecast quality is directly related to the use of balancing power and, thus, additional costs. The data needed for the evaluation is the following:

1. Day-ahead wind power forecast for the calculations of spot market revenue.
2. Intraday forecast for intraday market trading.
3. The real feed-in for the balance energy cost calculations and for calculations of the direct selling market premium.

The four German TSOs publish the power feed-in and the day ahead forecast for the wind power in their grid. The intraday forecast, however, is not published. The quality of the intraday forecast can be anticipated from the trading volume on the intraday market and its relation to the required balancing energy.

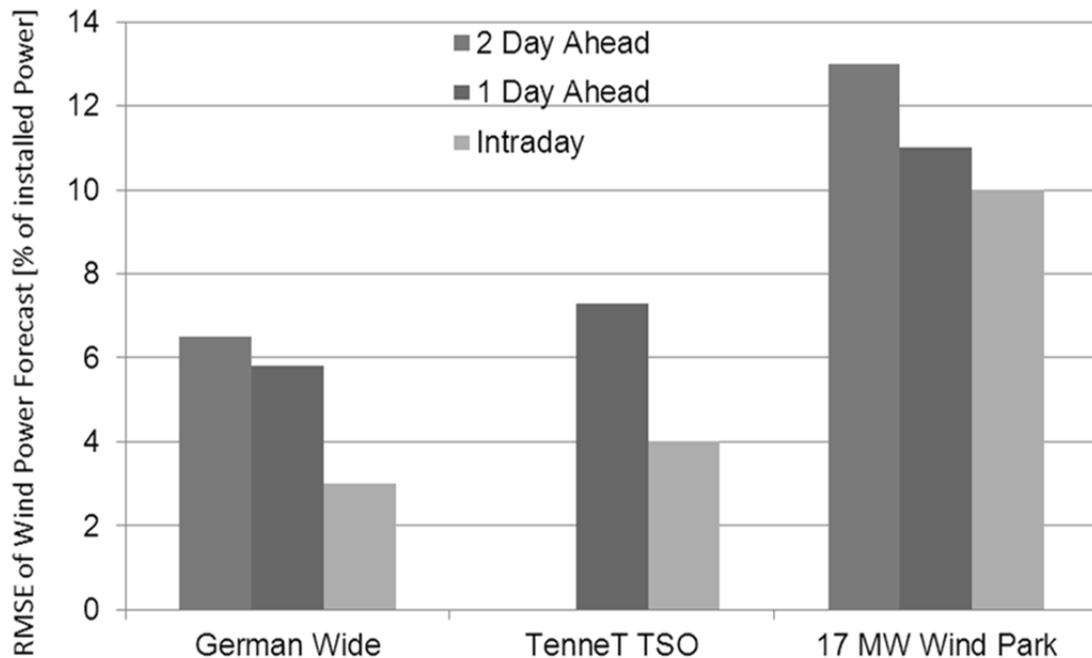


Figure 3: RMSE for wind power forecast, German wide, TenneT TSO grid, and 17 MW wind park; Source: MOSTAFA 2011: 54

However, this data cannot be directly used for the wind park estimation. Just reducing the wind power data of the grid zone of TenneT TSO for the wind park level of 100 MW is not sufficient, mainly due to the following facts. The first point is the forecast quality, which is noticeably reduced for single wind parks. The most popular error-measure to assess the quality of the forecast is the root mean square error (RMSE) based on the deviation between prediction and measurement normalized to the installed wind power. Figure 3 shows the RMSE for different cases. The figure shows that in case of small wind park of 17 MW, the RMSE is noticeably higher than the averaged RMSE over the grid zone of TenneT TSO and the German wide.

The Germany-wide prediction has a comparatively low forecast error because it can take full advantage of spatial smoothing effects (cf. LANGE/FOCKEN 2008: 3), i.e., errors at one location cancel out partly with other distant locations. Therefore, for a single wind farm the power prediction is associated on average with a relatively higher forecast error.

The DENA Grid study II estimated a forecasting improvement of 45 % reduction of the current RMSE value by 2015. The forecast quality depends also on the location: in GIEBEL et al. (2007: 9) different cases with different forecasting models are described. Considering these data and information, for the case study evaluation the forecast quality of 100 MW Wind Park in TenneT TSO grid is selected to have an RMSE of 10.5 % for the day ahead and 6.3 % for the intraday forecast. The revenue sensitivity against these factors will be simulated. The second is that the wind power of a single wind park is not necessarily timely synchronized with the power feed-in in the whole grid. This is important for two facts, the balancing energy cost (cf. STROM NZV §8 & §9 and TENNET TSO 2) and the calculation of the direct selling premium (cf. EEG 2012, §33g).

