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A combined modeling approach for wind power feed-in and electricity spot prices

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HIGHLIGHTS

- Wind power feed-in can be directly simulated with stochastic processes.
- Non-linear relationship between wind power feed-in and electricity prices.
- Price reduction effect of wind power feed-in depends on the actual load.
- Considering wind power feed-in effects improves the electricity price simulation.
- Combined modeling of both parameters delivers a data basis for evaluation tools.

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ABSTRACT

Wind power generation and its impacts on electricity prices has strongly increased in the EU. Therefore, appropriate mark-to-market evaluation of new investments in wind power and energy storage plants should consider the fluctuant generation of wind power and uncertain electricity prices, which are affected by wind power feed-in (WPF). To gain the input data for WPF and electricity prices, simulation models, such as econometric models, can serve as a data basis.

This paper describes a combined modeling approach for the simulation of WPF series and electricity prices considering the impacts of WPF on prices based on an autoregressive approach. Thereby WPF series are firstly simulated for each hour of the year and integrated in the electricity price model to generate an hourly resolved price series for a year. The model results demonstrate that the WPF model delivers satisfying WPF series and that the extended electricity price model considering WPF leads to a significant improvement of the electricity price simulation compared to a model version without WPF effects. As the simulated series of WPF and electricity prices also contain the correlation between both series, market evaluation of wind power technologies can be accurately done based on these series.

1. Introduction

Renewable electricity generation has been considerably growing throughout the past 10–15 years in some countries, like e.g. Germany, and wind energy has strongly contributed to this boost. This development is mainly driven by renewable promotion schemes, whereby guaranteed feed-in-tariffs have been most successful to stimulate investments in renewable energies (see Ragwitz and Held, 2007). These investments receive their income from the sold electricity on the basis of the installed renewable promotion scheme and not from the electricity sold on spot markets with highly volatile prices. However, the influence of electricity generated by renewable energy sources on the spot market price is gaining importance with increasing shares of renewable energy feed-in (see Ryu et al., 2010). The electricity feed-in from renewable resources reduces the remaining system load, which has to be satisfied by conventional power capacities. As the renewable feed-in shifts market prices along the merit-order curve of power plants, this effect is often called the merit-order-effect of renewable energies (see Sensfuss et al., 2008; Menanteau et al., 2003). The following figures for the German electricity system illustrate the impact of renewable feed-in especially based on wind energy: wind energy capacities in Germany amounted to approx. 26 GW in 2010, which corresponds to more than 30% of the maximum load of the year. The maximum feed-in of wind power equaled to 21.5 GW in 2010. Considering a minimum load of 40 GW (see Saint-Drenan et al., 2009), this means that in times with strong wind about 50% of the minimum

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load are served by wind power, which replaces the adequate amount of conventional capacities. Thus, it is obvious that the feed-in from wind energy has significant impact on spot market prices.

Several modeling approaches exist to analyze and predict spot market electricity prices. Within fundamental models the consideration of renewable feed-in, especially wind power feed-in, is plausible and evident, as all fundamental data has to be taken into account. Financial models are often favored to model electricity prices for a short and midterm planning horizon. These models try to explain electricity prices by deterministic and stochastic patterns. As the feed-in from wind energy is more and more of crucial importance in electricity price modeling also financial models have to integrate this new uncertain parameter in the modeling approach. Up to now, hardly any financial or time-series modeling approach exists, which explicitly model the wind power feed-in and which incorporates this uncertain parameter in an integrated time-series or financial model for electricity spot prices. Therefore this paper presents an analysis of the wind power feed-in (in Germany), proposes a modeling approach for wind power feed-in and presents an integrated approach which simulates electricity spot prices under consideration of wind power feed-in within a financial modeling approach.

The combined modeling of wind power feed-in (WPF) and electricity spot prices is existential, if specific energy technologies, which rely on wind power, are economically evaluated based on market prices. E.g. if investments in wind power plants or energy storages are assessed under liberalized market conditions, appropriate wind power feed-in series and electricity price paths will be necessary to carry out the economic evaluation. For the evaluation of wind power plants simulated prices and WPF series are required, if an evaluation approach based on market prices instead of fixed feed-in tariffs is used.

