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Future Economic Perspective and Potential Revenue of Non-Subsidized Wind Turbines in Germany

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Abstract. Thanks to the German Renewable Energy Act todays wind turbine operator are dealing with low risk on the revenue side in Germany. Fixed feed-in compensation ensures planning security and high system utilisation. Anyhow, the level of financial support is being reduced consecutively. Therefore, tomorrow's plant operators have to trade self-sufficiently on European electricity markets hence generate revenue only by marketing electricity. Against the background of uncertain future market developments as well as stagnation in the expansion of renewable energies in Germany, it is of interest to estimate future revenue potentials of those non-subsidized wind turbines. This way investment risks can be reduced and development goals for tomorrow's wind turbine technology can be deduced. To address this topic, a model has been developed using a modified merit-order approach to forecast long-term day-ahead prices on European electricity markets at an hourly resolution. The model is solely based on open access data. The results show how changes in the German power generation landscape like dismantling of coal and nuclear power plants as well as different emission prices impact the wind turbines potential revenue. A scenario analysis highlights that most of today's wind turbines are not able to yield financial profit over their lifetime without guaranteed subsidies in Germany. This underlines an urgent need for technical development and new business models. Possible business models could be Power Purchase Agreements (PPA) for which the model results can be used for setting and negotiating appropriate terms, such as an energy price schedule or penalties. Moreover, the results can be used as input for investment calculation and analysis. Hence, the given forecasting model can help to reduce risks on revenue side for plant operators and finally support the expansion of wind energy as a whole.

1 Introduction

Renewable electricity generation technologies have been heavily subsidised by the German Renewable Energy Act (EEG) in the past to achieve energy policy goals by reducing greenhouse gas emissions. Investments in the renewable energy sector have been particularly attractive and led to a strong expansion. In the form of the tendering procedure, an attempt was then made to create a market economy environment and increased competition to promote the competitiveness of wind energy. However, at the same time increased requirements and more lengthy approval and licensing procedures led to stagnation in onshore wind energy expansion in Germany (Bundesministerium für Wirtschaft und Energie, 2018, 2019).

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The final investment and thus expansion decision usually takes place on a local and project-specific basis. Whether a new wind farm is erected is therefore a new consideration for each individual case. In Germany, relevant decision-makers are often located at municipal level (Hirschl et al., 2010). In this context, the development of the electricity exchange price represents a relevant external factor for the investment decision.

The aim of this research is to address the barrier of uncertain marketing revenues from wind turbines (WT) without subsidies in Germany by estimating future electricity exchange prices. For this macroeconomic topic, national up to European market environments and electricity sectors must be considered. However, due to the decentralised nature of renewable energies it is also necessary to look into individual expansion projects on a microeconomic level. By forecasting future prices it is desired to support municipal decision-makers at planning and designing local expansion more independently.

In the following section 1.1 the current marketing situation for WT operators in Germany is summarized. Afterwards in section 1.2 existing forecasting models with a similar scope are being discussed. Based on these two sections the elaborated forecasting model will then be derived and discussed in section 2. Finally in section 3 model results are interpreted along a brief case study.

1.1 Revenue situation for wind turbine operators in Germany

In 2017, the whole EEG support scheme has been overhauled. The level of subsidization is now being determined through tendering. The operator receives an individual market premium after successfully taking part in a tendering procedure (Bundesverband WindEnergie e.V., 2018). In addition, the EEG 2017 defines a maximum tender volume for each year. Bids that exceed the set limit are not receiving financial support (Fachagentur Windenergie an Land).

Since 2016 new power plants with an installed power over 100 kW are bounded to direct marketing (§21 EEG 2017, §EEG 2014). For operators of WTs that have been approved before EEG 2014 direct marketing is optional. (EEG 2014, §100, subsection 1, number 6) The first step towards direct marketing is to choose a direct marketer and then conclude a contract, which regulates payment terms, possible compensation payments and the remote controlling. The latter is required for direct marketing. The direct marketer then needs to register the new plants at the distribution grid and include them into his accounting grid to be finally able to enter the electricity exchange market.