The balancing energy cost depends not only on the difference between submitted power schedule and the real power feed-in, but also on the timely correlation between the sign of grid demand and the sign of the wind park balance area situation. The process used to calculate the wind park data for the case study is based on the following steps:

1. Downscaling of the TenneT TSO wind power data of 2010 to a 100 MW scale.
2. Then shifting the data by one hour in time. This is done to desynchronize the wind park data from the whole TenneT TSO wind feed-in power, so that the effect mentioned in the paragraph above is modelled.
3. Increasing the RMSE of the data to the needed value for the evaluation to consider the RMSE values shown in Figure 3. The deviation profile however is kept the same of TenneT TSO.

Market price data

The EPEX SE provides a data package with all spot market results and intraday. The average market price for 2010 is 44.48 €/MWh. Although negative prices were observed, its occurrence is very limited to a couple of times in the whole year. The majority of cases are in the range of 20 to 70 €/MWh. The average market price is much below the EEG feed-in tariff of 89.3 €/MWh, which indicates the needs for an incentive like the market premium for direct selling as described in the EEG 2012. The hourly prices are used for the calculation of the market revenue of the wind power in the day-ahead market. These prices are used for the calculation of the market premium for the paper at hand.

For the intraday market, the EPEX publishes only the highest, lowest, and average prices. In the evaluation, the average prices will be used. The correlation between day-ahead and average intraday market prices is close to unity, with an average of 45.62 €/MWh. This indicates that

trading activities on the intraday market, which are used to compensate the forecast error, will not represent a high loss factor.

The last component in the market data are the balanced energy price. According to EnWG (Energy Industry Act), the data is published for each transmission grid on the corresponding website of the TSO. For the majority of the cases the prices in 2010 ranged between 73 €/MWh and 173 €/MWh for the positive prices, and -2 €/MWh to -30 €/MWh for the negative energy prices.

EEG direct selling market premium

The method to calculate the market premium is described in EEG 2012, appendix 4 as follows:

$$MP = EV - MW_{EPEX} + P_M$$

EV is the valid feed-in tariff at the time of calculation according to the EEG rules. MW is the market value which is calculated for each month as follows:

$$MW_{EPEX} = \frac{\sum \text{Wind Power}_h \times \text{Price}_{hEPEX}}{\sum \text{Wind Power}_h}$$

The idea behind this calculation is to achieve the **average** market value that a wind park would achieve if its electricity is sold to the market.

The management premium P_M of 12 €/MWh is considered to cover two main cost factors, the profile service and the administrative spends associated with participation in the market. According to SENFUSS and RAGWITZ (cf. 2011: 11f.) the total of 12 €/MWh is composed of 9 €/MWh for profile service and 3 €/MWh for market participation fees. For this evaluation it will be assumed that the 3 €/MWh are completely spent on market participation activities and thus will not be considered in the market premium revenue. The value of the market premium (MP) is multiplied by the actual generation of wind power in each month and provides additional revenue to the participant in the direct selling scheme.

2.2 Case 1: Wind power without reserve capacity

In case 1 the revenue obtained by a wind park is evaluated based on the data set described in the previous section. This revenue is compared to the other option to sell wind power energy using the EEG feed-in tariff. The revenue R_t obtained by a wind park in the electricity market for one day period can be calculated as follows:

$$R_t = \text{Power}_{DA} * \text{Price}_{DA} + (\text{Power}_{ID} - \text{Power}_{DA}) * \text{Price}_{ID} + (\text{Power}_{Real} - \text{Power}_{ID}) * \text{Price}_{BE} \\ + \text{Forecast Trading Spends}$$

Table 1: Main parameters for the baseline scenario; Source: own research based on Fig. 3

Parameter	Value	Unit
RMSE Day Ahead forecast	10.5	% of installed capacity
RMSE Intraday forecast	6.3	% of installed capacity. 60 % of RMSE Day Ahead. The 60 % ratio will be kept in the sensitivity analysis
Intraday liquidity	100%	All trades required on Intraday market are achievable

Firstly, the simulation is run as a base line scenario with the parameters listed in Table 1. The programming tool MATLAB[®] was used to calculate one year of operation using an hourly based model for the electricity market and a model with a 15 minute scale for the balance energy market. Afterwards a sensitivity analysis is carried out to explore the effect of each factor on the result.

