ARE COMPLEX ENERGY SYSTEM MODELS MORE ACCURATE? AN INTRA-MODEL COMPARISON OF ENERGY SYSTEM OPTIMIZATION MODELS

Jan Priesmann*, +49 241 80 49879, jan.priesmann@eonerc.rwth-aachen.de
Lars Nolting*, +49 241 80 49901, lnolting@eonerc.rwth-aachen.de
Aaron Praktiknjo*, +49 241 80 49691, apraktiknjo@eonerc.rwth-aachen.de

* RWTH Aachen University, Institute for Future Energy Consumer Needs and Behavior (FCN), Mathieustr. 10, 52074 Aachen, Germany

Overview

The analysis of energy systems with computational models is a widely applied method for plant operation planning, investment decision making, and assessing the impact of policy measures. Energy systems are complex systems that require simplification in order to analyze them (Bale et al., 2015). The complexity of energy systems can be reduced by using a range of complexity reduction techniques. The reduction of complexity, however, influences the accuracy of the model in representing the real-world system. Currently, the standardization of the modeling process is low, there are ever-increasing possibilities of modeling through technical progress, and a low willingness of joint development or even public provision of models exists. This results in a high number of available models, high costs in terms of development and running time of the models and at the same time an unclear assessment of the capability of and the accuracy in answering distinct research questions. Consequently, the allocation of scarce resources for computational modeling could be more efficient. Holistic examinations of and best practices for energy system modeling and the trade-off between complexity and accuracy can be an accelerator for a model development and analysis that is more efficient in terms of development and execution times while guaranteeing sufficiently accurate results (DeCarolis et al., 2017, Voll 2014). This is addressed in the paper by developing a modular and scalable optimization model for simulating market mechanisms of electricity markets. Multiple variants of models for the same electricity market can be generated. Their results are compared in complexity indicators, dispatch and invest decisions, as well as electricity prices. This systematic analysis gives insights into the suitability of modeling practices for the specific research questions that are based on an empirical evaluation of the trade-off between complexity and accuracy. By validating the model against historical data, the findings indicate how much complexity is necessary to calculate sufficiently accurate results.

Methods

A modular and scalable energy system optimization model (MaSESOM) is developed that allows an efficient generation of a large range of models. Included in the model are energy system components in several implementation variants (e.g. different grid model implementations). Thereby, the optimization model can be executed as a linear programming (LP), nonlinear programming (NLP) or mixed-integer programming (MIP) model. Different complexity reduction techniques, such as linearization, discretization, aggregation, technological simplifications, and reformulations that are common in the literature and scientific models are identified (Kotzur et al. 2018, Palmintier et al. 2013). They are applied to the system components and analyzed for their influence on selected complexity and accuracy indicators. Besides technological modularity, MaSESOM implements automatized temporal and spatial scaling of input data. This allows generating models for short-term analysis (e.g. dispatch analysis) and long-term analysis (e.g. investment planning). Currently, MaSESOM can generate 1280 different modular combinations that can be tested on three spatial (national, federal, and administrative district level) and an infinite amount of temporal resolutions.

Using MaSESOM, a large data basis of different optimization model formulations can be generated, and their optimization results assessed. This allows for a systematic cost-benefit analysis of different model formulations by testing components individually and collectively. Different indicators for complexity and accuracy, such as solving time, memory usage, deviation from benchmarks, and scalability are postprocessed from the optimization results and subsequently analyzed using statistical and visual methods. Finally, conclusions are drawn based on the complexity and accuracy assessment to give recommendations for specific model requirements.

Results

The results, which should be regarded as a first overview of the possibilities of the approach developed, show interesting insights into the impact of different implementations on the accuracy and complexity indicators observed. Implementations for the coefficient of performance (COP) of conversion units perform differently well depending on the analyzed decision problems. For both, dispatch and investment models, optimization models using constant COPs have an accuracy close to more detailed implementations while having the lowest solving times and memory usages. Regarding the more accurate implementations, COPs with constant loss terms show to be the best alternative for dispatch models, while piece-wise linearization methods work best for investment models.