A currently discussed alternative for marketing of electricity from renewable sources are long-term Power Purchase Agreements (PPA). These enable bilateral trading including consultation between contracting parties. Those agreements normally cover a period of up to ten years and are established individually each time by the contract parties. PPAs define the following aspects of power purchase: amount of electricity, price, contract terms and penalties for breach of contract (Javadi et al., 2011). A distinction is made between on-site and off-site PPAs with different subcategories. On-site PPAs include a direct physical electricity delivery from the producer to the customer. That is the reason why a geographical proximity is

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significant for these types of PPAs. The costumers minimize their risks by outsourcing power generation while long-term contracts ensure economic viability and calculability for the operator. (Elwakil and Hegab, 2018)

Off-site PPAs on the other hand deliver the defined electricity amount through the public electricity grid. No direct physical delivery of electricity between producer and costumer is happening. A network charge needs to be paid for these PPAs, but also geographical flexibility exists. This means that producers can choose their location by site-specific factors, which allows production to be optimized. Plants may enter several PPAs with different customers at the same time.

So far long-term PPAs are highly controversial. Proponents state that they are a good and necessary tool to support renewable energy. Opponents criticize that the PPA price is currently often set well below the exchange market price and thus makes the economic operation of plants even more difficult. Existing non-subsidized WTs that have exceeded the 20-year limit can either be repowered, deconstructed or further operated (Steinhausen et al., 2018). First contracts for PPAs have been concluded for old WTs, but also new WTs. Compared to other European countries the PPA market in Germany is much less developed. In a lot of neighbouring countries PPAs are already an established procedure (Fischer et al., 2019; Tang and Zhang, 2019).

1.2 Existing forecasting models

Extensive literature is available in the field of modelling and forecasting electricity exchange prices. However, there is no consensus on the approach and methodology of modelling. Most models are designed for a specific market situation or forecasting horizon in which they perform well and deliver robust results (Weron, 2014). However, many models aim to predict EEX price movements reliably. In the following, some practical examples of forecasting models of electricity exchange prices are presented which are of methodological interest for this work.

In 2010 Jonsson et al. investigate the influence of wind energy forecasts and actual wind volume on the Danish electricity exchange price. They use a non-parametric regression model and the statistical distribution of the spot price for different scenarios and conclude that a high forecast feed-in from wind turbines lowers the exchange price. The actual amount of wind energy also influences the price. In both cases the correlations are strongly non-linear. The authors observe growing price volatility and weather-related price patterns (Jónsson et al., 2010).

In 2013 Jonsson et al. then pursue a two-step approach to model the short-term spot prices in Denmark for the years 2010 and 2011. They forecast grid load and feed-in from wind turbines. Non-linear and transient influences of these two variables are considered in the first step of the model by a non-parametric regression. Subsequently, time series based models are used to represent remaining autocorrelations and seasonal effects. The authors conclude that models with variable parameter estimation can yield better results over time than those with static parameters (Jonsson et al., 2013). However, robust parameter estimation has the advantage that models are less vulnerable to abrupt parameter changes e.g. due to excessive price peaks.

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Fanone et al. are able to generate both negative and positive price peaks with a forecast model of the German intraday market with hourly resolution. The model parameters are calibrated using historical EPEX intraday data. The hourly spot price is divided into two components, namely a time-dependent adjustable component and a deterministic component containing long-term variations and seasonalities. When investigating daily spot prices an annual and a half-yearly periodicity can be observed (Fanone et al., 2013).

Šumbera and Dlouhý model the German spot market based on the assumption that the demand for electricity and the system load equal the generation capacity provided by all power plants at all times. A merit-order approach is used for pricing, which is subsequently extended. The power plants are divided into dispatchable and non-dispatchable power plants and others. The dispatchable power plants and their schedules are presented in high detail. Non-dispatchable power plants are grouped together in the model according to energy source and defined as "must-runs". Power plants whose generation depends only on their availability are modelled with variable costs of zero (Šumbera and Dlouhý, 2015).
A disadvantage of this methodology is that a set of all generation units or at least a representative data set must be available.

A criticism of existing models is the general lack of transparency and accessibility of the calculation methods and databases. Therefore, only openly accessible data is used for the presented forecasting model, except for the historical exchange market price development of EPEX Spot used for validation. However, these are not necessary for the subsequent use of the tool.

2 Methodology and forecasting model

To make investment decisions based on the revenue potential of wind turbines the entire life cycle must be considered, which lies usually in the range of at least 20 years. Therefore, the long-term development of the electricity exchange price has to be estimated. At the same time microscopic market effects like increased volatility due to feed-in of renewables should also be considered. These effects are represented better by short-term forecast models. In conclusion, a long-term forecast period with a high temporal resolution will be simulated.
Due to the changing political conditions, it is advantageous to be able to calculate different future scenarios.

