GENERATION EXPANSION PLANNING UNDER UNCERTAINTY – AN APPLICATION OF STOCHASTIC METHODS TO THE GERMAN ELECTRICITY SYSTEM

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Overview

The traditional generation expansion problem aims at minimizing investment and operational costs of the electricity system from a regulated utilities' perspective. Throughout the last decades the traditional perspective became more complex with inter alia the development of new generation and demand technologies, the deregulation and restructuring of electricity markets, the stronger interaction with other resources, and an increasing environmental awareness. As a consequence of these new complexities, a wide range of generation expansion models and techniques evolved with differing goals and perspectives on the long-term generation planning. Among others, the ambitious climate targets and the corresponding political targets to decarbonize national energy sectors initiated the substantial growth of renewable energy sources in particular in the electricity sector. In the future, renewable energy sources are expected to be the main electricity generation source. However, the special characteristics of renewable energy sources, e.g. weather dependent generation pattern of wind and solar, and the upcoming sectoral coupling of the electricity sector with other sectors, e.g. mobility or heat, pose particular challenges to the generation expansion modelling as corresponding uncertainties need to be taken into account. Moreover, the incorporation of specified uncertainties in the generation expansion model can be done in different ways. Stochastic programming is a well-known concept in which uncertainties are reflected by their possible realizations accounted with specified probabilities of occurrence. The resulting problem consequently minimizes the expected costs by optimizing first-stage (or here-and-now) and recourse (or wait-and-see) decisions or variables. Moreover, stochastic programming approaches are extended in the literature by specific risk measures, e.g. CVaR, to account for different underlying risk preferences with respect to cost variations in different uncertainty realizations. Another approach is robust optimization which does not require probability distributions of the specified uncertainties and can be used for different objectives such as regret minimization or worst-case optimization. The aim of this paper is to analyse the implications of different approaches to optimization under uncertainty, ranging from stochastic optimization to robust optimization. We apply these approaches to the generation expansion problem of the German electricity system and compare them to a deterministic optimization for each realization of the uncertainty.

Methods

We use the deterministic generation investment model DIETER and extend this by different stochastic optimization approaches. The model is a cost-minimizing system planning model and optimizes the future generation portfolio under varying minimum renewable shares on the generation mix. It accounts for investment options in different conventional and renewable generation technologies. Generation technologies are differentiated by investment and operational costs as well as operational flexibility. Contrary to conventional technologies, renewable technologies, like solar and wind, are considered as non-dispatchable energy sources and characterized by hourly weather-dependent generation pattern. Moreover, demand-side management as well as different storage options, e.g. pumped-storage, battery, are considered to allow for an inter-temporal shift of load or generation, respectively. The model accounts for an hourly dispatch covering an entire year with 8,760 hours.

We extend the model by stochastic optimization approaches and focus our analysis on incorporating short-term uncertainty which directly effect at the dispatch level as well as long-term uncertainties, like technology costs. A typical short-term uncertainty is the generation pattern of renewable energy sources or the hourly load pattern. Given these uncertainties, we firstly implement a stochastic programming approach which accounts for different hourly renewable generation pattern and their probability of occurrence. Secondly, we extend the stochastic programming approach by introducing a risk measure, e.g. valuing the volatility of cost variations of different realizations. This enables us to investigate for instance the impact of risk-averse planning on generation portfolio and generation mix. Finally, we extend the model by a robust optimization that minimizes the maximum regret and does not require probability distributions. We end up with two different variants of generation expansion under uncertainty, a stochastic and a robust variant, and a deterministic model. We are firstly interested in the value of stochastic programming by comparing stochastic and deterministic model versions. Secondly, we analyse the robustness of the generation planning and compare it to the robust optimization approach. Moreover, we analyse the implications of the different modelling approaches in terms of the resulting generation mix, total system cost as well as dispatch pattern.

Preliminary results

First results show that a stochastic optimization approach yields different generation expansions than deterministic approaches. As the stochastic approach accounts for different renewable hourly generation availabilities, dispatchable generation technologies, like storage or demand-side management options, and renewable generation technologies, which show a higher correlation with hourly demand patterns, like solar, are more relevant than in deterministic versions. In contrast, the deterministic generation expansions are sensitive to the considered hourly generation pattern and consequently differ significantly for different weather years. We expect that the robust optimization approach yields higher total generation capacities and a differing mix of technologies than the stochastic approach, as critical or worst case realizations of uncertain parameters are more pronounced. Thus, the generation mix is expected to be more robust to unexpected and critical uncertainty realizations. Based on the results we will discuss the benefits of the individual approaches and their suitability for policy advice and market analysis.

Conclusions

Our model-based analysis suggests that deterministic approaches are insufficient to provide a robust capacity mix and the capacity mix strongly depends on the underlying assumptions. The classical approach to address these issues is through extensive sensitivity analyses, which provide insights on sensitive assumptions but do not allow for an endogenous incorporation of possible variations of input assumptions within the decision problem. Thus optimization methods that directly accounting for uncertainties are a methodological option to provide insights on future development paths as well as occurring path dependencies in a dynamic setting.

With respect to the applied uncertainty methods, we show that accounting for uncertainty does neither escalate investment volumes nor associated investment costs in any of the applied uncertainty methods. Moreover, robustness of the future capacity mix with respect to expected and unexpected uncertainty realizations can be achieved by applying stochastic or robust optimization approaches. Surprisingly, first results indicate that the technological mix differs in particular among the two robust approaches as the underlying definition of the worst case is different. Thus, beside the general implementation of methods dealing with uncertainty, it is important to motivate and justify the underlying planning and decision calculus, especially in robust optimization settings.

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