MODELLING TO GENERATE ALTERNATIVES FOR THE ENERGY TRANSITION – ADVANCEMENTS IN PARTICIPATORY AND MARKET-BASED APPROACHES

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Overview

Energy system models are a key to tool to generate insights and support decision-making for the energy transition. Over the past decade, modelling to generate alternatives (MGA) has become more and more established in energy systems modelling to tackle parametric, but above all structural model uncertainties (DeCarolis, 2011). In a nutshell, MGA generates a set of diverse, near-optimal solutions instead of the single least-cost solution to explore energy futures close to the cost minimum that may be more societally feasible or desired. With the increased use of MGA, various methodological advancements have been made (for an overview, see e.g. Lau et al., 2024). While many advancements focus on the formulation of the optimisation problem, the transfer between MGA models and decision support in practice must also be improved. For instance, Lombardi and Pfenninger (2024) develop human-in-the-loop MGA in a recent preprint by integrating stakeholder preferences through their interaction with a tentative set of alternatives.

In this paper, we present two recent advancements that improve on the transfer of MGA outcomes to practical decision-making. The first one is a participatory approach involving stakeholders in the entire modelling process. This approach is demonstrated for, but not limited to, a small-scaled energy system with a central, accessible decision-maker. The second approach is an economic interpretation of MGA for energy systems with profit-maximising decision-makers that interact via competitive markets. It is demonstrated for a large-scale power system with multiple European countries.

Methods

The first advancement is a participatory MGA approach developed by Esser et al. (2024). It improves and formalises the involvement of stakeholders in the entire modelling process. While applicable with any stakeholder (group), we demonstrate its usefulness for the decarbonisation of the heating, cooling and power supply of a large university campus. The campus system is particularly suitable for a participatory approach for two reasons. First, it is centrally administered so that real data is available and responsible energy managers can be involved in the model creation as experts. Second, there is a small and well-defined group of decision-makers for key decisions on the energy system, which can directly be addressed and supported to exploit modelling results.

The second advancement is a market-based approach developd by Finke et al. (2024). It links MGA to competitive market equilibria and thus facilitates an economic interpretation of MGA models for energy systems governed by markets instead of a central planner. First, theoretical results are derived analytically. Then, they are applied and demonstrated for an expansion planning problem in a multi-national power system. While more broadly applicable, the power sector case study is particularly relevant as capacity expansion decisions must be both, economically feasible for individual profit-seeking investors and societally feasible.

Results

For the participatory MGA approach applied to the decarbonisation of a university campus, we find that the cost-optimum is extremely flat with significant room for choices in heating and cooling technologies only 1% above the least cost. At 10% extra cost, there are no must-have heating technologies and some individual technologies can provide up to 100% of the heating demand if desired. Within this room for choices, we highlight alternatives that could be particularly desired due to risk diversification, realisation and maintenance efforts or synergies with research and teaching activities. Moreover, we obtain guidelines for a workflow and stakeholder interaction in a joint retrospective workshop that can be used to adopt the participatory MGA approach to other applications. It comprises five steps: identifying the problem and target; creating and validating the model; applying the optimisation model, including the MGA procedure with multiple subsequent sub-steps; communicating the findings; and taking the decision.

For the market-based MGA approach, we prove equivalence between near-optimal MGA results and adapted competitive equilibria under interventions (e.g., a capacity-based subsidy) induced by a governmental planner. This implies cost-recovery properties that guarantee profitability of endogenous investments. In particular, if MGA outcomes are desired by governmental planners, our findings show what subsidies or penalties (amount and type, e.g. capacity- or generation-based) guarantee their economic feasibility. The capacity expansion case study confirms the theoretical findings numerically.

Conclusions

We presented two recent improvements for the transfer of MGA results to support decision-making in practice: a participatory approach involving stakeholders particularly suited for small-scaled systems and a market-based approach linking near-optimal model outcomes to competitive market equilibria under intervention of a governmental planner. We demonstrated with two case studies how these methods can be used to support decision-making for the energy transition.

Future work should link energy system models with MGA and methods from multi-criteria decision analysis (MCDA), in particular to support the elicitation of one preferred alternative among the many near-optimal solutions obtained. Furthermore, the presented approaches should be improved to incorporate parametric uncertainty and incomplete information in the MGA model and the entire decision-making process.

References

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