WIND ENERGY EXPANSION IN ELECTRICITY SYSTEM MODELS AND IN REALITY – KEY DRIVERS AND IMPLICATIONS FOR MODEL SIMPLIFICATIONS

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Overview

The increasing share of renewable energy production in future energy systems poses multiple challenges to energy modelers. Among other things, complexity and model size lead to increasing computation times, especially for optimization models with endogenous capacity expansion. Reducing the computing time by aggregation requires a comprehensive understanding of factors that affect the resulting optimal expansion plan. As optimizing energy system models are frequently used to inform policy makers or even help shaping policies, it is equally important to get an improved understanding of the factors that drive differences between model results and reality.

Especially we are interested which simplifications in models are most harmful in terms of obtaining realistic model results. On the other hand current individual economic decisions may be influenced by market conditions and policy frameworks that will not persist in the future. Therefore purely data driven modelling approaches might be misleading and a conceptual understanding of system optima (aka market equilibria) and how they are driven by modelling assumptions and simplifications is needed.

The objective of the presented approach is to provide such an analysis for the case of wind energy, more precisely: to identify drivers that explain in which order technologies at multiple locations are installed. In contrast to potential studies, our approach does not focus on finding the optimal energy expansion for specific scenarios but rather on identifying the key mechanisms of renwable expansion as a basis for finding adequate spatial and technological aggregation approaches. Given the higher complexity of wind production in comparison to PV or other renewable energy sources, we focus on the more challenging case of wind energy expansion in this analysis. Results are expected to be transferable nevertheless.

Methods

We start by comparing the diversification of wind power plants in Germany (2017) with the wind energy expansion in a very stylized future electricity market model to identify value and decision drivers for both cases. Second we analytically define four distinct value components for investment choices. By investment choices we thereby mean possible combinations of sites (locations) and turbine types (technologies, e.g. strong vs. low wind turbines). The value of an investment choice may then be decomposed additively into: 1. the yield value component (driven by the site-specific full load hours/capacity factor), 2. the resource related value component (driven by the general market value factor of wind), 3. the technology specific value component (driven by the selected turbine type) and 4. the spatial heterogeneity value component (driven by wind profile of the selected site).

Those components may be computed for the existing wind plants and current prices as well as for the wind plants selected in a future scenario and the corresponding future prices. Even we may combine future wind plants with current prices and vice versa. This yields 16 indicators for each investment choice, namely four value components computed for each of four possible settings (plant portfolio – price combinations). These indicators may be compared both between investment choices and between settings.

In view of technology and location aggregation we propose to undertake a cluster analysis for the investment choices with the 16 indicators as attributes. If investment choices (objects of the cluster analysis) are similar with respect to the 16 indicators, this is a good indication that they may be aggregated to one decision alternative and that this choice is robust under different scenario settings – if the two scenarios used for deriving the indicators are sufficiently contrasted.

Results

Preliminary results show that the utilization of single indicators, i.e. only one component of those described above (e.g. full load hours) are not sufficient to describe relevant mechnisms of optimization models or identify possible principles of aggregation. First results also suggest that the spatial heterogeneity, i.e. the diversity of wind profiles at different sites, does not contribute much to the investment value. If confirmed this implies that complementarity in sites is not that important for overall optimal system designs.

In the context of an optimization model, the obtained prices can be utilized to explicitly assess each investment choice but our findings suggest that they can not be estimated easily beforehand to predict the order in which technologies at multiple locations are installed. During the evaluation of single components we found that the mutual dependency of spatial and technological aspects disqualifies any analysis that focusses only on one single indicator or one type of aggregation (either spatial or technological). To identify model simplifications that do not cause major deviations in results, multiple indicators and interdependencies need to be taken into account. Clustering the investments decisions as described allows to reduce the quantity of investment decisions that have to be included in long-term electricity market models without compromising the quality of results.

Conclusions

We show that most intuitive drivers do not fully explain the mechanisms of wind power expansion in electricity market models if considered in isolation but rather the combination of multiple components and levels of aggregation needs to be considered.