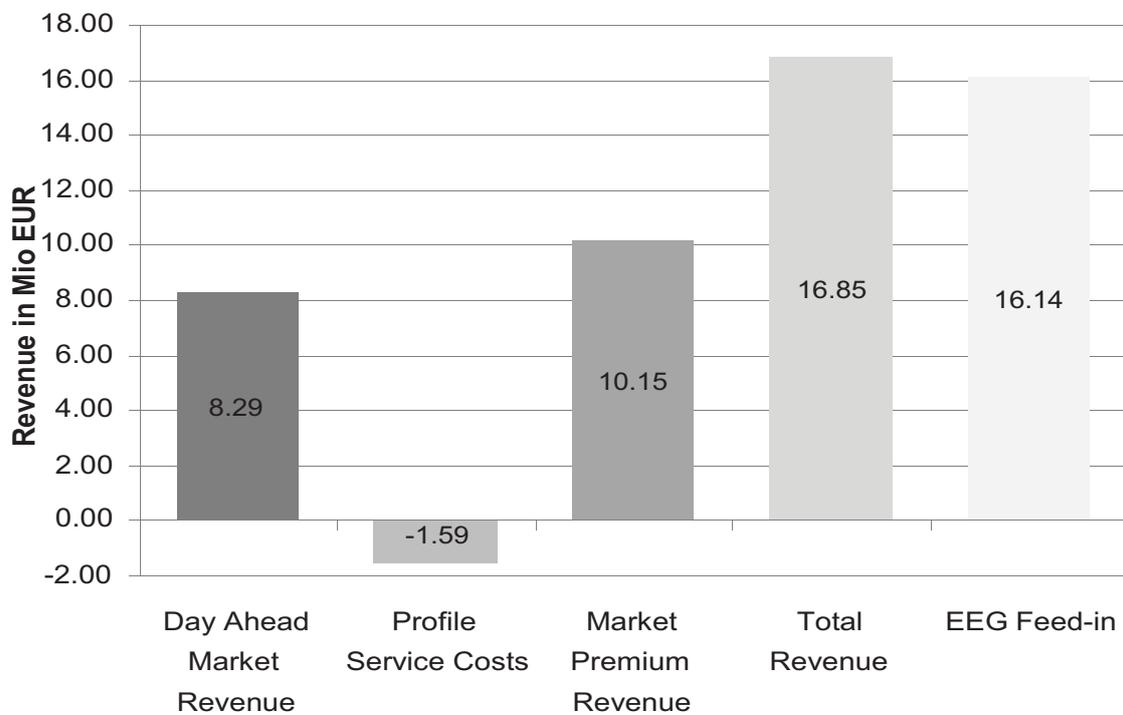


Figure 4: Different revenue components of direct selling of 100 MW wind park; Source: own research

The results for the direct selling of the 100 MW wind park are illustrated in Figure 4. The evaluation shows that the direct selling total revenue is higher than the EEG feed-in tariff. The simulation data shows that the profile service component, i.e., the costs needed to fulfil the submitted day-ahead forecast power are less than the EEG estimated value of 9 €/MWh. In the simulated

case, the cost was 5.1 €/MWh, which is the variable part of the profile service costs divided by the total generation. The profile service component will be reduced in the subsequent years as shown in EEG 2012. The value for 2015 is 6 €/MWh. This is, according to this example, still enough to cover the profile service costs.

Sensitivity analysis and Monte-Carlo simulation

In MOSTAFA (2011: 62) a detailed sensitivity analysis is done to investigate the effect of each factor on the total revenue of the direct selling model. The investigated factors are forecast quality, balance energy prices, intraday market liquidity, and volume of generated power. The most important factors in this study here are the forecast quality and the prices of the balance energy. As an example, the sensitivity against the RMSE of the day ahead forecast quality is given here. It will be changed from 6 % to 17 %, and the whole model will be evaluated for each case. The results show that the revenue decreases with increasing the RMSE, i.e. with decreasing the forecast quality. Figure 5 shows these trends.

