PROSUMERS WITH POWER TO GAS (P2G) IN CROSS-COUNTRY ELECTRICITY MARKETS BASED ON A GAME-THEORETIC EQUILIBRIUM MODEL

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Overview

Electricity demand profiles typically exhibit a mismatch to energy supply in many countries, which is for example caused by the intermittent generation of solar PV and wind power, or by the seasonal availability of hydro power. The increasingly fluctuating renewable power production needs sufficient flexibility options, which requires shifting energy between day and night as well as from summer to winter (Kober et al., 2019). Additionally, the pressure to mitigate climate change and the phase-out of conventional technologies require the deployment of new low-carbon energy solutions. This motivates us to consider P2G technologies to avoid CO_2 emissions and to increase the energy system's flexibility and reliability. It is likely that these technologies will compete in future energy markets, which motivates the investigation of their market impacts. We present results from a fundamental electricity market model that measures the impact of P2G and related short/long-term storage facilities within a coupled market area. In particular, we employ P2G-Storage systems in two levels and give each level two settings. In the national level, P2G-Storage system is given as embedded technologies of current wholesale market utilities or as a separate national player. In the distribution level, two price-taking prosumage players in different scales (village scale and city scale) with P2G facilities are under consideration. We use data from an existing energy-system-integration platform (PSI-ESI, 2020), and consider the cross-country markets in the case of Switzerland and its surrounding countries. Performances of P2G-Storage system with different sizes and different storage technology combinations are evaluated quantitatively as well.

The frequency and the time periods of using the P2G-Storage is captured by using a technology-detailed game-theoretic Nash-Cournot equilibrium model. The main analysis comprises how P2G-Storage systems contribute to the electricity supply and demand load shift and their impacts on electricity prices and generation shares on the market. Optimal strategies are investigated for a country player with multiple generation technologies including P2G plants and for a separated P2G player. In particular, a comparison of P2G operation patterns is included.

Methods

We analyze a coupled market area comprising (in the current analysis) Germany, France, Italy, Austria, and Switzerland. For the fundamental modelling of the electricity prices, we employ a technology-detailed game-theoretic Nash-Cournot equilibrium model (Panos & Densing, 2019). We model the day-ahead market with the 24 hourly sub-markets in four yearly seasons with the underlying available generation mix. Electricity plants in the countries are aggregated on plant type level. The numerical model has in total 96 representative load periods for a year and three renewable scenarios, today, year 2030 and year 2050 are taken into account in this work. Based on the cross-country model, we integrate power-to-gas plants together with daily storage (battery and hydrogen) and seasonal storage (methane) technologies in two ways. Firstly, we model the P2G as integrated technologies for country players to determine the role of P2G plants in the supply mix. Secondly, we consider the P2G-Storage system as a separate player to investigate its operation strategy and its impacts on other players in different electricity market areas. Additionally, considering the electricity-intensive pattern and high products' transport expense of P2G plant, the distribution level and the concept prosumer is introduced into the model in two different scales, (village scale using data profile from Zernez, Switzerland and city scale adjusted based on data profile of Basel, Switzerland). P2G-Storage systems are considered as pilot plant in these prosumers. Cases with or without hydrogen market, which allows players to directly sell hydrogen as a product to residential, industry and transport sectors are take into account. Empirical data of P2G plants is taken from the PSI-ESI platform (PSI-ESI, 2020).

Results

Integrating P2G and short/long-term storage technologies into the electricity market modeling is delicate due to the various energy carriers' transition processes and different charging/discharging periods. Implemented in renewable scenarios, Today and Year 2030, where decarbonization targets is not as strict as in Year 2050, P2G technology turns out to be rarely used because of its low current energy conversion efficiency. In scenario Year 2050, the electrolyser is operated when a lot of renewable electricity is generated and market prices are reduced. The current analysis suggests that P2G technology with long-term storage facilities can consume the surplus electricity generation (usually happens in summer) partly, which helps to flatten electricity price profiles and encourage additional deployment of renewable generation. However, under an elastic market environment assumption, instead of shifting the surplus electricity in summer to winter to meet the short supply of electricity in winter season, the market tends to adjust its load and employs P2G-Storage system to transform electricity to other energy carriers, like hydrogen and methane, and sell these new products.

As a prosumer with P2G facilities, we observe different market behaviors and operation patterns from the prosumer who is usually a buyer in the market and the prosumer who is usually a seller. In these prosumers with certain electricity and heat demand profiles, fuel cell (CHP) is under operation in winter when electricity market prices are relatively higher. Another observation is that distribution capacities and distribution grid tariffs can be considered as factors that have effects on the operation of P2G of prosumage players.

Conclusions

Integrating multi-energy-carriers system with storage technologies over different time scales into electricity market modeling is challenging. Energy-carriers, conversion efficiency, storage limits and the way P2G plants integrate into the market influence their benefits and market-driven operation strategies. From the national cases, our results show that P2G technologies can help reduce market variance, promote additional deployment of renewable generations, and partially replace the usage of batteries if multiple/large plants are invested (more likely when direct H2 selling is introduced). From the case of price-taking prosumers, who are connected to the distribution grid, more P2G technologies are used with reduced grid capacities or increased grid tariffs, indicating that P2G-Storage system are likely to enhance the energy independency and security of a prosumer. Our analysis provides a better understanding for the operation of P2G plants from an economic point of view and explores their potential in a cross-country electricity market. Further investigations include implementing P2G-Storage systems into an integrated electricity and gas market and expanding the functions of P2G-Storage systems to provide auxiliary services besides spot market operation.

References

Kober, T., Bauer, C. (eds.), Bach, C., Beuse, M., Georges, G., Held, M., Heselhaus, S., Korba, P., Küng, L., Malhotra, A., Moebus, S., Parra, D., Roth, J., Rüdisüli, M., Schildhauer, T., Schmidt, T.J., Schmidt, T.S., Schreiber, M., Segundo Sevilla, F.R., Steffen, B. and Teske, S.L. (2019), *Perspectives of Power-to-X technologies in Switzerland - White Paper. Swiss Competence Centers for Energy Research: Joint Activity "White Paper Power-to-X"*

PSI-ESI (2020). ESI-Platform Description. https://www.psi.ch/de/media/esi-plattform

E. Panos, M. Densing (2019). *The future developments of the electricity prices in view of the implementation of the Paris Agreements: will the current trends prevail, or a reversal is ahead?* Energy Economics, 84, 104476.