IS POWER-TO-GAS ALWAYS BENEFICIAL? THE IMPLICATIONS OF OWNERSHIP STRUCTURE

Camille MEGY[1,3,4] | +33 6 67 65 02 77 | camille.megy@centralesupelec.fr

Olivier MASSOL[3,4,5,2,1] |+33 6 64 38 16 46 | olivier.massol@ifpen.fr

1 Université Paris-Saclay, CentraleSupélec, Industrial Engineering Research Department, France
2 Chaire Economie du Climat, Université Paris Dauphine, France
3 IFP Energies Nouvelles, France
4 IFP School, France
5 City, University of London, Department of Economics, UK

Overview

Alongside renewable electricity, low-carbon hydrogen is presented in many scenarios as a crucial energy carrier for the energy transition [1]. Currently produced from natural gas through steam methane reforming, hydrogen can be made in a low-carbon way from renewable electricity by electrolysis of water. This technology, called Power-to-Gas (PTG), could play a significant role in the energy sector's decarbonization by alleviating the curtailment of variable renewable electricity (VRE), and replacing coal, oil, natural gas, and conventional hydrogen for uses where energy needs cannot easily be met by electricity. PTG, whose main applications are currently industrial, is expected to start playing a role in balancing a renewables-based electricity system in Europe by 2025-2030 [2]. The first pilot projects are being developed, and technology investments are expected in the coming years.

PTG has been studied from several perspectives in the literature. First, several papers focus on the costs of adopting PTG as an electricity system flexibility solution [3,4]. Then, other articles examine specific case studies, looking at the development of PTG in different regions or contexts, particularly in systems with high renewable energy content [5]. Finally, various studies have looked at the impact of PTG inside a perfectly competitive energy system to determine the optimal operation of the production units and power-to-gas structures present in the system [6,7,8].

However, if one can wonder whether market failures occur, the development of PTG is likely to differ from the findings obtained when positing the presence of pure and perfect competition as in [9] also hold in case of imperfect competition. Indeed, As PTG investments are currently undertaken by large companies with a strong oligopolistic presence in the energy sector [10]. Against this background, market power considerations can naturally affect the market outcomes. Furthermore, these large firms substantially differ in nature. Depending on the case, electrolyzers will be owned and operated by either existing electricity producers, gas midstreamers, hydrogen producers, or independent private players. In case of a multimarket player, the actions taken in one market may affect the firm’s profitability in the other market and one also has to consider the effects of the resulting strategic interactions on the firm’s decisions.

The purpose of this paper is thus to examine the effects of these market power and strategic considerations on the future market outcomes. To investigate it, we propose a generic computerized model of these three industries and their interactions. Consistent with the usual static comparisons conducted in standard industrial organization textbooks, the model is solved using a predefined set of alternative market structures that are representative of the different ownership models that can be envisioned for the PTG assets. We then methodically compare the obtained market outcomes in the gas, power, and hydrogen markets and analyze the equilibrium prices, quantities and the resulting social implications.

Methods

The research question is investigated using an innovative common modelling framework that represents the interactions between the power, gas, and hydrogen sectors. We posit that firms compete à la Cournot and decide the quantities sold in each market. We thus specify and solve a market equilibrium problem that is formulated as an instance of a Mixed Complementarity Problem (MCP). In recent years, MCPs have been increasingly applied to examine the effects of imperfect competition in the energy sector [11]. One of the great merits of this approach is in its direct theoretical connections with non-cooperative game theory as it allows for a direct representation of the strategic interactions among between interdependent players. Each player is posited to solve a player-specific optimization problem, and the MCP format makes it possible to allows tolink these individual optimization problems to compute a Nash equilibrium.

Our model aims to compare the results obtained between different scenarios of PTG ownership. We thus consider different scenarios whereby PTG is controlled by various strategic players in the electricity, gas, and hydrogen sectors who differ in the generation units they own.

We calibrate the model using the Dutch energy system. Ideally situated to drive the adoption of hydrogen as a clean energy source, The Netherlands has a strong interest in developing this technology to achieve decarbonization targets and preserve the region's industrial activities [20]. Where future data forecasts are required, we use projections for the year 2030.

Results and Conclusions

This study shows that, in an imperfect electricity, gas, and hydrogen market, PTG operation and, therefore, the effects linked to the introduction of PTG vary according to PTG ownership. Thus, agents with renewable electricity production capacities are more interested in overusing the PTG than other agents. Conversely, producers already established in the hydrogen market or with sector coupling technologies tend to under-use it to optimize the revenues obtained in the different markets.

At the same time, comparing the short-term welfare associated with the introduction of PTG in the system with the costs of investing in PTG shows that even with a strategic use of PTG, companies without renewable electricity production capacities have no interest in investing in PTG. Only the company with renewables would be interested in investing in this technology, as the extra profits obtained by overusing the PTG are sufficient to cover the investment costs.

However, the strategic overuse of PTG has several consequences. On the one hand, from an environmental perspective, the over-utilization of PTG can lead to increased CO2 emissions. Indeed, a substantial amount of variable renewable energy is used to produce hydrogen, sometimes replaced by carbon-based electricity to meet consumer demand. On the other hand, from a social point of view, the overuse of PTG reinforces the welfare gap between producers and consumers, especially in the electricity sector.

Our results thus suggest that regulating the renewable electricity that can be used to produce hydrogen could avoid an increase in CO2 emissions and an over profit for electricity producers. At the same time, such regulation risks making the PTG unprofitable for renewable electricity producers. Thus, such regulation should potentially be coupled with an investment support mechanism to limit the strategic use of PTG while supporting its development.

Research on the impact of such regulation on PTG operations in our model could provide guidance on how to formulate this regulation and will be the focus of future work.

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