LONG-TERM STRATEGIES TO ENSURE A ROBUST PERFORMANCE OF THE EUROPEAN ELECTRICITY SYSTEM

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Overview

In this paper we combine optimization methods and the tools of robustness analysis for developing long-term strategies that ensure a robust performance of the European electricity system under shocks.

Electricity systems are characterized by high capital intensity and long-living assets, which makes long-term planning indispensable. Therefore, a variety of numerical optimization models is applied today to inform policymakers about the cost-efficient future composition of individual power systems. However, due to computational restrictions or overestimated certainty by their authors and clients, many studies concentrate only on a few scenarios. Consequently, such studies fail to provide for abnormal situations.

With the electricity system being constantly exposed to political, techno-economic and natural risks, it is crucial to ensure security of supply and minimum costs for a variety of possible futures – not only the ones that are perceived as the most likely. In this context, sudden short-term shocks that do not allow an adaption of the capacity stock are particularly challenging. The ability of liberalized electricity markets to provide a satisfying level of security of supply is contested. If necessary incentives for investors to ensure security of supply are missing, policymakers may wish to implement additional policies to overcome this failure.

Simple scenario analysis with optimization models is not sufficient for generating and analyzing such strategies. We therefore enhance the established energy scenario analysis by employing the framework of “Robust Decision Making” (RDM) described by Lempert et al. (2006). Combining optimization methods and robustness analysis in the long-term European electricity system model LIMES-EU (Nahmmacher et al. 2014) allows us to generate efficient long-term strategies for improving the robustness of the European electricity system under shocks; and thereby close an important gap in the literature. In this paper we focus on two kinds of shocks: (i) gas supply shocks and (ii) extreme weather events related to further climate change.

Methods

The core of our analysis is the long-term investment model for the European electricity sector LIMES-EU. It is used to calculate cost-efficient investment and dispatch decisions until 2050 for different future techno-economic scenarios and policy strategies. It is also employed for calculating the impact of short-term shocks on the system. For analyzing the effectiveness and efficiency of the different strategies we adopt the RDM framework by Lempert et al. (2006).

Instead of stochastic approaches that require estimating the *probability* of the shocks beforehand, robust decision making starts from the perception of *possibility*. This makes robustness the suitable concept for decisions under deep uncertainty, particularly in presence of low-frequency future uncertainties such as shocks. The criterion for selecting a robust strategy is not optimality but a good performance compared to other strategies across a wide range of plausible futures. Performance of a strategy for a specific future is measured by its regret (i.e. the cost difference) towards the cost-minimizing strategy for that future.

In short, our approach for developing robust strategies for electricity systems can be summarized as follows: (i) optimizing capacity investments and dispatch for each scenario-strategy combination and re-optimizing dispatch for each scenario-strategy-shock combination; (ii) selecting candidate robust strategies based on the regret with regard to overall cost; (iii) analyzing vulnerabilities of the candidate strategy and evaluate possible hedging options.

We start from typical long-term *scenarios* that each describe a possible future development of different investment and fuel cost. In addition to a policy internalizing the climate externality, we combine these scenarios with a variety of *strategies*. A strategy is an additional criterion, such as fuel diversity, that may help to improve the robustness of the electricity system. With the objective of cost-minimization LIMES-EU calculates the optimal future investment pathways for each scenario-strategy combination – plus for the default cases without such additional strategy. After the optimization we fix the investments determined by LIMES-EU and expose the electricity system to *shocks*. Further investments in order to respond to those unexpected shocks are not possible; only dispatch can be re-optimized. Consequently, shocks may lead to additional costs resulting from a different dispatch, a shortage of electricity supply, and/or a failure to meet the emission target. Table 1 provides an overview of scenario variations, candidate strategies for enhancing the robustness of an electricity system and short-term shocks. The exact kind and strength of each shock are again subject to variation and are to be covered by multiple separate model runs.

Table 1: Scenarios, strategies and shocks

Scenarios	Strategies	Shocks
- Nuclear power investment cost - CCS investment cost - Wind capacity factor - Solar investment cost - Biomass price - Gas price	- None - Diversity in generation / fuel mix - Import share of electricity - Redundant (reserve) capacities - Transmission expansion - RES share in generation mix - Nuclear power in generation mix - Storage expansion	- Gas supply - Weather/climate effects *(e. g. breakdown of transmission lines, reduced availability of thermal power plants, etc.)*

After calculating the overall costs of each scenario-strategy-shock combination we follow Lempert et al. (2006) and compare the different strategies based on their regret towards the best performing strategy for each scenario-shock combination. Candidate robust strategies have a relatively low regret over all analyzed possible futures compared to other strategies. However, these candidate strategies may have serious vulnerabilities (i.e. high regrets) for single scenario-shock combinations. In a next step, those vulnerabilities are analyzed in order to generate possible hedging options in form of new or refined strategies or by creating combinations of strategies that may be more robust. Performance of those strategies is subsequently assessed by additional model runs. In case no strategy is undoubtedly the best or that significant vulnerabilities remain for every strategy, preference for single strategies can be described to policymakers as a function of their individual probability assumptions or their risk aversion towards certain shocks.

Results

For the sake of brevity, we only present illustrative results for the case of gas supply shocks here. Figure 1 shows the regrets of strategies (S0 to S13) for various scenarios and gas supply shocks. Of the individual strategies, strategy S1 (diversifying the national generation mixes) has the lowest median regret. However, based on the more important upper quartile and maximum regret, strategy S9 performs best. It represents the introduction of a European wide target for the deployment of renewable energy sources that is above the cost-optimal deployment level for scenarios without shocks. Even in scenarios with low wind capacity factors, this strategy shows only minor vulnerabilities for all implemented gas supply shocks. Combining strategy S9 with strategy S5 (the installation of excess capacities) further increases the system’s robustness.

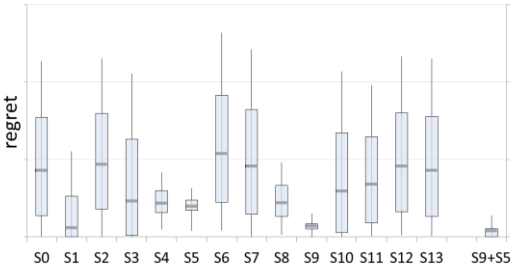

Figure 1: Regrets of strategies in case of gas supply shocks

Conclusions

The presented results constitute only a small share of the analyses we conducted. The innovative way we combine common optimization methods with robustness analysis allows us to analyze the effectiveness of different strategies for a large variety of possible shocks to the electricity sector. It is particularly useful in case that stochastic analysis fails to provide meaningful results, e. g. when probabilities of the shocks are unknown or when there are more than only a few possible futures. Both cases apply to today’s electricity systems. Our analysis focuses on the European electricity system, but the methods applied are applicable to all regions of the world.

References

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