THE IMPACT OF VECTOR COUPLING ON PRICES QUESTIONS THOROUGHLY THE ECONOMICS OF THE POWER SYSTEM

Dupré la Tour Marie-Alix, RTE & CIRED, +33673493091, marie-alix.dupre-la-tour@rte-france.com
Dussartre Virginie, RTE, +33139244069, virginie.dussartre@rte-france.com
Le Du Marc, RTE, +33139243998, marc.le-du@rte-france.com
Quirion Philippe, CIRED, +33143947395, quirion@centre-cired.fr

Overview

In 2050, with the objective of decarbonization, the power system will face more constrained operation due to the use of variable renewables and limited amounts of biomass and will therefore need storage. In perfect competition, the supply curve is determined from the marginal costs of production [1]. Due to inelastic demand and low storage, prices reflect these marginal production costs. The difference between marginal costs and the exchange price must enable the financing of investment costs: the inframarginal rents send investment signals. According to Boiteux [2] and in theory, these signals allow an optimal production mix to be achieved since short-term and long-term marginal costs converge. Even if the relevance of prices as a unique signal for investment is strongly questioned [3], the evolution of prices remains a major question in the economic analysis of the energy transition. This is increasingly true since carbon neutrality implies a generation mix mainly composed of high investment cost and very low to zero marginal costs (nuclear and renewables), but also of expensive and limited sources (biomass). Some studies [4]–[7] have concluded that electricity prices become very volatile, and often zero or negative in mixes with a high proportion of variable renewables. On the other hand, as part of the transition to zero carbon emissions, electrification is expected to increase, with new electricity uses (mobility, Power-to-Gas (P2G)). These new uses, likely to be more flexible than specific electricity demand, will have an impact on the electricity demand curve, and consequently on prices. The issue of the impact of these uses on electricity prices has been addressed by [8] but this study completes the approach with a representation of the hydrogen and methane vectors. The aim here is to study explicitly the impact on electricity, hydrogen and methane prices of vector couplings (P2G and Gas-to-power) and storage management.

Methods

The simulations are carried out using the Antares tool [9]. This open-source software simulates the hourly supply-demand balance and optimizes the use of production resources to meet demand at the lowest operating cost (no investment costs are considered). The modeling is based on the M23 scenario of the study "Energy Pathways to 2050" published by RTE, the French transmission system operator [10]. This M23 scenario is one of those that concentrates new French investments on renewable energies, and particularly on large wind farms, which allows better efficiency and economies of scale. The system considered here covers three energy vectors, electricity, methane and hydrogen (Figure 1), which are represented at the national level (one node per country) in 17 countries of Western Europe in 2050.

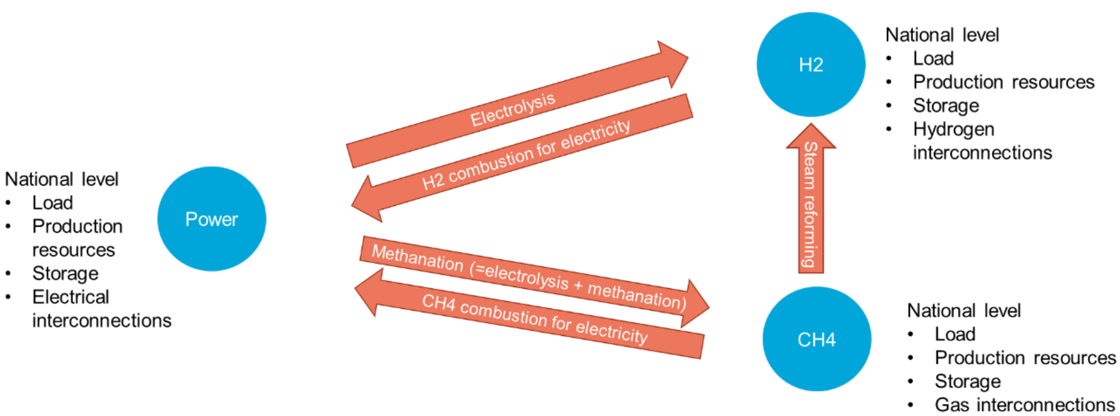

Figure 1 - Simplified representation of the simulated energy system

Methane and hydrogen storages are managed with marginal storage water values (MSWV) [11][12]. Many algorithms have been developed to calculate MSWV, involving dynamic stochastic optimization methods [13]. However, in a very simplified modeling, MSWV were calculated assuming a linear relationship between MSWV and the storage filling level. MSWV play the same role as the different marginal production costs in the supply curve for setting the price. They are determined iteratively so that stocks can arbitrate between different generation sources (imports or P2G, and sometimes local production). In addition to the presence of MSWV and generation units in the supply curve,

some price steps correspond to the demand shedding of other vectors. For example, in the electricity supply curve, the shedding price of hydrogen and methane production via P2G appears, which allows the electrolyser to arbitrate between the electricity and gas markets.
Among limitations, what is called "price" does not result from a market process but reflects the value of the supply constraint in the optimization problem solved by Antares. This optimization problem relies on an assumption of perfect competition and in particular on perfect information on the week-long optimization period.

