THE WELFARE AND PRICE EFFECTS OF SECTOR COUPLING WITH POWER-TO-GAS

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Overview

The EU's objective to decarbonise the energy system by 2050 has raised questions among energy regulators about the future role of gas (CEER, 2018). Electricity markets with high installed Renewable Energy Sources (RES) capacities have experienced periods of supply and demand mismatch, resulting in near-zero and even negative prices, or curtailment of RES. The challenges associated with evacuating large amounts of RES generation will increase with higher renewable energy targets. Emerging technologies such as power-to-gas may represent a critical linking asset for a sector coupling strategy of electricity and gas systems, according to recent studies (European Commission, 2018). Installing power-to-gas can alleviate electricity system imbalances which can productively repurpose this stored energy for later use in the gas system (Blanco et al., 2018). The conversion of renewable power into hydrogen via power-to-gas can be subsequently blended into the existing gas network, acting as such as a means of seasonal storage and providing an electricity derived domestic supply source of gas. In the academic literature, however, challenges still need to be addressed regarding who will invest in the power-to-gas assets, the ramifications of their participation in energy markets and the net impact across sectors measured in terms of social welfare distribution (Lynch et al. 2018; Vandewalle, 2015). If the support of power-to-gas from the electricity and gas sector diverges due to expectations about what impact power-to-gas' presence may have on the redistribution of welfare across sectors, then investments in power-to-gas may never materialise.

The aim of this paper is to study the power-to-gas investment decision from the point of view of a perfectly competitive electricity and gas system where each sector is optimising for its welfare maximization respectively. We study whether or not there is a convergence in the optimal deployment of power-to-gas capacity and what is the distribution of welfare across both sectors. Similar cooperative and non-cooperative behaviour has been studied for transmission investment in interconnectors between countries to cost-effectively integrate RES using a mixed complementarity (MCP) formulation, but the authors only considered an electricity system (Saguan et al., 2014). MCP modelling has been adopted for a wide class of problems related to energy markets thanks to the straightforward way of combining the optimization problems of multiple actors, as well as the ability to constrain primal variables (e.g. gas flows, power generation) and dual variables (e.g. prices) together (Gabriel et al., 2013). MCP formulations have also been used to model wholesale gas markets incorporating gas demand from the electric power sector, but the the direct participation of sector coupling assets such as power-to-gas are absent (del Valle, 2017). Some sector coupling studies have considered the role of power-to-gas, but have utilised other methods than a MCP (Buttler et al., 2018).

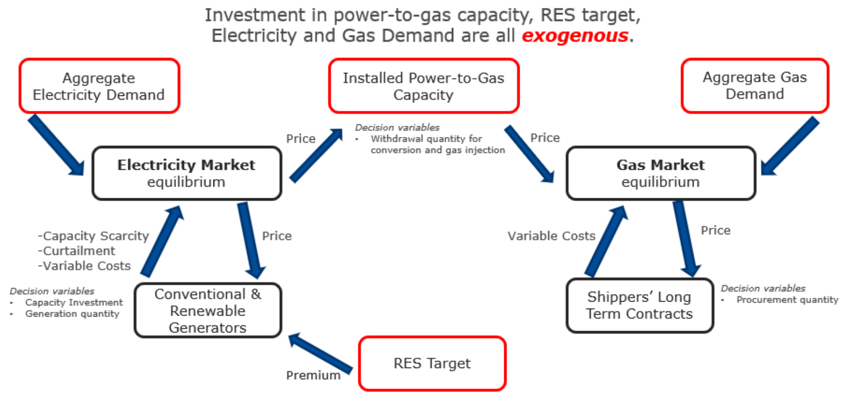
Inspired by the previous sector-specific MCP models, we propose a stylized long term equilibrium model which is built up using a MCP formulation. We are the first to model power-to-gas as the critical asset that drives the joint market clearing of the electricity and gas market simultaneously. We study the welfare distribution and price effects at sector optimal capacities of power-to-gas to know if we can expect a cooperative or non-cooperative long term equilibrium between the electricity and gas sector.

Methods

A stylized long term equilibrium model is introduced which is comprised of three main components: an electricity market, gas market and power-to-gas operations. Physical network constraints are not taken into account in this single node integrated market model. The wholesale electricity market is perfectly competitive, meaning generators – either RES or conventional technologies– bid their variable costs and invest in generation capacity up until they recover their fixed investments cost. In the case that electricity market revenues for renewable generation are insufficient to recover their investment costs, a capacity based renewable energy premium is endogenously determined to satisfy the exogenous RES target. The wholesale gas market is assumed to be a mature gas hub with perfectly competitive shippers who have access to long terms contracts which are represented by a simplified pricing formula.

Multiple iterations are executed in the model, for each iteration investment in power-to-gas capacity increases by 250 MW increments, reflecting the lumpiness of such investments, and the market clearing conditions lead to an equilibrium in both in the electricity and gas market simultaneously. In each iteration, the operation of the power-to-gas assets depend on profit which is determined by the inter-fuel arbitrage between the costs of hydrogen production – the electricity market price and quantity demanded, the sales revenue – the gas market price and quantity of hydrogen injected, and the efficiency of power-to-gas' energy conversion process.

Welfare calculations are conducted ex-post for each iteration's solution to identify Nash equilibrium and system optimal points. Total system welfare can be obtained by adding consumer surplus of electricity and gas, and subtracting renewable energy premium costs and power-to-gas profits.



The main sensitivities driving the model results are power-to-gas investment costs and the RES target, and we vary these parameters to compare our results. For each model run we analyse the evolution of sector welfare and total welfare as power-to-gas capacity is increased.

Results

The first set of observations focus on welfare effects and we examine three aspects as the installed power-to-gas capacity increases over iterations when maximized by each sector respectively. For high RES targets, preliminary results indicate that power-to-gas improves consumer surplus in both sectors. But, the welfare gains to the electricity sector are much greater than the gas sector.

The second set of observations provide insights on the market framework under which an optimal amount of power-to-gas will be reached. If there is a perfectly competitive market environment for merchant power-to-gas investment and operations, then the market outcome for power-to-gas capacity coincides with the system optimum.We also illustrate how far we might deviate from this optimum due to imperfect competition and/or lumpiness of the investment in power-to-gas assets.

The third set of observations reveal the price effects arising when power-to-gas plays a role as the main linking asset between electricity and gas markets. Without power-to-gas, high RES targets lead to zero electricity market clearing prices in low demand periods due to excess and curtailed renewables. At near zero prices, renewable generators' market revenues are insufficient to recover their investment costs and the out-of-market capacity based premium corrects for this missing money problem. However, as you increase power-to-gas capacity, the absorption of excess renewable generation sets a higher electricity market clearing price based on the power-to-gas conversion efficiency and overall inter-fuel arbitrage opportunity. Therefore, the participation of power-to-gas provides a more meaningful electricity market price and reduces the dependence on out-of-market payments.

Conclusions

The main conclusion from the welfare analysis is that both sectors will benefit from power-to-gas. The risk for non-cooperative behaviour is therefore limited, even though the electricity consumers will benefit more than gas consumers. It will also be important to monitor to what extent the power-to-gas market can become a competitive market. The main conclusion from analysing the price effects is that power-to-gas technology can help solve the "zero-marginal-price" challenge in the electricity market of the future with high volumes of renewable energy.

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