2.1 Forecasting objective

The given model is oriented towards the mechanisms of the existing power exchange. The EEX markets and stock exchanges represent a highly relevant objective for forecasting, due to their central location and economic influence. One of the most relevant markets for trading electricity from wind turbines is the day-ahead market. On this market, electricity is traded for every hour of the following day. In practice most OTC trades are based on the current level of the (day-ahead) spot market. When drafting PPAs, it is customary to use the course of the stock exchange price as reference. The forecasting objective of this study is therefore the day-ahead spot price for the next twenty years. This automatically satisfies the initially formulated requirement for a high temporal resolution.

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Figure 1 shows which input variables and calculations are necessary to describe this objective and how they have been connected within the presented model. In the following, the input data and intermediate steps used are explained in more detail. The electricity spot price is calculated using a merit-order concept extended by a multi-agent approach for every hour of the time period under consideration. The required data and steps are descried in the following subchapters.

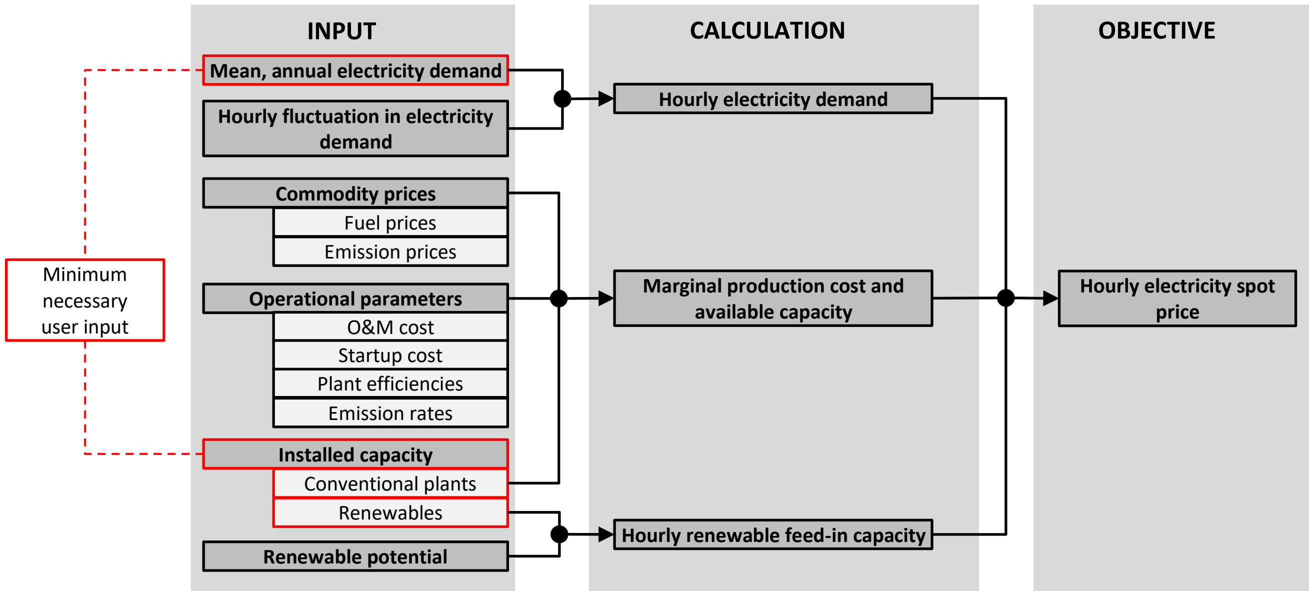

Figure 1: Schematic model structure and input data requirements

The average annual electricity demand and the annual installed plant capacity are the only data to be provided by the user. Reference values are available for all other parameters. This represents an improvement towards the criticized excessive data requirements of existing models.

2.2 Hourly electricity demand

The hourly demand for electrical power of a country for each year is composed of an annual mean value D_{mean} and an hourly fluctuation factor f_{var} according to Eq. (1). D_{mean} is determined by the user or assumed scenario while f_{var} remains the same for any scenario. The time series for f_{var} is derived from TYNDP18 (Ten Year Network Development Plan) data from the European network of transmission system operators (Entso-e, 2018b). Figure 2 shows annual (a), weekly (b) and daily (c) sections of f_{var}. It can be observed how f_{var} covers different cyclic characteristics of the actual electricity demand like higher demands during winter as well as peak and off-peak hours. All long-term demand trends have to be considered within D_{mean}.

