The Welfare and Price Effects of Sector Coupling with Power-to-gas

BY MARTIN ROACH AND LEONARDO MEEUS

Introduction

Sector coupling has been given increasing attention in EU policy debates. One study states that sector coupling can substantially reduce the costs of the transition to a decarbonized system through the use of existing energy infrastructure, including gas networks and storage facilities, which can reduce the additional capacity needed in electricity transmission and distribution grids (EU Parliament). The challenges associated with evacuating RES generation will increase with higher renewable energy targets.

Power-to-gas (PTG) has been identified as a technology capable of producing carbon-neutral or carbon-free gases to decarbonize the gas sector and provide demand flexibility to the power sector. The two conversion processes associated with PTG are hydrogen production by electrolysis of water and synthetic methane production by methanation, in this study we only consider the former. Some industry studies highlight that the production of hydrogen produced via PTG using renewable electricity will depend on major production cost reductions primarily driven by electrolyzers and access to cheap renewable electricity (Gas for Climate).

Many academic studies have focused on assessing either the economic potential or technical feasibility, but few such as Vandewalle et al. (2018) have explored challenges related to cross-sector market coordination and incentives. If the support for PTG from the electricity and gas sector actors diverges due to the impact that PTG presence may have on the redistribution of welfare across sectors, then investments in PTG may never materialize.

Method

The aim of this paper is to study the PTG investment decision in a context which has perfectly competitive agents in the electricity and gas market, each market is cleared separately but coupled by PTG. We study the welfare distribution and price effects at sector optimal capacities of PTG to know if we can expect a cooperative or non-cooperative long term equilibrium in the electricity and gas sector. Inspired by other sector-specific Mixed Complementarity Problem (MCP) models, we propose a stylized long-term equilibrium model using a MCP formulation (Gabriel et al., 2013). We solve the model using PATH in GAMS.

The electricity market has generators maximizing profit, subtracting its variable costs (VC) and investment costs (IC) from market revenues. Two conventional and one renewable (RES) generator, with 100% and 30% availability factors, respectively, participate in the market. An inelastic demand is represented by a Load Duration Curve (LDC) taken from Joksow et al. (2003) of 10 periods, each period has 876 hours. Each period simulates representative hours. The instantaneous balance between supply and demand and ramping constraints are not represented. As in Saguan et al. (2019), a renewable electricity target in the market clearing constraint imposes that a percentage of gross consumption must be satisfied by RES. This constraint drives a capacity-based premium paid by electricity consumers and paid to RES generators to support investment recovery in order to meet the RES target. Maximizing electricity welfare consist of minimizing energy market and premium costs.

Martin Roach (Martin.roach@vlerick.com) is a Doctoral Researcher at Vlerick Business School and a PhD student in Business Economics at KU Leuven. **Leonardo Meeus** is the Director of the Energy Centre at Vlerick Business School and Professor at the Florence School of Regulation at the European University Institute.

Similar to del Valle et al. (2017), shippers maximize profits by accessing their portfolio of Long Term Contracts (LTC) at a cost determined by a procurement cost function and selling it at the price on the gas market. Elastic gas plants and inelastic gas consumers participate in the market in the same 10 period structure, and are not subject to any RES subsidy costs. Maximizing gas welfare consist of minimizing energy market costs.

PTG is the perfectly competitive market coupling agent with the objective of maximizing profits, earning revenues from the arbitrage between markets at a conversion efficiency and subtracting its VC and IC. The main sensitivities driving the model results are PTG investment costs and the electricity RES target. We annualize investment costs for a range of PTG technology costs: 0, 200, 500 and 1000 €/kw. Each combination of RES target and PTG annualized investment cost form a single scenario to analyse the impact of PTG on electricity and gas markets. For each scenario, in iterating from the baseline of 0 MW of PTG capacity by increments of 50 MW, we obtain a frontier of perfectly competitive outcomes representing the long-run equilibrium points of all agents. For each agent, we measure the positive or negative welfare change of each equilibrium point relative to the baseline. This grid search for agent-specific welfare and total system welfare equilibrium points confirm whether cooperative or non-cooperative behaviour is present.

