Optimal Investment Decisions in Integrated Energy Systems: The Case of Power-to-Gas

Valentin Bertsch, Economic and Social Research Institute and Trinity College Dublin, email: valentin.bertsch@esri.ie
Muireann Lynch, Economic and Social Research Institute and Trinity College Dublin, email: muireann.lynch@esri.ie
Mel Devine, University College Dublin, email: mel.devine@ucd.ie

Overview

Energy systems based on renewable energy sources (RES) have an increasing demand for flexibility. Beyond traditional sources of flexibility, energy systems integration (ESI), i.e. increasing integration between energy pathways that were traditionally considered in isolation and making use of the arising synergies, is a valuable but yet largely untapped source of flexibility. In this paper, we analyse the possibility to integrate the power and gas systems more strongly through power-to-gas (PtG) as one such ESI option. PtG, is a technology that converts electrical power to gas fuel. It has gained increasing attention recently but the majority of existing research focuses on the technology itself without considering system effects. Those studies that consider the system are mostly limited to analysing the system impact when adding a predefined capacity of PtG on the system. Finally, there are a small number of studies that consider PtG expansion as an endogenous optimisation variable but these studies are based on least cost optimisation models exclusively, i.e. they may find that a certain amount of PtG is beneficial for the system but shed no light on whether it proves optimal for any of the market participants to make this investment. In analysing the role of PtG in a future energy system we therefore wish to understand what level of PtG is optimal, what determines this level, and which market player(s), if any, have an incentive to invest in this technology. Thus, we develop a model which endogenises the PtG investment decision and which considers the optimisation problems of the different market participants individually.

Methods

To this end, we present a game-theoretic equilibrium model, namely a stochastic mixed complementarity problem (MCP), where the individual optimisation problems of each player are solved simultaneously and in equilibrium. The players we consider on the supply side include power generating firms with different generation portfolios, i.e. specialised baseload, midload and peakload firms as well as a specialised RES firm and an integrated firm with generation capacity across all considered technologies. All firms maximise their profits by optimising the dispatch of their existing assets and making investments into new conventional and/or RES generation as well as PtG. Firms earn revenues from an energy market and a quantity-based capacity market. On the demand side, we consider a number of both industrial and residential consumer groups. We apply this model to a case study based on the future Irish power system with a high penetration of wind power and examine whether the profitability of PtG investments depends on the firns' existing generation portfolios.

Results

We find that there is no investment in power-to-gas at lower levels of wind penetration but once wind penetration exceeds roughly 50% of demand, the integrated and the renewable firm have an interest to invest. This is in spite of the fact that the PtG plant itself is loss-making, and so the investment is driven by portfolio effects. As PtG increases power demand, prices increase particularly in low-load/high RES hours, and revenues for the integrated and renewable firms' wind generators increase, which justifies the investment. In addition, we find that the level of wind curtailment remains almost constant for increasing levels of wind penetration in the presence of PtG, whereas it increases strongly when no PtG investment is possible.

Conclusions

There are methodological as well as content-related conclusions that can be drawn from the results above. Methodologically, the importance of considering the impact of a particular technology on the generation portfolio, rather than considering the costs and benefits of the technology in isolation, is highlighted by this work. This holds both in relation to firm portfolios and market portfolios. Metrics such as Levelised Cost of Electricity (LCOE) exhibit significant weaknesses as a means of determining the relative strengths and weaknesses of generation technology investments. In spite of this, such metrics are still widely used. The use of net present value to determine whether to invest in a particular technology is also a poor metric as it does not consider the potential for one technology to impact on the profitability of another technology held by a given firm. Focussing on the content, our results show that PtG, as one technology contributing to an enhanced energy systems integration, provides a valuable source of flexibility that helps integrate renewable generation in increasingly variable energy systems. However, as mentioned above, PtG leads to increased prices in low-load/high RES hours and thus to increased consumer costs. Thus, there is a greater total transfer from consumers to wind power producers in the presence of PtG compared to a scenario with no PtG. Future research should therefore include competing technologies (e.g. distributed storage technologies) as possible investments on the demand side.