Master Thesis Proposal

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Lehr- und Forschungsgebiet
Kombinatorische Optimierung

Nuclear Fusion as a Building Block for Renewable Energy Systems

General Setting

The transition to energy systems based on variable renewable energy technologies is a major challenge of the 21st century. While the importance for, e.g. wind turbines and photovoltaics is clear, the role of nuclear fusion in future energy systems is still up for debate. The newly formed German government has now outlined in their coalition agreement the goal to build the world's first fusion reactor for energy generation in Germany. Furthermore, in recent work by Lion et al. [3] presents a novel design concept aimed at overcoming several of the remaining challenges for nuclear fusion to become a reliable as well as economically viable energy source. Additionally, potential markets were identified by Handley et al. [2] and the economic viability based on a European project was estimated by Entler et al. [1]. In this thesis we want to investigate the potential role such nuclear fusion power plants could play in a fully renewable future energy system.

Research Questions

When discussing the economic viability of nuclear fusion, focus is often put on the price per kWh of electric energy supplied. This is already a complex question, as different kinds of subsidies, taxes, investment horizons and decommissioning costs may impact the calculations.

However, at a systems level, the utility of an energy source becomes more multi-dimensional: There, an energy source's economic viability depends on its interaction with other existing energy sources and the availability and flexibility of energy supply. This leads us to the central question of this thesis: How far away is nuclear fusion from generating electricity that is economically competitive? What would the role of nuclear fusion in a fully renewable energy system be? Would it be used as a backup capacity, to produce Hydrogen or to overcome critical time periods, e.g. dark lulls? Which technical components are the main cost factors and what are potential cost savings that can be leveraged to increase the competitiveness of nuclear fusion?

Expectations

You should study mathematics, computer science, engineering with a focus on energy systems or a related field. You need to know integer programming, and we expect you to have some programming experience (any of Python, C++/Java, Julia, Rust, ...), including using MILP solvers (any of Gurobi, AMPL, CPLEX, SCIP, JuMP, ...). Ideally, you bring a basic knowledge about optimisation under uncertainty, but this is not required. Additionally, you have to know some physics and concepts of engineering, including a basic understanding of the process of nuclear fusion.

Furthermore, you should be willing and motivated to implement your ideas. That includes reading in instances, building an integer program, modifying it, and solving it using standard solver software. Thus, your work would contain theory, implementation, and finally computational verification.

Your tasks

The general goal of this thesis is quantifying under which circumstances nuclear fusion is utilised in energy systems modelling. The relevant components for nuclear fusion reactors need to be modelled and potential developments identified. Therefore, all kinds of approaches, from statistical to optimization, can to be looked into.

- Literature research on nuclear fusion in energy systems modelling (Lion et al. [3])
- Development of a counterfactuals approach to include nuclear fusion in energy system modelling
- Demonstration of working principle within an energy system modelling framework or a simplified approach in e.g., gurobi
- Analysis and estimation of the possibility of the necessary changes

We Offer

The topic is close to the work of two researchers, who can offer guidance during the thesis. The aim is to integrate these results into an existing energy system modelling framework that is used in Jülich. Thus, we also provide well-formatted data.

References

[1] S. Entler, J. Horacek, T. Dlouhy, and V. Dostal. Approximation of the economy of fusion energy. *Energy*, 152:489–497, 2018.

[2] M. C. Handley, D. Slesinski, and S. C. Hsu. Potential early markets for fusion energy. *Journal of Fusion Energy*, 40(2), July 2021.

[3] J. Lion, J.-C. Anglès, L. Bonauer, A. B. Navarro, S. C. Ceron, R. Davies, M. Drevlak, N. Foppiani, J. Geiger, A. Goodman, et al. Stellaris: A high-field quasi-isodynamic stellarator for a prototypical fusion power plant. *Fusion Engineering and Design*, 214:114868, 2025.