$$D(t) = D_{\mathrm{mean}} \cdot (1 + f_{\mathrm{var}}(t)) \quad (1)$$

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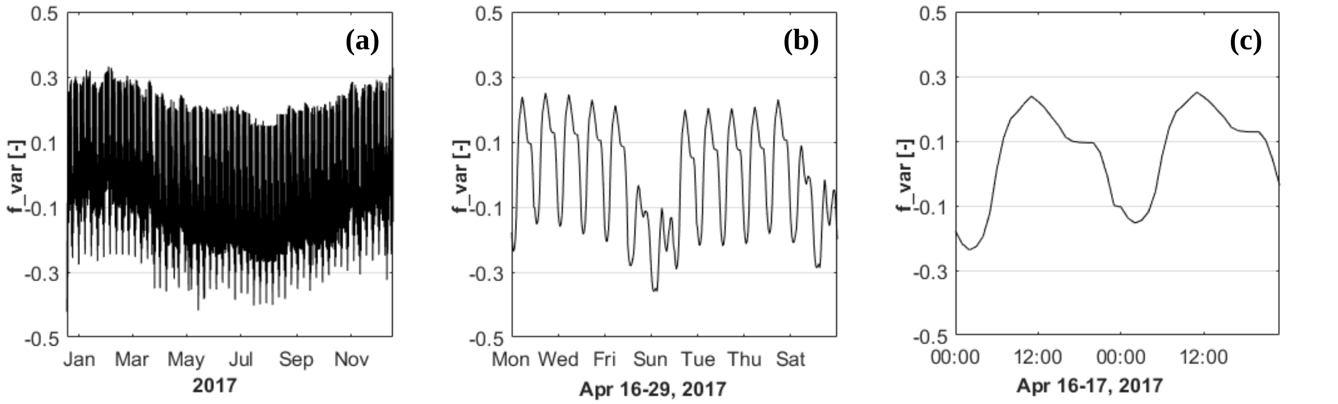

Figure 2: Demand variation factor f_{var} for Germany in 2017 with annual (a), weekly (b) and daily (c) characteristics

2.3 Available generation capacity and marginal cost

The national installed capacity and generation plants are classified by conventional and renewable plants, where gas, hard coal, lignite, oil and nuclear fuelled plants are considered as conventional. On the other hand hydro, solar, wind (onshore and offshore) and others (mainly biomass) are considered as renewable.

Based on these categories a total installed capacity per year is required as user-input. In a next step the model derives individual objects to generate an object oriented plant fleet based on reference data. Afterwards each object can also be parametrised individually. Marginal generation cost c_{var} is then calculated for every plant following Eq. (2)

$$c_{\mathrm{var}} = c_{\mathrm{fuel}} + c_{\mathrm{o\&m}} + c_{\mathrm{CO_2}} \quad \text{with} \quad c_{\mathrm{fuel}} = \frac{p_{\mathrm{fuel}}}{\eta} \quad \text{and} \quad c_{\mathrm{co_2}} = \frac{p_{\mathrm{CO_2}}}{\eta} \cdot f_{co_2} \tag{2}$$

where c_{var} is the marginal generation cost of a specific power plant used for the merit order approach. Commodity prices are split into fuel prices p_{fuel} and emission (CO_2) prices $p_{\mathrm{CO_2}}$ which are both assumed to be constant over time during a simulation run. The resulting cost are then calculated regarding both, efficiency η of plants as well as emission rate $f_{\mathrm{CO_2}}$.

During this research values given in Table 2 have been assumed as reference. The values have also been derived from TYNDP18 data. The specific cost terms can be varied for each individual power plant. Also, when adding additional plants, cost values can be set individually. For the plant efficiency it was assumed that over all power plants the efficiency follows a beta-distribution defined by η_{min}, η_{mean} and η_{max} where the oldest plants operate at the lowest efficiency and vice versa. Every plant is also given a date of commission and shutdown date. Outside the resulting time span, the respective power plant is not taken into account for the price calculation.

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Table 2: Reference values for commodity prices and plant efficiencies (Entso-e, 2018a)

Property	**Sign**	**Unit**	Gas	Hard Coal	Lignite	Oil	Nuclear
O&M cost	$c_{o\&m}$	€/MWh	1.46	3.3	3.3	2.57	9
min efficiency	η_{min}	%	25	30	30	25	30
mean efficieny	η_{mean}	%	44	40	40	36	33
max efficiency	η_{max}	%	60	46	46	43	35
fuel price	p_{fuel}	€/MWh	21.96	8.28	3.96	50.76	1.692
emission rate	$f_{\mathrm{CO_2}}$	kg/MWh	205.2	338.4	363.6	280.8	0

2.4 Hourly renewable generation capacity

For the implementation of weather-dependent electricity generation technologies such as photovoltaic plants and WTta are essential and of fundamental importance. In the presented model, the influences of wind speed and solar radiation are taken into account by previous work of Staffell and Pfenninger publicly available (Pfenninger and Staffell, 2016; Staffell and Pfenninger, 2016). The influence of the ambient temperature was investigated in a previous study, with the result that for Germany there is no significant influence. (Blickwedel, 2018) All other weather and climate influences are neglected in the model. In addition, the assumption is made that there are no long-term climate trends.