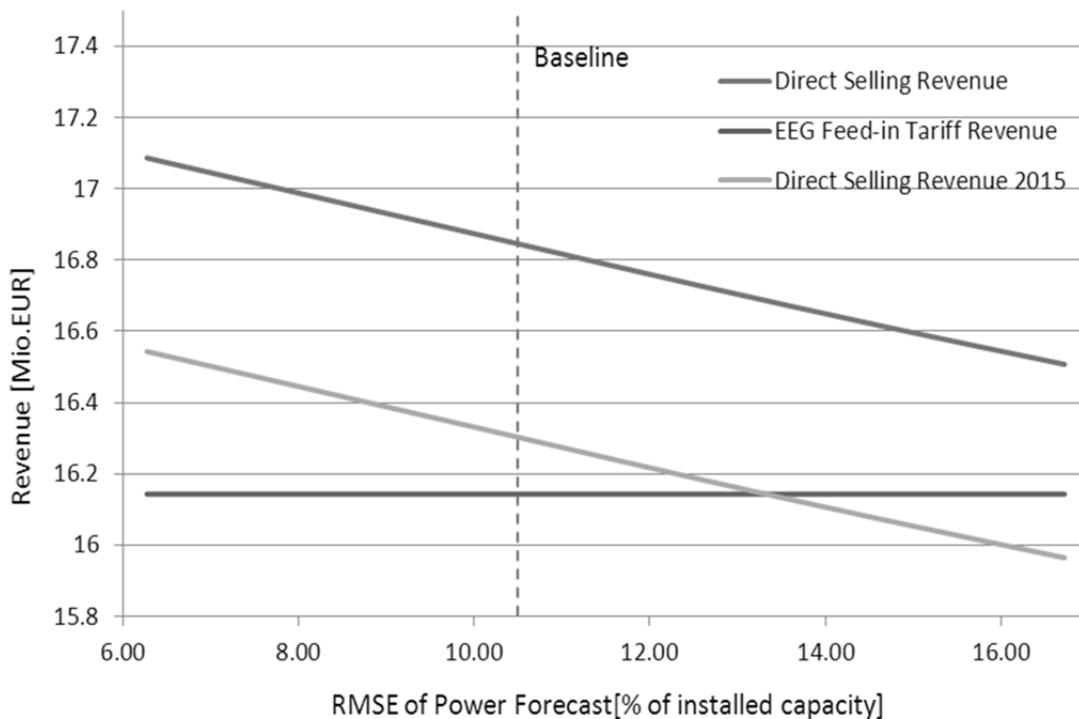


Figure 5: Revenues vs. RMSE of day ahead forecast; Source: own research

For a probabilistic based decision making over all factors and its possible distribution function Monte Carlo Simulations (MCS) can be used. In BORCHERT et al. (2006) more details are given

about MCS and their applications in the electricity field. This method relies on repeated random sampling to compute the results. To use MCS, a set of data has to be generated for each variable. These data are fed-in the simulation model and the results are shown as a probability function. The input data set shall reflect the input variable distribution. Because of their reliance on repeated computation of random or pseudo-random numbers, these methods tend to be used when it is unfeasible to compute an exact result with a deterministic algorithm.

Table 2: Parameter distribution; Source: own research

Variable Name	Distribution	Parameters	
RMSE Day Ahead forecast	Normal	Mean 10.5 %	Standard Dev. 1.55 %
RMSE Intraday forecast	Normal	Mean 6.3 %	Standard Dev. 1.06 %
Balance Energy Price	Uniform	Min. 100%	Max. 200 %

For the simulation runs, a certain parameter set has to be selected and varied in a realistic range. In the sensitivity analysis it was shown that three parameters have a significant effect on the results. These parameters are listed in Table 2. For MCS these parameters will be given a series of value based on a certain distribution, and its parameters as listed in Table 2.

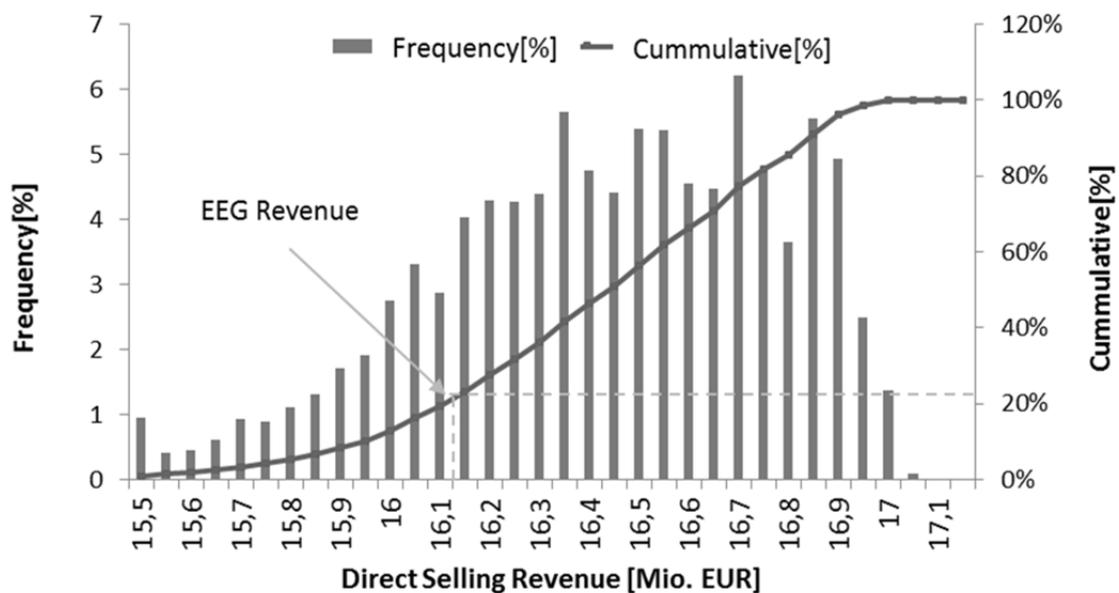


Figure 6: Monte Carlo simulation results; Source: own research

A combination of all cases within the given distribution gives 5,760 cases. For each case the revenue model is evaluated for each hour in the year as described in the previous sections (cf.

