How to explore a large scenario space of future power systems? - A multi-perspective analysis for Germany

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Motivation and research question

There are four challenges in energy systems analysis. The first is that future pathways are highly contingent on assumptions [1]. The second is computational limitations. The third is that, given a certain methodology, only few aspects of scenarios are usually analyzed [2]. The fourth is the identification of desirable futures within the target triangle of energy supply (affordability, security, sustainability).

Addressing these problems means to create many scenarios using powerful hardware and software (problem 1), to sample from a huge parameter space (problem 2), coupling different tools, (problem 3), and to evaluate scenarios from multi-dimensional perspectives (problem 4).

Methods

We implemented a high-performance computing (HPC) workflow on the supercomputer JUWELS [3]. To utilize this HPC system efficiently, the parallel solver for linear programs, PIPS-IPM++ [4], has been applied. This solver is part of a tool chain including scenario generation, energy system optimization (REMix [5]), agent-based market simulation (AMIRIS [6]) and results evaluation based on a set of multi-dimensional indicators. In particular, we coupled a large diversity of software packages in a fully automated workflow (JUBE [7]) enabling the calculation of a multitude of large-scale scenario analyses in a matter of days.

The real-world problem investigated is future power supply in Germany. It is either modeled as market where the interactions of decentral actors are simulated, or operation and investment planning are optimized from a central planner's perspective. For the latter, the model comprises 479 network nodes that represent unique locations of transformer substations in the transmission grid. Neighboring countries, different weather profiles and techno-economic parameters are also part of the parametrization.

To sample the huge parameter space [8], a literature research considering about 50 sources derives statistical descriptors of the most important parameter values to be varied.

Results and conclusions

First results with 1000 simplified optimization models proof the plausibility of our approach. As next step, we investigated 120 spatially fully resolved power systems.

We compiled a set of more than 40 indicators [9] to provide comprehensive assessments of the simulated power systems cover quantities, such as electricity prices, energy self-sufficiency rate, ecosystem quality or grid congestion. Our results show correlations between indicators as expected, e.g., a high renewable energy penetration corresponds to low CO_2-emissions, etc. Points of interest are all scenarios where a majority of indicators show values one standard deviation above or below the mean of all scenarios. Overall, there are few points of interest, i.e. systems where many indicators would point to a system that is satisfactory concerning system affordability, security and sustainability. Yet, differences between scenarios are small, i.e. t-tests between desirable and undesirable systems are not significant.

With our final results, we expect to pave the way to more robust energy system modeling, e.g. evaluating systems in terms of resilience by extending our methodology for both unit commitment modeling and scenarios of infrastructure outages. This enables the derivation of measures for preparing for disruptive events like price shocks in the vast parameter space.

Literature

1. Gils, H. C., Gardian, H., Kittel, M., Schill, W. P., Murmann, A., Launer, J., Gaumitz F., van Ouwerkerk J., Mikurda J. & Torralba-Díaz, L., *Model-related outcome differences in power system models with sector coupling—Quantification and drivers*. Renew. Sustain. Energy Rev. 159 (2022)
2. Ringkjøb, H. K., Haugan, P. M., & Solbrekke, I. M., *A review of modelling tools for energy and electricity systems with large shares of variable renewables*. Renew. Sustain. Energy Rev. 96 (2018)
3. Jülich Supercomputing Centre, *JUWELS Cluster and Booster: Exascale Pathfinder with Modular Supercomputing Architecture at Juelich Supercomputing Centre*. Journal of large-scale research facilities, 7, A183. (2021), http://dx.doi.org/10.17815/jlsrf-7-183
4. Rehfeldt, D., Hobbie, H., Schönheit, D., Koch, T., Möst, D., & Gleixner, A., *A massively parallel interior-point solver for LPs with generalized arrowhead structure, and applications to energy system models*. Eur. J. Oper. Res. 296.1 (2022)
5. Gils, H. C., Scholz, Y., Pregger, T., de Tena, D. L., & Heide, D., *Integrated modelling of variable renewable energy-based power supply in Europe*. Energy 123 (2017)
6. Deissenroth, M., Klein, M., Nienhaus, K., & Reeg, M., *Assessing the plurality of actors and policy interactions: agent-based modelling of renewable energy market integration*. Complexity 2017 (2017)
7. Lührs et al., *Flexible and Generic Workflow Management.* In Proceedings of International Conference on Parallel Computing 2015, Edinburgh, United Kingdom, (2015), http://dx.doi.org/10.3233/978-1-61499-621-7-431
8. Simon, S., Xiao, M. A *multi-perspective approach for exploring the scenario space of future power systems: Input Data*, [Data set] (2022). https://b2share.eudat.eu. https://doi.org/10.23728/B2SHARE.4E5E2D11B8224FB8809CDC2D07EEFF04
9. Buschmann, J., von Krbek, K., Schimeczek, C., *Energy System Indicators* (2022) [Data set]. https://b2share.eudat.eu. https://doi.org/10.23728/B2SHARE.FE70B138419243C0817425A0D2D5AE32