2.5 Implementation of cross-border transactions

To include cross-border electricity transfer the net transfer capacity (NTC) provided by the European network of transmission system operators has been used. For Germany NTC values are implemented as given in Table 3. At this state NTC is assumed to be constant over time.

Table 3: Cross-border NTC capacities for Germany (Entso-e, 2018b)

Country	AT	BE	CH	CZ	DK	FR	LU	NL	NO	PL	SE
NTC [MW]	5000	1000	4600	2100	2765	1800	2300	4250	1400	2500	615

To estimate power import and export every neighbouring country is modelled as a hypothetic power plant with individual capacity and marginal cost. The given NTCs are being used as potential generation or demand capacity of a neighbouring market and the local spot price as the corresponding marginal cost. To estimate local prices of the neighbouring markets a pre-simulation for each country has to be executed during which import and export are neglected. In Figure 3 the neighbouring countries are depicted as red bars. The electricity demand on the German market is depicted by the dotted line at around 80 GW. Whenever the market price on a neighbouring market is lower than the local price, the neighbouring market is used at as a hypothetic power plant that can supply electricity for the German market. This applies to the two countries at the left of the dotted line. When a country exhibits a higher market price than the local price it is considered to be a potential market for

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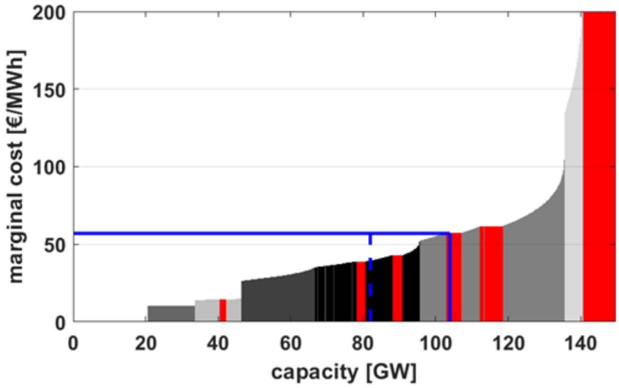
export of electricity. Within the model this means that the actual demand must be extended by the NTC of the according countries. The continuous line at around 105 GW shows the resulting calculatory demand that finally defines the price.

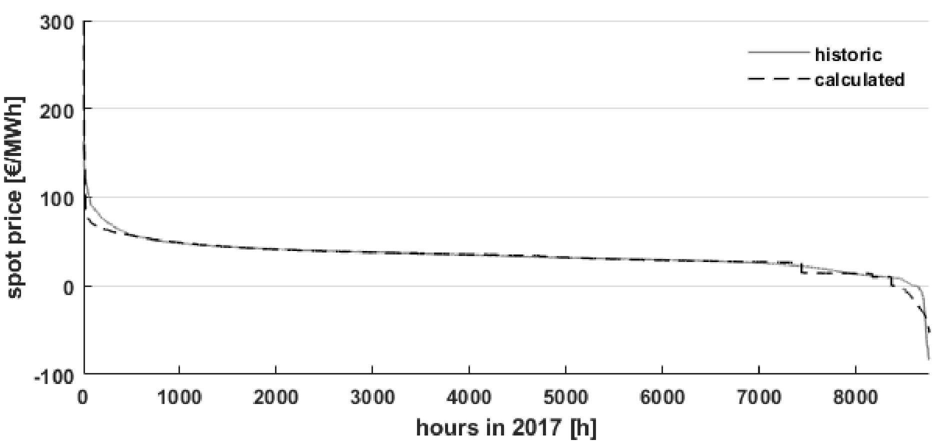


180 **Figure 3: Exemplary merit-order plot from forecasting model with cross-border considerations**

2.6 Model validation

To validate the model, calculated prices for a past year have been compared to actual prices on the EPEX Spot day ahead market (EPEX Spot, 2018). Since in the past Germany and Austria have been a coupled market, backtesting has also been
185 done for both countries together. Figure 4 shows the ordered annual price duration curve for Germany and Austria as well as the prices calculated by the presented forecasting model for the year 2017. The year 2017 has been chosen, because in 2018 the two countries markets have been separated.