Figure 6). In 78 % of the cases, the direct selling revenue was higher than the EEG feed-in tariff. This is illustrated by the dotted line at 22 % cumulative and around 16.1 Mio. Euro direct selling revenue. This indicates that the provided market premium model gives secured investment options for wind park operators if they decide to sell their electricity directly to the market.

2.3 Case 2: Wind power with reserve capacity

As shown in the previous evaluation, the profile service efforts cost a significant amount of 1.59 Mio Euro. The balance energy portion of it was – at the baseline scenario – 838,000 € spent to compensate the intraday forecast error by using the balance energy market. The cost of balance energy does not only depend on the mismatch between the submitted power profile and the real feed-in, but it also depends on the situation on the grid at the specific moment of feed-in. For example, if the wind park is long, i.e., there is more feed-in than scheduled, and the grid is also long, i.e., it has more power than needed the wind park is most likely to pay in this case. In some cases, if the excess energy can be sold – for a normally very low price – the wind park will receive this small amount as well. If however, the grid is short and the wind park is long, the wind park will receive money from the TSO for this excess power at this measurement and calculation period. The case study evaluation at the baseline shows the ratio in Table 3, first column. More details about the composition of these costs are given in MOSTAFA (2011: 63).

Another option, instead of using the market, is to use own operated reserve capacity, which can provide the power quality needed in terms of response time and capacity. Important decisions about the reserve capacity are mainly the technology type and the capacity. Currently there are two major technology types that are being discussed in the literature and in news articles (e.g. AL-AWAM/EL-SHARKAWI 2011: 2; VDE 2008) on balancing energy needs for wind parks, storage and gas fired generators. Key features of these technology types are response time and easiness to build. In MOSTAFA (2011: 80) the gas fired power station is investigated and shown to be a non economical option even if the prices of balance energy raise, because gas prices will raise as well. The next section investigates the economic feasibility of operating own capacity using battery storage.

In the ideal case, the reserve capacity covers all the balance energy demand. However, this is not necessarily the most economic design. The distribution of the deviation gives an idea about the design value of the reserve capacity. Figure 7 shows that 80 % of the forecast errors range from -10 MW to +10 MW. An optimum capacity usage suggests covering the majority of the cases and not all of the possible cases. As the specific cost to value ratio to cover the extreme cases will be much higher than the most frequent cases. A selection of the capacity value of the

reserve power will be defined to be 10 MW for the evaluation, and the remaining deviations will be covered by the balancing energy market.