Results

Hydrogen and methane prices are seasonal and steady every week. They are mostly set by MSWV, which is explained by their large volume and place in the stack. Hydrogen prices have more seasonality than methane prices, due to lower storage volumes.
P2G shedding sets the price of electricity for most of the year, sometimes in a direct way (intersection of the supply curve and the demand curve on the P2G shedding level). Sometimes it does so indirectly when the price is set by short-term storage (electric vehicles, batteries, pumped storage) that are limited in injection or withdrawal at times of P2G marginality.
Overall, electricity prices are separated into three portions. The first one corresponds to zero or very low prices, a consequence of renewable or nuclear marginality. This zone is very small because of P2G and storage capacities, which reduce the renewable marginality. Second, during 2/3 of the year, electricity prices correspond to P2G shedding, reflecting the marginal cost of unproduced H2 or CH4 energy, sometimes supplemented by the efficiency of short-term storage. Finally, during the rest of the year, electricity prices are set by hydrogen or methane power plants marginal costs.

Conclusions

Vector couplings challenge two major properties of the electricity product, undermining the basis of the economics of the power system. First, the inelasticity of demand is questioned: in 2050, with P2G and electric vehicles, the flexibility of demand could set prices on a majority of time steps of the year. Secondly, non-storability is contested: the breakthrough does not come from the existence of electricity storage facilities but from their volume, which induces very strong price dependencies between time steps within the week due to short-term storage and during the year with seasonal storage.
As a result, prices are no longer mainly set by electric power generation units, but depend mostly on demand modulations and storage management. Storage management already has an important role in the current energy system for hydropower, methane and nuclear, but it takes on an even more important role in the represented energy system where most of the flexibility is provided by storage resources.
Several limitations to the presented representation have been identified and future work has already been initiated to address them, especially the perfect market hypothesis and the notion of perfect anticipation over the week.

References

[1] S. Stoft, *Power system economics: designing markets for electricity*. New York: Wiley-Interscience, 2002.
[2] M. Boiteux, “Peak-Load Pricing.” 1960.
[3] P. Vassilopoulos, “Les prix des marchés de gros de l’électricité donnent-ils les bons signaux et les bonnes incitations pour l’investissement en capacité de production électrique ?,” 2007.
[4] R. Green and N. Vasilakos, “Market behaviour with large amounts of intermittent generation,” *Energy Policy*, vol. 38, no. 7, pp. 3211–3220, Jul. 2010, doi: 10.1016/j.enpol.2009.07.038.
[5] W. Steggals, R. Gross, and P. Heptonstall, “Winds of change: How high wind penetrations will affect investment incentives in the GB electricity sector,” *Energy Policy*, vol. 39, no. 3, pp. 1389–1396, Mar. 2011, doi: 10.1016/j.enpol.2010.12.011.
[6] J. I. Muñoz and D. W. Bunn, “Investment risk and return under renewable decarbonization of a power market,” *Climate Policy*, vol. 13, no. sup01, pp. 87–105, Mar. 2013, doi: 10.1080/14693062.2012.750473.
[7] B. Peluchon, “Decarbonizing the electricity sector efficiently requires a change of market-design,” p. 21, 2021.
[8] O. Ruhnau, “How flexible electricity demand stabilizes wind and solar market values: The case of hydrogen electrolyzers,” 2021.
[9] “Antares Simulator Website.” https://antares-simulator.org/
[10] RTE, “Energy pathways 2050 - Key results.pdf.” 2021.
[11] B. François, B. Hingray, F. Hendrickx, and J. D. Creutin, “Seasonal patterns of water storage as signatures of the climatological equilibrium between resource and demand,” *Hydrol. Earth Syst. Sci.*, vol. 18, no. 9, pp. 3787–3800, Sep. 2014, doi: 10.5194/hess-18-3787-2014.
[12] Bellman, “Dynamic Programming.” 1957.
[13] M. Cassagnole *et al.*, “Impact of the quality of hydrological forecasts on the management and revenue of hydroelectric reservoirs – a conceptual approach,” *Hydrol. Earth Syst. Sci.*, vol. 25, no. 2, pp. 1033–1052, Feb. 2021, doi: 10.5194/hess-25-1033-2021.