Due to the market premium mechanism of the latest renewable energy legislation in Germany, wind power plant operators have also the opportunity to sell their power output directly on the electricity spot market. In this case they receive grants (market and management premiums) additionally to their earnings on the spot market (see EEG, 2012). These earnings and the funding premiums can be applied to a market evaluation. However, if a market evaluation should also consider the uncertainty of prices and WPF, a multistage stochastic optimization approach is necessary. This is not only relevant for wind power plant evaluation, but also for other technologies, such as storage or gas power plants. To carry out the stochastic optimization, a large number of price and WPF simulations, describing all possible developments of these parameters, can be reduced to a stochastic tree and applied to the optimization.

Besides, if a deterministic evaluation approach is applied for the evaluation of wind power plants or energy storages, a model for WPF and electricity prices is also useful. As historical data of both parameters is only available for a limited time-period, the combined modeling and simulation of these parameters can deliver the necessary time series for future years. These data series can also consider the extension of installed capacities of wind power in the coming decades.

Furthermore, an electricity price modeling including WPF effects allows analyses of changes in the future price structure. These analyses can be not only essential for power plant investors, but also for energy policy makers, as they can adjust their policies regarding market design and renewable energy funding with a better knowledge of possible price effects resulting from their actions. All these arguments necessitate a combined modeling of WPF and electricity spot prices with the help of stochastic processes, as it is introduced in this paper. Thereby, it is important to mention that an adequate modeling of both parameters has to capture also their correlation, as the electricity prices and WPF series are correlated due to the so-called merit order effect of wind power.

The paper is structured as follows: the next section gives an overview of the uncertainty in wind power generation and quantifies its impact on the electricity spot prices that is related to the merit-order effect of wind energy. Section 4.2 focuses on the simulation of wind power feed-in (WPF) based on the hourly utilization of the overall wind power capacity installed in Germany. Thereby the focus will be set on the removal of deterministic patterns, such as seasonality, and on the modeling of stochastic properties of the hourly capacity utilization series. The autoregressive behavior of the stochastic part of the capacity utilization will be captured by a recursive method simulating the change rate of the next capacity utilization level by its preceding values. After generating the stochastic component, the time-series will be reseasonalized to receive final capacity utilization series representing the hourly WPF of a year. The hourly WPF series will be used in Section 4.3 to extend the simulation of electricity prices considering the short-term impact of WPF. Thereby, an already existing electricity model will be shortly described, before the focus is set on model extensions integrating the impacts of WPF. The description of the extended electricity price model will be followed by the results section, in which simulated WPF and electricity price series will be compared with original series to determine in-sample performance of the simulation models. In the conclusions the main outcome is summarized and further work is presented that can be carried out in that area.

2. Impacts of wind power feed-in on electricity prices

The effect of wind power feed-in on electricity prices has been analyzed in various papers (see Ray et al., 2010). In general it can be distinguished between model based analysis (see Sensfuss et al., 2008; Weigt, 2009; Delarue et al., 2008; Bode and Groscurth, 2006; de Miera et al., 2008) and statistical analysis. Main goal of the statistical approaches is to quantify the price spread of market prices with a high and a low wind power feed-in (see Jonsson et al., 2010; Neubarth et al., 2006).

The price reducing impact is also called merit-order effect (see Fig. 1) and can be explained with the right shift of the supply curve when wind power with low variable costs is integrated into the supply curve. Assuming an inelastic demand, electricity price as intersection between supply and demand will thus decrease. The height of the merit-order effect depends apart from the feed-in of wind power mainly on the two factors demand height and gradient of the supply curve. The gradient of the supply curve depends mainly on technologies, efficiencies, fuel price spreads and CO_2 price.

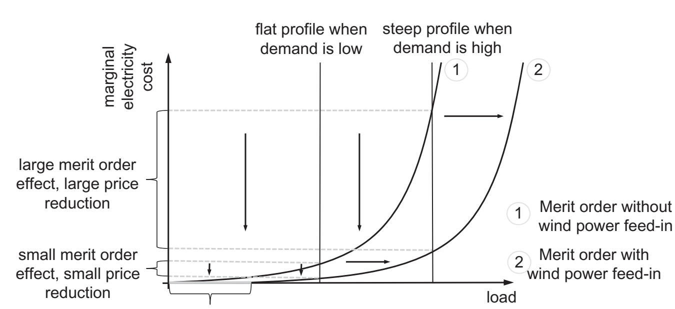

Fig. 1. Right shift of the merit order and the supply curve particularly due to wind power feed-in.

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