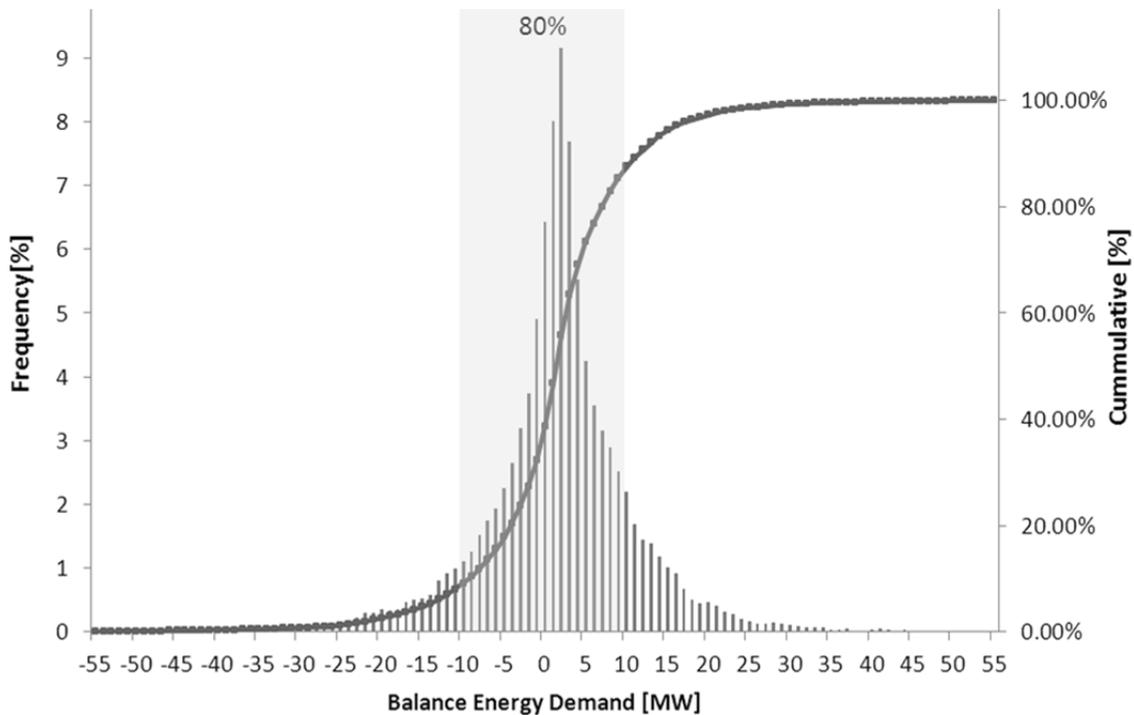


Figure 7: Distribution of balance energy demand for a 100 MW wind park; Source: own research

Electricity storage can be utilized in different scenarios to integrate wind power in the electricity system. There are different types of technologies for building electricity storage. Each type is suitable for different scenarios of utilization. In case only the forecast error will be compensated and not the seasonal fluctuation, and in case that only a power capacity of 10 MW is in place, there are not many ways of storage suitable. For such a scenario a chemical storage, i.e., battery storage will be the most suitable technology type. The battery has the advantage of easiness of installation and the modularity in the design. From the existing type of technologies the Sodium based high temperature battery, e.g., NAS (Sodium NA Sulfur S), will be selected for the following reasons: (cf. VDE STUDY 2008: 5):

- High energy density, i.e., little space demands.
- Availability in the required power range as a sellable product.
- Modularity in the design which allow extendibility.
- Relatively long operation life time of 15,000 cycles.

Operating the battery power station with a wind park in the electricity market needs a daily optimization depending on the day ahead forecast and the battery state of charge (SoC). The state of charge is the level of energy available in the battery, which vary between 0 to 100 %. For the selected NAS battery the storage capacity is four times the power, i.e., for a 10 MW power, the battery station will have 40 MWh of capacity. In other words, the battery need four hours at full discharging power to fully discharge the battery from 100 % SoC to 0 % SoC. This feature of being fully charged or discharged puts additional limitation on the battery utilization. In some cases if the wind park needs balance energy and the battery is empty, even if the power demand is less than the power limit of 10 MW, the energy limit is reached. And the case is the same if the balance energy demand is to withdrawal power and the battery is fully charged. The trading process shown in Figure 2 will be adapted in our design of a trading process of wind power with battery storage as illustrated in Figure 8. The highlighted section indicates the extra logic needed for battery storage operation.

