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Interactive comment on "Future Economic Perspective and Potential Revenue of Non-Subsidized Wind Turbines in Germany" *by* Lucas Blickwedel et al.

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Thank you for this detailed and very specific review. All points raised are clearly understandable and will be discussed below.

The general scope and purpose of the presented model is to deliver macroscopic long-term trend estimates for a given electricity exchange market at a comparatively slim data demand and low computational cost. Along other (partly strong) simplifications there is no spatial resolution of the generation units. Ultimately, this makes it possible to make a statement on the development of electricity exchange prices without having to solve an optimization problem first. This is of course at the expense of less

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detailed model results. Nevertheless, this approach helps to analyze possible future challenges for non-subsidized wind power plants at adequate accuracy as shown with the backtesting in Section 2.6.

1) Expansion of literature review by (equilibrium) energy system models:

As with all commercial tools, PLEXOS has the problem of general accessibility of data and code. Moreover, the possibility of subsequent model adaptation and improvement does not seem to be given. Balmorel was not known to the authors at the time of writing this paper. It appears to be a very interesting tool that will be included in the discussion in the revised version of the paper (Section 1.2). Balmorel has been directed towards the solution of an optimization problem in GAMS. A higher technical level of detail is expected, which in turn leads to increased model complexity and therefore effort compared to the presented model.

2) Clarification of time series data used:

2a) Weather data: Historical weather data for the years 1985 to 2016 are used under the assumption that there will be no significant weather trends in the occurrence of wind and sun by 2040. The time series data provided by Pfenninger and Staffel is used. They use weather data from global reanalysis models and satellite observations (https://www.renewables.ninja/about).

2b) Are any changes in the capacity factors of wind and solar generations considered towards 2040? Not yet. This would be a very interesting extension for a follow-up study. Right now, the energy provided from wind and solar only scales with the overall installed capacity.

2c) How is the load profile modelled and is the same profile used up until 2040? Exactly. The total annual demand of a country is used as the input variable. This parameter is much easier to obtain than an entire time series. Uniform profiles are then used for the hourly variations, which include medium-term (daily and weekly cycles) and long-

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term (seasonal) effects (see Section 2.2). These profiles are derived from entso-e data (TYNDP18).

2d) Are wind, solar and load profiles synchronized? Wind and solar are synchronized. The same weather year from the studies of Staffel and Pfenninger is used for these technologies. The demand is not synchronized. It was found that especially in Germany the influence beyond the cycles described in 2.2, especially the outdoor temperature, is negligible considering the application area of this model. In countries with high electricity demand for cooling of buildings like Australia this may be different (see Hyndman & Fan, 2010, DOI: 10.1109/TPWRS.2009.2036017)

3-5) How is annual energy consumption and cross-border capacity assumed to change towards 2040?

The simplifications described at the beginning of this response also include an assumption of temporal constancy for most model variables. This includes the total annual electricity demand, commodity prices, export and import (cross-border) capacities as well as generation capacities in neighboring countries. The temporal changes of all these variables are currently already possible and have been carried out in part. In this paper, however, it was intended to first present and discuss the basic function of the model. Therefore, only the installed plant capacities and emission prices were varied. It is undisputed that electricity demand is a very important model parameter whose variation over time should be displayed and investigated. An influence of P2X or electric vehicles on the demand can be made in the assumption of the demand development and is reasonable and intended for future work. For example, a simplified assumption could be made that demand will increase in proportion to the market penetration of electric vehicles. However, a flexibilization of demand would lead to an optimization problem and therefore require a much more extensive adaptation of the model.

6) How are different generation mixtures between countries considered?

Before the main simulation takes place, a pre-simulation is executed for every neighbor-

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ing country based on the momentary power plant portfolio and total annual demand. This pre-simulation provides the assumed generation mix for each individual neighbouring country and every hour of the forecast period.

7) Can the model capture the likelihood of the highest spot prices?

The absolute price peak at 300 €MWh is in fact hit by the model. So, the curves do not diverge. Rather, the model results show a more regressive course in the area of high market prices. This is probably due to the assumptions made for marginal generation cost of the corresponding conventional power plants (oil and gas).

8) Marketing revenue vs market revenue:

The term is owed to the translation from German into English. In fact, "market revenue" is much more accurate and fitting. Thank you very much for this hint.

9) Addition to figure 8 and PPA prices used:

In contrast to the exchange price of electricity, the remuneration under a PPA is negotiated bilaterally between the contracting parties. However, the negotiation is also based on the exchange price, with the difference being charged to the increased security. The two prices quoted are in fact fictitious. They can be understood to mean that, for example, the WTG operator prepares possible price concepts prior to PPA price negotiations and compares these with various exchange price scenarios for valuation purposes. When using LROE and depending on the assumed PPA mechanism, it is not trivially possible to compare the average stock exchange price with possible PPA remunerations. This should be reflected in the explanations around figure 8. The revised version of this paper will contain appropriate additions.

10) Are transmission bottlenecks inside Germany modelled?

As a spatial resolution is not available, the national transmission network including possible network bottlenecks cannot be mapped. This is a strong simplification of the model.

11) Elaboration on LROE:

During the research for this paper hardly any existing literature on the concept of LROE was found, except for one forum article which will be cited in the revised version of the paper. To differentiate between LCOE and LROE, it is assumed that the economic efficiency of a wind turbine can be assessed based on three essential quantities: Costs, market revenues and electricity yield. LCOE considers the costs and the electricity yield for a specific case (a specific plant). The value can be interpreted as the minimum revenue required for an economical plant operation. LROE on the other hand provides information about the financial revenue potential in a given market as well as for given site conditions. The value is therefore not just a plant information, but it also considers the market in which the plant is operating in. The main advantage and difference to the LCOE concept is therefore, the additional market information. Furthermore, plant costs and associated uncertainties are not included in the measured variable. The latter also leads to a good transferability to different plant concepts. You are right that the denominators of both sizes are the same. Therefore, for an economic operation of WTGs without subsidies on a market, it must apply that LCOE $\leq$ LROE. Just like LCOE, LROE can be used to define and evaluate technical and financial development goals for engineering. Moreover, it can be used by authorities within future subsidization considerations. The subsidies in the form of the tendering procedure follow the LCOE. Accordingly, a funding which considers the LROE for different technologies would be a more holistic approach and a more indirect technology support.

12) Conclusion section:

It is agreed that the conclusion is not given enough attention in the current version of the publication. In the revised version, this section will be supplemented based on the given reviewers' comments and the response above. Especially the results chapter will be extended.

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