INVESTMENT DECISIONS AND MARKET PRICING IN COUPLED ENERGY MARKETS UNDER UNCERTAINTY

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Overview

The transition of an energy system dominated by fossil fuels into a climate-neutral energy system will rely mainly on low-carbon electricity and hydrogen-based fuels. Future allocation of energy demand and market interactions between the two sectors remain highly uncertain. This uncertainty is reflected on in different scenarios but its implications on investment incentives and market prices are not well understood. This work addresses the uncertainty in a combined electricity and hydrogen market model with optimal investment decisions according to the linked spot markets of both sectors. We address uncertainty for two dimensions, i.e., for future electricity and hydrogen demand with different weights on the scenarios which represent the beliefs of market participants, and for different generation scenarios dependent on different weather years.

Methods

The key uncertainty in our Case Study is the distribution of future demands between electricity and hydrogen sectors. To reflect this key uncertainty about the future demand distribution, we consider two extreme demand scenarios: one based mainly on electrification and the other with hydrogen playing a more prominent role. It is assumed that agents have joint expectations regarding the likelihood of being in one or the other demand scenario, and that they base their long-term decisions on these expectations. When a demand scenario is actually realized, the expectations may either match the actual demand scenario or prove to be incorrect. Key agents in the markets are consumers, storage operators, and producers. Besides the short-term operation decisions of these agents, our model considers the long-term investment decisions in storage and generation capacities. Consumers determine their levels of consumption maximizing their utility. The supply side maximizes profits and depends highly on the considered sector. We distinguish between sector-specific and sector-coupling suppliers. Whereas sector-specific suppliers operate only in one market supplying an energy commodity using exogeneous production costs, sector-coupling suppliers buy one commodity at a specific market, transform it into another commodity and sell it at the commodity specific market. An overview of the different agents in our theoretical setup is given in Figure 1. This setup results in a techno-economic market model that builds upon the theoretical work by Egerer et al. [1] and Grübel et al. [2] for uniqueness in equilibrium models of coupled energy markets and storage.

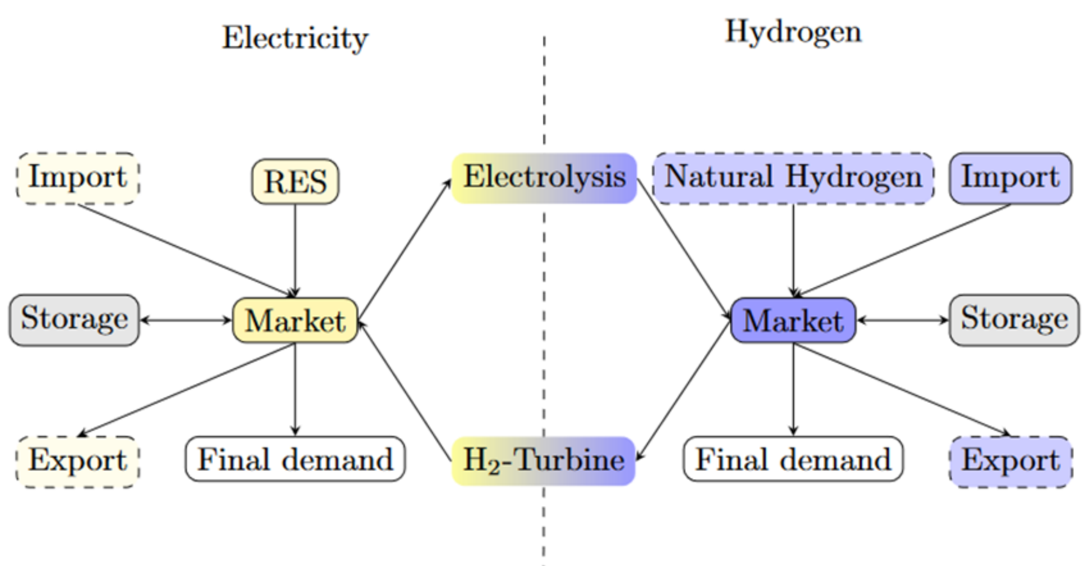

Figure 1: General structure of the coupled energy market model

Results

The model is applied to possible projections of the German energy system without fossil fuels in the year 2045. Our findings indicate that a future reliant on hydrogen will demand substantial renewable energy due to the power needs of electrolysis, despite a lower final electricity demand compared to a system with higher electrification. Hydrogen turbines are essential for stabilizing renewable energy systems, particularly when the system is more electrified. Incorrect demand scenario expectations can lead to considerable losses in welfare, necessitating either additional hydrogen imports or excessive investment in capacity. Comparing the scenarios hydrogen and electrification in which expectations match the actual demand scenario shows higher fluctuations in the demand weighted average market prices of both hydrogen and electricity over the different generation scenarios in the electrification scenario. Furthermore, over-investing in renewables does not lead automatically to lower electricity prices, as in the case of the wrong anticipation of the hydrogen centric system, insufficient investments in hydrogen turbines result in increasing average electricity market prices in the actual demand scenario electrification. From an investment cost perspective, expectations for a hydrogen-centric system should be supplemented by the potential of an electrified scenario, unlike the projections for a purely electrified demand framework.

Conclusions

To prevent welfare losses from wrong investment decisions, it is imperative to provide clear policy guidance and effective communication to market participants, thereby minimizing the welfare losses associated with wrong expectations. As our study analyzes only variables independent on the actual operation within the specified combination of demand and generation scenario, further research could address this question by developing mixed final demand scenarios.

References

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[2] J. Grübel, T. Kleinert, V. Krebs, G. Orlinskaya, L. Schewe, M. Schmidt, and J. Thürauf. “On electricity market equilibria with storage: Modeling, uniqueness, and a distributed ADMM.” In: Computers & Operations Research 114 (2020). PII: S0305054819302254, p. 104783. doi: 10.1016/j.cor.2019.104783.