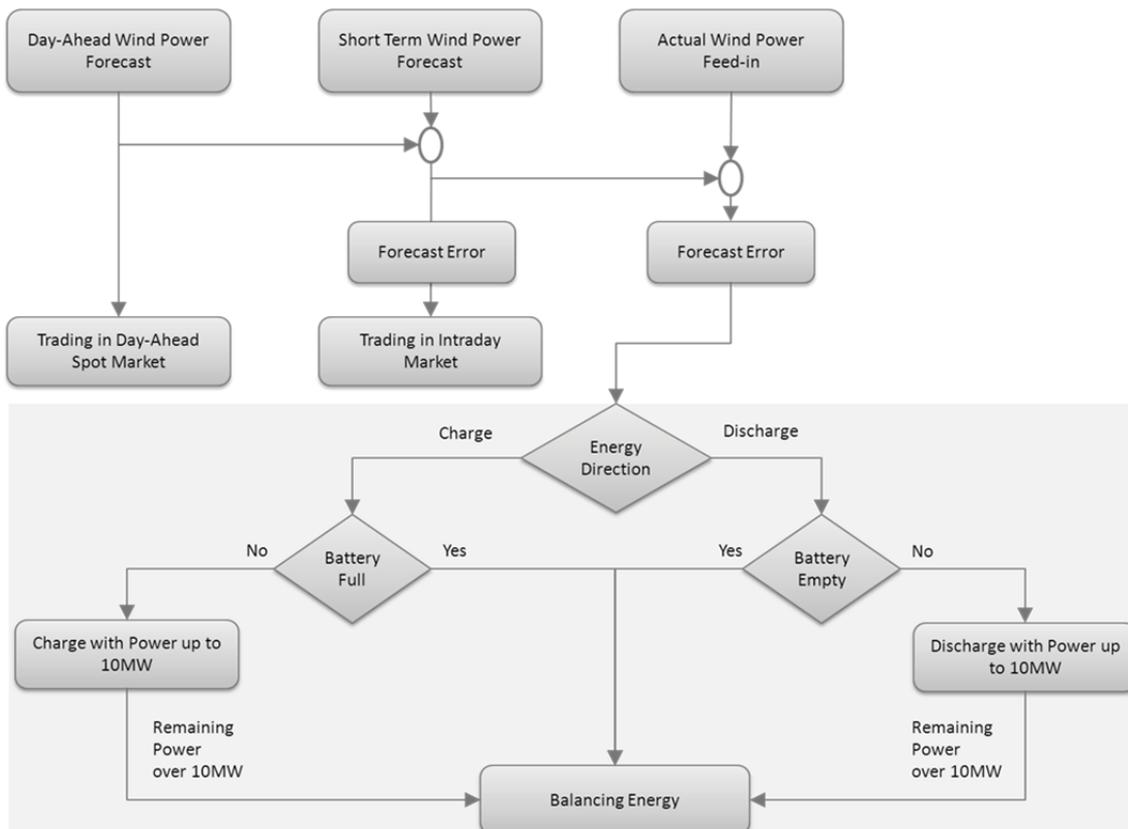


Figure 8: Illustrative trading process of wind power with battery storage; Source: own research

The process shows that the balancing energy market will be needed not only in case the power demands exceed the design value of 10 MW. It also shows that the intraday market is used for the first compensation using the intraday forecast. That is due to the following two facts:

1. Intraday market prices are very close to the spot market.
2. Storage is associated with energy losses due to battery system efficiency. The selected battery has a charging/discharging efficiency of 90 %, which means a cycle efficiency of 81 %. This means that only 81 % of the stored energy can be used.

The operation of the battery can be either simple or optimized. A simple battery operation just follows the balance energy demands. The SoC level will not be considered in the day ahead trading. Although this option is very easy in the operation, it reduces the utilization of the battery noticeably because the SoC reaches the upper and lower limits very often. And thus the balance energy market will be needed very frequently through the year. In this mode of operation the battery utilized only 30 % of the balance energy demand.

Table 3: Benefits of battery storage utilization for balance energy for different cases; Source: own research

	Baseline	Battery storage without SoC optimization	Battery storage with SoC optimization
Pay for mismatch	-1,820,000 €	-1,418,000 €	-503,000 €
Receive for the mismatch	+982,000 €	+616,000 €	+247,000 €
Total payment	-838,000 €	-772,000 €	-256,000 €
Saving comparing to baseline	NA	+66,000 €	+583,000 €

This simple operation reduced the balance energy costs only by 66 T€. Table 3 shows these results in column 2. Although the wind park pays less, it receives less in similar amount. And therefore the overall saving is very small.

Another operation mode was introduced in the literature (cf. YUAN et al. 2010: 4). To avoid reaching the operation limits of the storage, the market bidding (day ahead and intraday) will consider the SoC. Simply said, if the battery is close to be fully charged, the bidding will be set higher than the forecast, so that the probability to discharge the battery is higher and vice versa. Assuming that this would work properly, the SoC would hit the limits much less than without this optimization and thus increase the utilization factor of the battery. This algorithm will not be implemented in this work: rather an assumption of the published results will be simulated. The evaluation results are shown in Table 3 row 3.

As the battery power station costs millions, Case 1 with savings of about 66,000 € is not worth economic evaluation. It is not feasible at any case. However, case 2 might be considered. The battery system of 10MW/40MWh assumes a cost of 16 Mio. € and needs 105,000 €/year for costs of operation and management (O&M). The saving of 582,900 € and the O&M costs can be used as a basis for the first year and increased with an assumed inflation rate of 4 % for the next 20 years. With these parameters the battery power station has a negative net present value of -12 Mio. € and also a negative internal rate of return (IRR) of -7 %.

This evaluation shows that with the current market circumstances, the battery power station is not an economic option for error compensation of the intraday wind power forecast. The interesting question is under what conditions the battery storage would be a feasible option. Figure 9 shows the development of the net present value (NPV) and the Internal Rate of Return (IRR) vs. the balance energy price. The condition for the project to be in money is relatively unrealistic for short term in Germany and is that balance energy prices exceed 250 % of its current level or battery system is becoming cheaper with the same ratio. If these conditions apply for other markets, then storage solution would be a feasible option.