Results

PTG plays an important price-setting role in the electricity market. Following its short term zero profit condition in each period, PTG consumes RES spillage when the electricity market price is 0 €/MWh, converts it with an efficiency loss and subsequently injects the produced hydrogen into the gas system at the gas market price, when profitable. In a given period, if there is sufficient PTG capacity installed to absorb all of the spillage, the electricity price is determined through this zero profit condition. For example, when the spillage is absorbed in that period, if the gas price is 20 €/MWh and the conversion efficiency of PTG is 80%, then the electricity price becomes 16 €/MWh. PTG puts a value on the zero marginal cost generation, based on this inter-fuel arbitrage. However, through this price-setting role, PTG also erodes its arbitrage profits. As more PTG capacity is installed, the arbitrage opportunity disappears in more periods.

In our stylized setting, PTG is only installed in scenarios where RES targets are high enough to cause spillage and subsequently limited by PTG investment costs. PTG can have a positive impact on total system and sector welfare, and we do not observe a divergence in incentives to install PTG. In participating as a new supply source in the gas market, PTG places slight downward pressure on gas prices benefiting gas consumers. PTG improves the capacity factor of renewables through the absorption of spillage and creates non-zero electricity prices for the spillage consumed. From this price-setting behavior, RES generators are less dependent on out-of-market capacity-based premium to recover their IC. As a result, electricity consumers pay higher prices compared to the baseline, but gain more from the reduction in premium costs paid to RES generators.

The installed capacity of PTG is optimized in a stylized setting, so a complimentary sensitivity analysis exposes how the sizing of PTG and resulting welfare benefits can vary under the same RES targets. In short, the availability factor of renewables and the LDC characterize an electricity system which ultimately specify when spillage occurs and how much. The added value of PTG depends on the electricity consumer costs associated with meeting RES targets across these sensitivities which can be cross-compared.

Conclusions

PTG plays a price-setting role in the electricity market, but this also erodes its arbitrage profits as more PTG capacity is installed. The system optimal PTG capacity leads to positive welfare gains in both the electricity and gas system, when installed, therefore non-cooperative behavior due to diverging incentives is limited. A sensitivity analysis highlights the stylized nature of the model, which reconfirms limited non-cooperative behavior but demonstrates optimal PTG installed capacities can vary based on system characteristics.

References

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Dual Plenary Session 4: Liquid Fuels and Transportation

SUMMARIZED BY YORMY ELIANA MELO POVEDA, PHD STUDENT, FEDERAL FLUMINENSE UNIVERSITY

This plenary session was chaired by Ron Ripple, University of Tulsa. He was joined by Adam Sieminski, from KAPSARC; Denis Arguin, from Enerken, and Sagar Kancharla, from WSP.

The session focused on biofuels, electric vehicles and the future perspectives for oil-based products. The speakers presented the possibilities and challenges of gaining access to cleaner transportation.

Denis Arguin provided deep insight about the Enerkem company. He pointed out that Enerkem is the World's first commercial facility in converting household waste into clean biofuels and green chemicals, such as ethanol and methanol. While Enerkem is located in Edmonton, Canada, it has a detailed expansion plan towards the rest of the world. The presentation showed that Enerka is an excellent innovation model of the sustainable transportation and managing waste.

Sagaar Kancharla presented the repercussion of electricity vehicles transportation. Likewise, he built comparisons with the transportation fuels: high low carbon fossil fuel, low carbon fossil and no carbon fossil fuel. He stressed that the share of EV in transportation is small. He highlighted that EV infrastructure needs to be developed through an integrated coordination between policy makers, automakers, regulators, utilities and consumers. Moreover, competition has an important role to play in the EV infrastructure.