A simple grid model (i.e. transshipment grid model) can increase the accuracy by applying grid constraints to the optimization model. Compared to models using the copper plate approach, this implementation shows to reduce the complexity in terms of solving time for the tested model. This might be assigned to an increase in tightness of the model. The relation between complexity and accuracy, in this case, seems to be rather a complementarily one than a trade-off.

In terms of the accuracy indicator tested, deviation from the objective function value of a benchmark model, the temporal resolution shows to have a greater influence on the accuracy indicator compared to the spatial resolution. Scaling the spatial resolution causes a high nonlinear increase in required memory space if the ESOM implements a grid model. The use of plant clustering has greatly reduced spatial complexity.

Finally, when analyzing the combination of different conversion unit implementations, such as minimum loads, start-up costs and ramping rates, especially the combination of several of these implementations has an impact on the tested complexity and accuracy indicators. While in combination they increase the accuracy significantly, they also increase the complexity in terms of solving time and scalability. This can be accounted to the different dynamics present within the component implementations that interfere when analyzed collectively.

Conclusions

The developed model shows to be efficient in generating a large range of models by using modular implementations and an automatized preprocessing that decouples the modeling process from the data acquisition. The holistic analysis of energy system models generates information with high value for practical application. Analyzing the absolute solving times instead of theory-based approaches such as defining worst time complexity or analyzing model tightness may be more accessible for regular modeling practice (Tehrani et al., 2010). The approach generates an empirical data basis that can be analyzed using statistical methods and visualizations. Based on this evaluation, recommendations for the required complexity in dispatch models for the market-based calculation of electricity prices, dispatch and investment decisions can be derived.

In the long run, a systematic analysis of complexity and accuracy in energy system models can accelerate the development process of models and furthermore improve the quality of the analysis results at lower accompanying costs. Based on the approach in this paper, subsequent research can be suggested. Currently, only one solver (i.e. SCIP, see Gleixner et al., 2017) is used. The influence of the solver itself should be analyzed by applying a variety of solving software. Having the modular structure, the model can be easily extended by further implementations that can give additional insights into the relation between complexity and accuracy within energy system models.

References

Bale, C. S. E., Varga, L., & Foxon, T. J. (2015). Energy and complexity: New ways forward. Applied Energy, 138, 150–159. https://doi.org/10.1016/j.apenergy.2014.10.057

DeCarolis, J., Daly, H., Dodds, P., Keppo, I., Li, F., McDowall, W., … Zeyringer, M. (2017). Formalizing best practice for energy system optimization modelling. Applied Energy, 194, 184–198. https://doi.org/10.1016/j.apenergy.2017.03.001

Voll, P. (2014). *Automated optimization-based synthesis of distributed energy supply systems (Doctoral dissertation)*. RWTH Aachen, Aachen.

Kotzur, L., Markewitz, P., Robinius, M., & Stolten, D. (2018). Impact of different time series aggregation methods on optimal energy system design. *Renewable Energy*, *117*, 474–487. https://doi.org/10.1016/j.renene.2017.10.017

Palmintier, B. S., & Webster, M. D. (2013). Heterogeneous Unit Clustering for Efficient Operational Flexibility Modeling. *IEEE Transactions on Power Systems*, *29*(3), 1089–1098. https://doi.org/10.1109/TPWRS.2013.2293127

Tehrani, A. S., Haiying Cao, Afsardoost, S., Eriksson, T., Isaksson, M., & Fager, C. (2010). A Comparative Analysis of the Complexity/Accuracy Tradeoff in Power Amplifier Behavioral Models. IEEE Transactions on Microwave Theory and Techniques, 58(6), 1510–1520. https://doi.org/10.1109/TMTT.2010.2047920

Gleixner, A., Eifler, L., Gally, T., Gamrath, G., Gemander, P., Gottwald, R. L., … Mu, B. (2017). The SCIP Optimization Suite 5.0 (ZIB Report No. 17–12) (p. 43). Berlin: Zuse Institute Berlin.