Title

Multi-product Supply Chain Optimization for Energy Systems

Problem

The transition to affordable, clean, and secure energy systems relies on intermittent renewables, creating a need for storage, which is further complicated by the electrification of the heating and mobility sectors. For the planning of this energy transition, optimization models are used, which are typically formulated as large-scale linear programs (LPs). An example is **EnergyScope Typical Days (EnergyScope TD)** by Limpens et al., an open-source LP for long-term planning of regional multi-energy systems that optimizes investment and operation (Limpens et al., 2019). Like most of these models, EnergyScope TD relies on the central planner assumption, where demand is fixed and supplied at minimum total system cost. While this identifies cost-optimal technology choices, it does not reflect how modern energy markets operate, where decentralized actors make decisions based on profitability. Yang Shu et al. compared central planner and market equilibrium-based optimization approaches at the national scale and found that considering competing stakeholders can lead to significantly different energy system outcomes (Yang Shu et al., 2024).

To address such limitations of the central planner assumption, energy systems can instead be represented as coordinated markets, where stakeholders submit bids to an independent system operator who clears the market. Tominac and Zavala introduced a **spatio-temporal multi-product supply chain (SC)** framework that formulates such markets as optimization problems, linking resource allocation (primal) with market price formation (dual). The resulting allocations correspond to a competitive equilibrium in which stakeholders maximize profits. The framework also captures product transformation, a defining feature of energy systems not represented in existing coordination models. (Tominac & Zavala, 2021) (Tominac et al., 2022)

Task

The objective of this semester project is to explore the feasibility and usefulness of applying a multi-product SC optimization framework to energy system modelling, with particular focus on its integration within EnergyScope TD:

1. **Literature review**: Assess existing energy system optimization approaches and summarize the multi-product SC framework.
2. **Model development**: Build a small-scale prototype of an energy system model using the multi-product SC approach, potentially extended with spatio-temporal features to capture important energy system dynamics such as storage.
3. **Evaluation**: Discuss the feasibility and potential benefits of integrating this approach into long-term strategic energy planning with EnergyScope TD.

Research questions

- What additional insights does a market equilibrium-based approach provide compared to central planner-based optimization in energy system modelling?
- How can the multi-product SC framework be adapted to represent (spatio-)temporal dynamics in energy systems?
- To what extent is this approach feasible and useful for improving strategic energy planning tools like EnergyScope TD?

References

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