It can be stated that the model provides satisfactory results at a mean absolute error of 2.38 €/MWh over the course of a year.



190 **Figure 4: Validation results, comparison of model results against historic values from EPEX Spot for Germany in 2017**

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3 Model application, results and case study

In the following section the forecast market results are being analysed and finally put in perspective within a brief case study. For this purpose a measurand for evaluation of model results based on the levelized revenue of energy is introduced. In most cases the overall performance of wind turbines (or other generation plants) is evaluated based on the levelized cost of energy (LCOE). The LCOE are defined as the total lifetime cost over the total lifetime energy production (Kost et al., 2018).

Since the scope of this paper does not include specific cost but deliberately only marketing revenue, the commonly used LCOE is no appropriate measure to interpret model results. Instead the levelized revenue of energy (LROE) will be introduced. The LROE are understood as the total lifetime revenue over total lifetime energy following (Eq. 5) where $W_{t,el}$ describes the quantity of electricity produced in the respective year t and i the calculatory interest rate. By using LROE instead of LCOE model results can be evaluated independent of plant specific cost and thereby have a more general character and global applicability.

$$LROE = \frac{\sum_{t=1}^{n} \frac{Revenue_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{W_{t,el}}{(1+i)^t}} \quad (5)$$

3.1 Market results and analysis

For this study, two different expansion scenarios have been evaluated for the years 2019 to 2040 (22 years in total). In Figure 5 the overall installed capacity for Germany is shown for scenario A (renewable energy expansion pursuant to the statutory expansion path of EEG2017) and scenario B (additional dismantling of coal and nuclear plants).

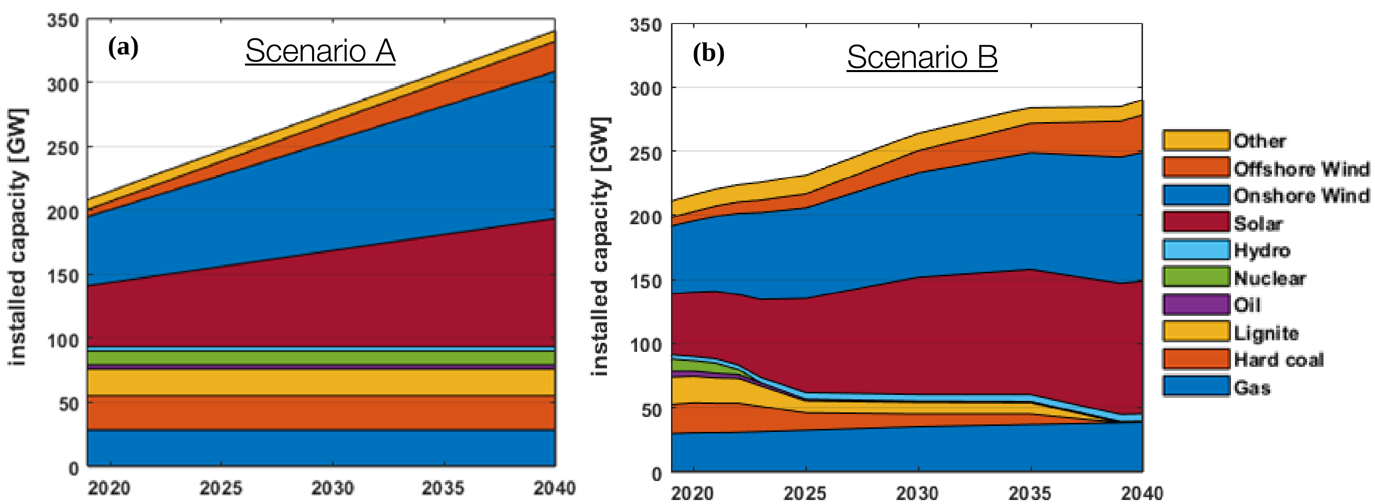

Figure 5: Installed capacity in Germany pursuant to statutory expansion (a) and additional dismantling of conventional plants (b)

It should be emphasised that scenario A with the pure addition of renewables is not a realistic scenario to be expected. The results from scenario A are used to provide information on the relationship between renewable energy feed-in and the German spot price within the model. Figure 6 shows the influence of the additional feed from renewables on the average spot price and

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price volatility at otherwise constant conditions. Comparing Figure 6(a) and 6(b), one can observe how a higher feed from renewables causes a decrease of the spot market price. As expected, almost constantly falling prices can be seen. The annual fluctuations are merely due to different weather conditions in the individual years. From the wind energy perspective this effect is further amplified at the hourly resolution as low prices occur especially during hours of high wind potential. Price volatility is represented in Figure 6(c) by the floating standard deviation of spot prices at a window size of 365 days. It is clearly observable how additional feed from renewables leads to an increasing fluctuation.

