SPATIAL INCENTIVES FOR POWER-TO-HYDROGEN THROUGH MARKET SPLITTING

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Overview

In the context of the energy transition and ambitious decarbonization goals, hydrogen is becoming essential both as a storage option for renewable energy surplus and a green fuel for multiple usages. The European Commission already foresees 40 GW of electrolyzer capacity by 2030, yet their locations will strongly affect the European transmission system. With a view to the ramp-up of power-to-hydrogen, zonal electricity markets with large market zones may fail to provide efficient locational investment incentives. Consequently, the electricity consumption of electrolyzers can reduce grid congestion but can also exacerbate it. Research has recently discussed potential market splits as a mid-term solution to improve congestion management, recognizing that the first-best solution of nodal prices is controversial. Using the example of Germany, this study investigates the impacts of market splitting on the operation and investment in electrolyzers. The optimization approach includes endogenous investment decisions linked to a detailed scheduling model. The results reveal that market splitting supports the efficient integration of electrolyzers into electricity markets, reducing internal congestion and grid expansion needs. Moreover, missing spatial incentives imply a considerable unused potential for the market ramp-up of electrolyzers. From a political perspective, market splitting benefits the system regarding (integration) costs and reduces subsidy requirements for reaching 2030 targets.

Methods

To study the integration of PtH_2, we apply an energy market model including a Benders decomposition approach (Benders 1962). This approach combines an upper level (master problem) including investment decisions and a lower level of operational decision making (subproblem). The overall framework aims at minimizing total system costs and includes the IDILES module (Leisen et al. 2022) at the upper level to handle investment (and disinvestment) decisions. It is used here to investigate the sizing and siting of electrolyzer investments. At the lower level, the widely used WILMAR Joint Market model (JMM, cf. e.g., Weber et al. (2009), Meibom et al. (2011) and Trepper et al. (2015)) is applied to solve the subproblem of determining the optimal operation (dispatch) of electrolyzers, power plants, storages and other flexible units. The interplay between the upper and lower levels follow an iterative process. Iterations are stopped if an economic equilibrium is reached (up to a given tolerance level). In equilibrium, a zero-profit condition holds for any technology selected for investment. I. e., the revenues of the marginal unit obtained during operations (computed based on the shadow prices) are just sufficient to cover the sum of all capital and operational costs. Using the Benders decomposition approach, IDILES thus optimizes long-term investment and disinvestment decisions while the JMM optimizes the dispatch. The effects of the investment and disinvestment decisions on market prices (and all associated decisions) and system costs are hence considered consistently.

Results

The runs for the four investigated scenarios achieve convergence to equilibrium electrolyzer capacities after 6 to 12 iterations. The computation time is on average 12:31 h per iteration on a high-performance desktop computer[1]. Correspondingly the computation takes around 3 to 6 days per scenario. In the four scenarios, different investment decisions are taken regarding electrolyzer capacities in Germany, depending on the market split and the CO_2 price level. The total electrolyzer investment under the market split exceeds the investment in the single-zone case by almost double in both CO_2 price scenarios. In the cases with a market split, the electrolyzer capacity is entirely allocated to the north zone. Compared to the status quo, no change, and thus no investment, occurs in the south zone. In any case, a higher CO_2 price leads to higher overall electrolyzer investments. The installed capacities without market split miss the government's target of 10 GW by 2030 regardless of the CO_2 price level. Both scenarios with market split exceed this target. All investments are only based on market incentives without any subsidies. The contribution margins of the electrolyzers are higher in the case of a market split within the north zone compared to the reference case. This is due to lower electricity prices in the north zone caused by high renewable production and

[1] We used a Intel® Core™ i9-9900K CPU with 3.60GHz.

limited NTC between northern and southern Germany. The impact of the CO_2 price indicates that the increased value of hydrogen leads to higher profitability of electrolyzers and, thus, higher investments. If a market split is assumed, hydrogen seems to be more economically advantageous in the north zone. The results of the sensitivity analysis show—in case the optimal capacities from the reference cases are used for market splitting—that the electrolyzer consumption is highest when the capacity is located entirely in the north. It is lowest when capacity is fully allocated in the south and somewhere between when capacity is equally distributed between the north and south. In the case of low CO_2 prices, the market split leads to higher consumption when capacities are equally distributed or completely shifted into the north compared to the reference case. In the case of high CO_2 prices, this observation is only true if the capacity is completely shifted to the north zone. The differences in capacities and thus in utilization between an optimized one zonal case—and starting from this point, the distributed capacities for sensitivity analysis—and an optimized case with market split show the missed potential for the market ramp-up of electrolyzers without market splitting.

Conclusions

The results indicate that market splitting induces substantial spatial incentives for PtH_2 integration. With a market split, we observe high investments in electrolyzers in the north zone due to higher market incentives compared to the south zone. This is due to the different price levels caused by scarce transmission capacities and high renewable generation in the north. While the investments are purely driven by market incentives in both the reference case and the market split case, a market split spatially incentivizes more efficient investments. This results in a higher deployment of PtH_2 in the market split case compared to the reference case. Overall, there is no identified need for subsidies for PtH_2. In the same way as the investment decision is spatially incentivized by market splitting, the electrolyzer utilization is also incentivized. Compared to the reference case with one market zone, the domestic production of hydrogen is further supported by market splitting. Here, we observe even higher installed capacities and higher electricity consumption. The results of the market split also reveal the electrolyzers' role as a flexibility provider. While the results show high volumes of curtailed energy in the status quo, curtailment is reduced due to PtH_2 integration in the optimized cases. Hence, the integration of renewables is also supported by PtH_2. Concerning our main contribution, we conclude that the interplay between the electrolyzers and market splitting suggests positive effects for the integration of PtH_2 and the electricity system. The grid congestion due to increasing amounts of renewable production, especially in the north, can be limited by the electrolyzers as demand-sided flexibility. Hence, the transmission system can be relaxed at locations with surplus electricity production. Moreover, the applied market split is beneficial for the market integration of PtH_2. In conclusion, we point out the following key results:

- Market splitting leads to more efficient deployment of PtH2 as prices indicate scarcity and lead to locational investment incentives.
- Market incentives are sufficient for inducing PtH2 investments; thus, there is no need for subsidies in this scenario.
- The locational signals for deployment and operation of the electrolyzers induce benefits for the system regarding costs as well as balancing of supply and demand.
- The choice of the location of electrolyzers and the necessary grid expansion cannot be separated.
- Missing spatial incentives imply that a considerable potential for the market ramp-up of electrolyzers remains unused.

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