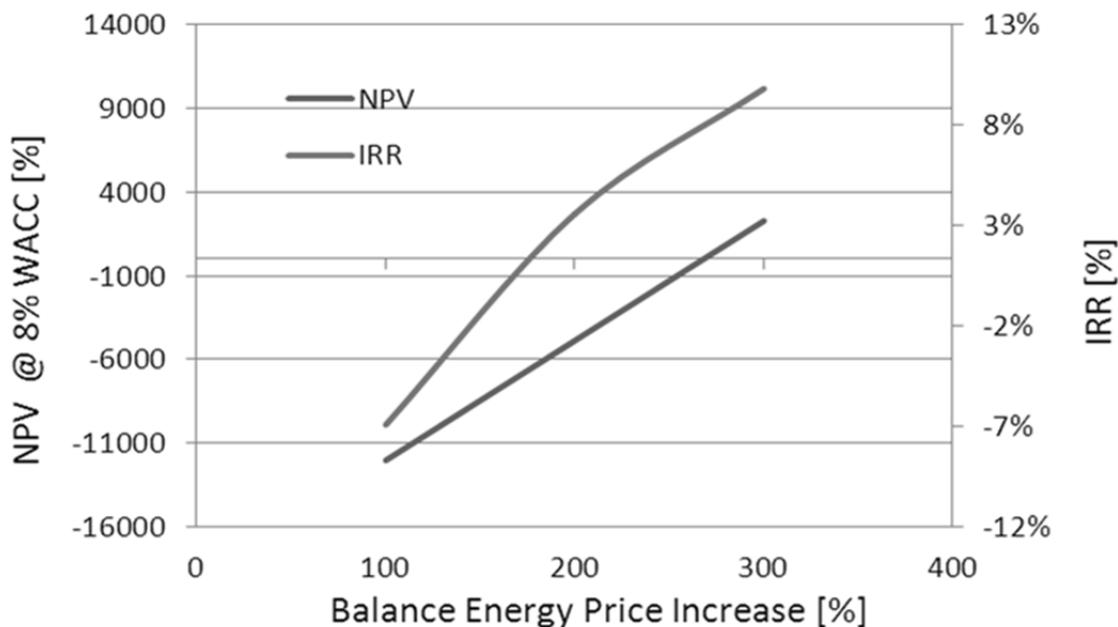


Figure 9: NPV and IRR for the battery power station vs. balance energy price; Source: own research

A Monte-Carlo Simulation showed that with a probability of 78 % the wind park with direct selling option as described in EEG 2012 will generate more revenue than the feed-in tariff. The battery utilization for forecast error compensation with the known prices for the storage technolo-

gy and balance energy does not seem to be an economically feasible option from the perspective of the wind park operator. A possible explanation to that is a mismatch between the power quality needed for compensation of forecast error and the capacity of the battery. The battery can offer a very fast response – in seconds – to the wind power fluctuation. However, this fast response is not needed for the compensation of wind power forecast within a period of 15 minutes. Therefore, this technology type can be utilized in a certain area of balance energy, the so called Secondary Control (cf. KAZEMPOUR/MOGHADDAMI 2010: 4).

3 Summary and future outlook

Through the previous evaluation it can be stated that **direct selling of wind power is an economically feasible option, and for the current market setup, the relevant market should be used for forecast error compensation.** In the majority of the cases the revenue gained by using the direct selling option exceeded the revenue based on EEG feed-in tariff. Thus, only when the key factors in the analysis reached improbable values, the direct selling will not be an attractive option any longer.

Although the technology prices for wind power are decreasing over time, the wind industry still needs incentives to participate in the market. This is especially due to the fluctuating nature of wind power and the limited predictability. This generates additional costs for forecasts and its compensation power. Furthermore, hedging instruments are not yet developed for wind power to cover such risks.

The market for electricity trading is setup for planned generation. Wind power is, by definition, only planned one day ahead. This limits the number of markets and products suitable for wind power. The spot market and intraday markets are suitable for active participation in the electricity market. The balance-energy market is also used however by definition in a passive way. The wind power forecast is used to define orders in the spot market. The spot market closing time is 12:00 pm of the day previous to delivery. The wind power forecast quality at this time is relatively poor. Delaying the closure date will give a chance to wind power traders to make use of the improved forecasts and thus reduce the need for balance energy and intraday trading. Participation in the spot market with high wind penetration is expected to affect the settlement price and possibly increase the volatility of the market price. An interesting evaluation, which could be accomplished in future, is to simulate the effect of the wind power penetration in the electricity market on the market price.

The evaluation done in this work shows that the balancing activities or the so called profile service costs represent a high cost factor in the firms' profits. What has been evaluated in this work is based on certain type of technology. It would be interesting to evaluate other technology types in order to validate our results. Options would be to use a combination of different types to provide the required power quality and avoid being over-qualified in terms of power quality. This could minimize the overall costs. Also the costs of technology are getting cheaper with the progress on technology and thus the evaluation can be run again with the new market situation.

Not only different technology types should be evaluated, but also the operation model. In YUAN et al. (2010) introduce a suitable approach. It describes mainly the optimization of day-ahead bidding and using the battery not only as balance energy provider, but also to shift the power from the low electricity prices time to the high prices time. In addition pooling of wind parks in one balance area can make use of the special smoothing of the forecast error and thus reduce the balance energy demand for the whole pool. This combined function of the battery could increase the market revenue gained by the battery and thus make it an economically feasible option.

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