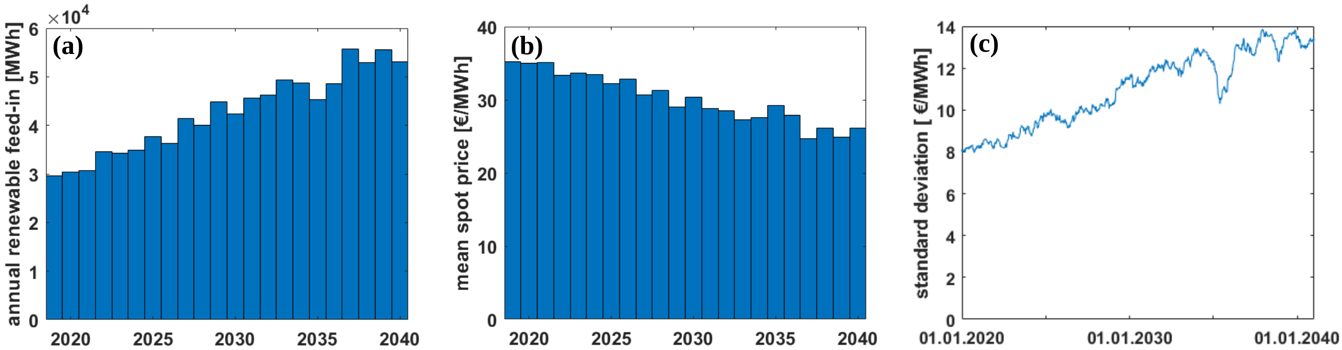

Figure 6: Influence of rising feed from renewables (a) on annual mean spot price (b) and price standard deviation (c) at otherwise constant conditions for scenario A

Unlike this hypothetic scenario the assumed paths of expansion and dismantling of scenario B are quite possible in reality. Figure 7(a) shows the model results for the average annual spot price for this scenario. In comparison to the previous, hypothetical scenario rising prices can be observed for the next five years due to the phase-out of nuclear energy. Prices then will fall until 2035 along the renewable energy expansion and finally rise again with the complete dismantling of coal energy. In this case the average price level unexpectedly remains roughly the same.

In addition to considering the two expansion scenarios, a variation in the CO_2 price is also investigated. For these considerations only scenario B is used. Four different specific prices were respected, namely 10, 18, 30 and 60 €/t. Figure 7(b) shows the corresponding results and sensitivity of spot prices against the CO_2 price. It can be observed how an increased emission price leads to higher mean spot prices. This influence becomes stronger the more conventional plants operate within the market. The converging lines in Figure 7(b) along the expansion shown in Figure 5(b) emphasizes this relation.

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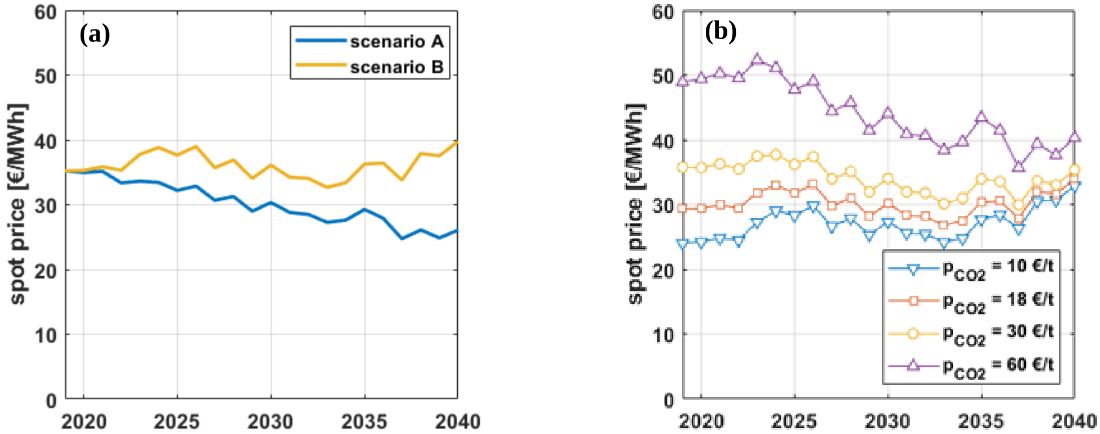

Figure 7: (a) Mean annual German spot price for the evaluated scenarios; (b) Calculated mean annual spot price in Germany for scenario B at different CO_2 prices

