A GUIDELINE THROUGH COMPLEXITY: ASSESSING THE SECURITY OF ELECTRICITY SUPPLY

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Overview

Energy system analyses are often used to provide a sound basis for political discussions and to enable evidence-based decisions. Against the backdrop of expansions of intermittent renewable energy capacities and market interventions such as planned nuclear phase-outs and the additional mothballing of coal-fired power plants in central Europe, there is a substantial increase in uncertainty regarding security of electricity supply. Many different studies are currently being conducted in this field of research, using different input-data and different approaches in varying degrees of complexity leading to a large array of results and conclusions.

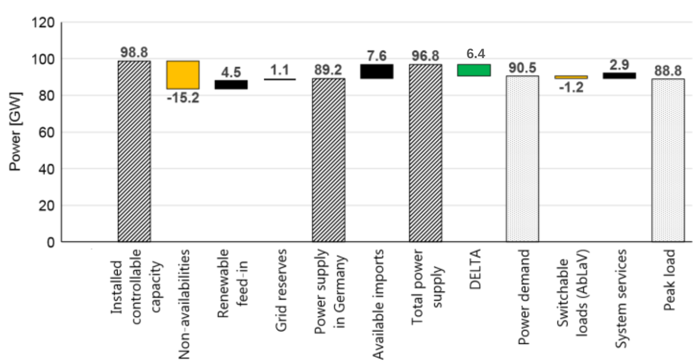
According to Bale et al. (2015), current developments increase the complexity of both energy systems and energy system models. Within the field of tension between simplicity and accuracy, the appropriate level of modeling complexity needs to be chosen with care. There is the need not to exaggerate simplifications (Stirling, 2010), but also to be sparse with resources leading to the overall goal of parsimony (DeCarolis et al., 2017). Studies from different fields of research have already revealed that modeling with higher degree of complexity does not necessarily lead to more accurate model results (cf. Orth et al., 2015; Li et al., 2015; Priesmann et al., 2019).

In this context, I distinguish two categories of approaches to assess the security of electricity supply and compare their methodological advantages and drawbacks both from the perspective of the modeler, i.e. scientist or consultant, and from the perspective of the interpreter of results, i.e. decision-maker from policy or industry: first, the rather straightforward deterministic forecast margin of available capacities and peak load. Second, complex probabilistic simulations in high temporal resolution that reflect stochastic fluctuations and weather dependencies of available feed-in and electricity load. My research goals are to

(1) investigate whether more complex approaches are per se more suitable to answer relevant questions in the context of security of electricity supply and
(2) derive a complexity guideline that addresses both the modeling community and the interpreters of model results.

Methods

By implementing both methods and applying each of them to a German case-study for the year 2023, I create the necessary foundation for my comparison (cf. Figure 1). I introduce two scenarios, a *base scenario* and a *reduction scenario* with reduced capacities of coal-fired power plants to reflect current discussions about a coal phase-out in Germany. In both approaches, I account for contributions of neighboring countries of Germany to the security of electricity supply. Further, I investigate influences of uncertain input data on results of both methods. Finally, I derive a guideline through complexity for the assessment of security of electricity supply that distinguishes the different modeling phases (i.e. data acquisition, data preparation, model implementation, model runs, visualization and evaluation of results, sensitivity analyses, sustainable model maintenance). This guideline is intended to serve as basis for future modelers' choices and to inform the interpreter of the results about benefits and drawbacks of different levels of modeling complexity.



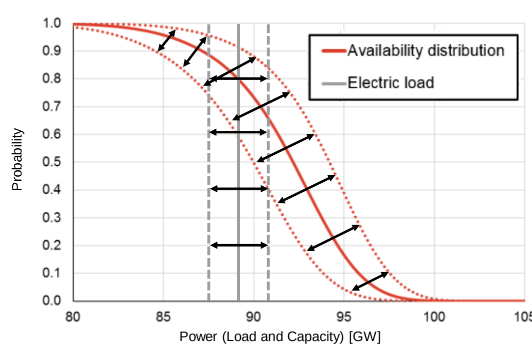


Figure 1: Exemplary illustration of modeling approaches - Deterministic forecast margin (left) and probabilistic simulation model (right)

Results

My analysis reveals substantial differences with regards to complexity during the aforementioned modeling steps. Further, my results indicate that the different levels of complexity lead to different applicability for certain questions: whereas the rather simple, spread-sheet based approach of deterministic forecasts margins is suitable to provide insights of more general nature, answers to questions with an intrinsically probabilistic character can only be found using more sophisticated modeling approaches. On the other hand, the more complex interdependency between given input data and model output in case of the probabilistic simulation model leads to a higher dependency of the accuracy of outcomes on the quality of input data. Uncertainties in input data can deteriorate results more substantially when highly elaborated simulation methods are applied. This becomes even more severe as the central European energy system is about to reach a tipping point with regards to security of electricity supply. Thus, both scientists and policy-makers need to bear in mind that more complex models are suitable and needed to answer more complex research questions, however simple approaches can also provide insights and come with a reduced need for input data and provide interrelations between model inputs and model outputs that are more comprehensible. Summing up, I find the following:

- With the increasing degree of complexity in world-wide energy systems comes a rising relevance of complexity management in energy system modeling
- When choosing a modeling approach, the whole chain of the modeling process should be considered
- Deterministic forecasts margins allow for easily comprehensible modeling, but are increasingly limited in their informative value due to growing shares of fluctuating renewables
- Deterministic forecasts margins provide a good overview on the system state and relevant influencing factors
- Complex modeling approaches can give a sense of control over the system, but the uncertainty of the results should not be overlooked, in particular near system-critical tipping points

Conclusions

I state that complex research questions with intrinsically probabilistic character require more sophisticated modeling approaches that come with a higher degree of complexity, too. Using highly elaborated models causes the need for different types of input data in high resolution and quality. Data errors or manipulations can influence the outcomes in a highly non-linear way. Thus, consequences of changes in input data are often hard to predict and accurate answers to complex research questions can only be guaranteed if reliable input data is accessible. With regards to basic research questions, also rather simple approaches are suitable to generate insights and more complex ones do not *per se* allow for higher quality of results. Even more severe: highly sophisticated models are often said to provide more reliable outputs, but their dependency on the quality of input data is higher, as my results demonstrate. Thus, complex models provide the opportunity to give answers to complex research questions, but also come with high uncertainties regarding the reliability of results due to substantial, and often non-linear, influences of uncertain input data. I introduce the term *complexity dilemma* to describe this situation.

Overall, I find that both rather simple approaches and more complex models have benefits and drawbacks, so a tailor-made combination and a clear weighing of pros and cons with regards to (1) the underlying research question, (2) the quality and availability of necessary input data and (3) the audience of the results are important. Thus, I provide a detailed guideline that outlines the respective pros and cons of the two modeling approaches under investigation.

My results have substantial indications for policy-makers as they advice not to unconditionaly rely on the accuracy of complex models as time-intensive and complex modeling approaches do not guarantee for reliable predictions of the future when data uncertainties occur. It is *a priori* difficult to predict all consequences of market interventions in complex energy systems even using complex models. Thus, I suggest to use flexible, market-based mechanisms to avoid situations, in which planned-economy approaches based on model outputs lead to undesired outcomes due to the complex behavior of the modeled energy system. I hypothezise that model outputs can serve as indication for needed market interventions but should not directly be seen as basis for planned-economy system planning due to the *complexity dilemma*.

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