3.2 Case study observing a small onshore wind park in Germany

The applicability of the model results shall be demonstrated in a brief case study. Therefore, hourly SCADA data of a German wind park with 5 turbines of the 3 MW class with average full load hours of 1920 h/a has been used. Potential marketing revenue has been calculated based on the extrapolated SCADA data and the modelled spot price forecast over the course of the next twenty years. Figure 8 shows the LROE of the wind farm investigated for direct marketing within expansion scenario B with two different emission prices (orange bars). Finally the results are compared by LROE to marketing revenue based on hypothetic PPAs with different prices. The LROE for marketing using PPAs with different purchase prices are also shown by Figure 8 (blue bars).

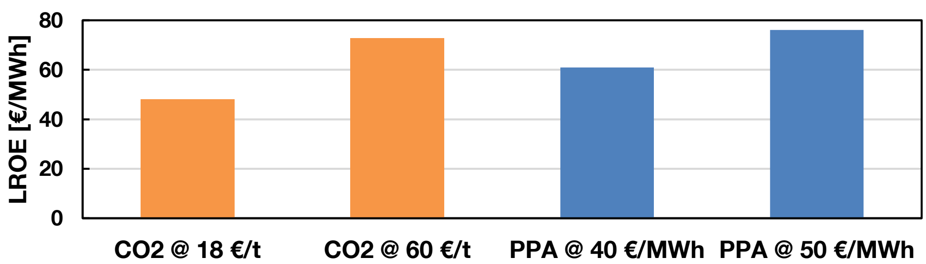

Figure 8: LROE of the observed wind park over 22 years at different emission prices for expansion scenario B and PPAs

On the one hand, it can be stated that in the event of higher stock exchange prices, higher revenues can also be expected from direct marketing (orange bars). Furthermore, it can be concluded that PPAs do not necessarily lead to higher revenues than direct marketing on the stock exchange. Against the background of the great uncertainty at the stock market this should be evaluated critically.

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4 Discussion and outlook

In the present study a model has been presented that estimates future electricity exchange prices to conclude on potential revenue of non-subsidized wind turbines. The elaborated forecasting model is based on a merit-order approach and can therefore be categorized as a fundamental model following Weron (Weron, 2014). An object-oriented approach has been chosen for implementation of plants, where individual characteristics and cost can be set. This model design adds a more agent-based approach, yielding additional benefits over a solely fundamental procedure. The object-oriented design makes it easy to adapt parameter variations and can be used to check plausibility of results on plant level. The presented model is therefore finally to be classified as a hybrid model.

The developed model is constructed deliberately simple with low data requirements to allow unproblematic adaptation and modification, which is often described as a disadvantage of modern complex optimization models. Despite the model's simplistic design, very satisfactory solutions can be obtained in terms of model evaluation and backtesting for Germany.

Due to the high resolution of hourly prices, a detailed analysis of daily price developments is also possible. The model can emulate effects like low prices during hours of high solar feed-in as well as price peaks during hours of high demand and low renewable feed-in. Computation of negative prices can also be achieved by defining must-run capacities for conventional power plants such as brown coal or nuclear plants.

The model results are suited for revenue estimation of wind turbine marketing models that orient by EEX/EPEX. Also it enables comparison of new business models like PPA against direct marketing at very low computational cost. Therefore, the results can be e.g. used during negotiation of contract conditions and thereby strengthen the position of wind farm operators.

On the other hand the model results can be used as reference at derivation of development goals and LCOE. In this context the model delivers the corresponding break-even values at considerations like cost reduction, increase in reliability or AEP.

The presented model could be particularly useful in conjunction with yield prognosis models. During the planning phase, it could be used in combination with planning and optimization tools such as wind farm optimizer WIFO to generate a more reliable economic yield prognosis in addition to the energy yield prognosis. (Roscher et al., 2018)

During further studies the model shall be further extended, e.g. by implementing dynamic time series for economic parameters like emission and fuel prices. Also additional expansion scenarios for Germany or other European countries could be simulated. Finally the above leads to overall reduced investment risks and therefore supports wind energy and its expansion as a whole. This in the end is a supportive step towards an ecologic electricity supply.

Achknowledgements

We thank the German Federal Ministry for Economic Affairs and Energy for funding the research project (acronym: ArkESE) in which we address this topic. In the three-year project (start December 2018), rural municipalities are investigated to design individual electricity supply systems on the basis of renewables. Municipalities shall be enabled to prepare, make and implement energy system related decisions more self-sufficiently.

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