A Merit-Order for End-Uses of Hydrogen

Albin Kasser: Université Paris-Saclay, INRAE, AgroParisTech, ENGIE Research and Innovation, Paris-Saclay Applied Economics, 91120, Palaiseau, France

Phone: +33787742666: , Email: albin.kasser@engie.com

Maryam Sadighi: Université Paris-Saclay, Université d'Évry, Centre d'Études des Politiques Économiques-[EPEE], ENGIE Research and Innovation, Bld François Mitterrand 91025 Evry cedex, France

Phone : +33 (0)755641127, Email: maryam.sadighi@engie.com

Overview

Zero and low-carbon hydrogen (H_2) produced by renewable sources of energy are a key part of a comprehensive portfolio of solutions to achieve the Net Zero Emission (NZE) target by 2050 that explicitly indicates a complete net decarbonization of emitting activities. Hydrogen and hydrogen-based fuels (e-fuels) could be deployed in a wide variety of sectors. However, whether the renewable hydrogen ultimately gains use in a specific sector and the priority of that sectors to deploy hydrogen (when the supply is limited) is defined through the "Merit-Order for End-Uses of Hydrogen". An optimal allocation of scarce source of renewable hydrogen among the sectors is essential due to uncertainty in its large-scale availability and its lower efficiency compared to direct electrification.

In literature [1-6], the priority of certain sectors for the use of renewable hydrogen and e-fuels has been determined by a number of factors including: *unavailability of the more efficient and less expensive low-carbon alternative*, *willingness to pay for hydrogen* (defined through the competitiveness of the hydrogen price with the dominant fossil fuel used in the sector and with low-carbon alternatives), *cost of retrofitting and replacing equipment*, *abatement potential*, *maturity of the hydrogen-based technologies* (both in terms of engineering development and manufacturing level), *safety issues*, and finally the amount of the *policy support* that the sector receives.

The challenge for public authorities and private decision makers is to mobilize multi-sectoral models to prioritize the energy transition of the sectors and draw relevant support policies. In this respect, Abatement Cost Curve (MACC) of CO_2 are often derived as a standard output of multi-sectoral models, similar to the work of McKinsey & Company [7], that measures the cost of reducing one unit of CO_2. However, those multi-sectoral studies are usually like a black box whose internal assumptions are not readily understood and cannot be directly used as a reliable and a comprehensive reference for the policy makers. As an emerging solution, renewable hydrogen has many uncertainties in the trajectories toward a widespread development and its ecosystem has many more dimensions that is currently integrated in the multi-sectoral analysis.

Methods

This study proposes a new methodology to define an optimal "Merit-Order for End-Uses of Hydrogen" by extending the standard Abatement Cost Curve (MACC) of CO_2 with additional dimensions.

First, we optimize the total cost of the hydrogen ecosystem while introducing a constraint on the availability of hydrogen supply in the short-term. We also introduce available concurrent low-carbon technologies in the model, which gives an edge to green hydrogen applications where no other low-carbon solution (e.g. direct electrification) is available. This approach leads us to define a new metric referred as "Opportunity Cost of Abatement", i.e. the cost of choosing one end use of hydrogen and renouncing the others. Its value compared to the price of CO_2 determines which sector in the considered ecosystem has the priority to deploy renewable hydrogen. This methodology integrates the classical MACC into the criteria used in the study of Ueckerdt et al. [5], on a merit order where hydrogen is deployed in a sector when its abatement cost is lower than direct electrification abatement cost.

Second, we introduce spillovers between sectors: developing certain applications has an impact on the cost of other applications, which is a common accusation against the standard MACC approach. We study the impact of these spillovers on the hydrogen merit order. In particular, we investigate whether taking these spillovers into account could change the order of merit, and whether they could make some uses of hydrogen more meritorious than direct electrification.

Finally, we extend our static methodology to a dynamic approach when the hydrogen availability constraint relaxes over time to determine the optimal launch time of hydrogen applications. We follow the work of Meunier & Ponssard [8] to define a dynamic abatement cost, taking into account the cost reduction potential of the different applications and their technological/commercial maturity.

Results

We applied the methodology to a case when the public authority should decide to allocate the renewable hydrogen produced in a hydrogen valley with a constraint of supply of 100 tons of hydrogen per day (tH_2/day) for two different existing local applications: decarbonization of an ammonia production plant (with total demand of 90tH_2/day) and/or a bus fleet (with total demand of 20tH_2/day). Assuming the current emission intensities, cost of emitting technologies, and the cost of deploying renewable hydrogen-based technologies in both applications, we find that the standard abatement cost of decarbonization of the bus fleet through hydrogen (150€/tCO2) is lower than its value for the ammonia plant (175€/tCO2) in the considered hydrogen valley. When the social cost of CO_2 (SCC) is higher than both sectors' abatement costs while there is constraint to supply both sectors' fully with renewable hydrogen, the social decision-maker needs to decide on an optimal allocation. Optimization of the total cost of the hydrogen valley, leads us to the definition of the "Opportunity Cost of Abatement" (180€/tCO_2) whose value compared to the SCC would be deterministic to define the optimal allocation of hydrogen among the two sectors. With our calibrated parameters, we find that hydrogen should initially supply the ammonia production, as battery electric buses are a competitive alternative to fuel cell electric buses in the main mobility segments. However, taking into account cost reduction through spillovers from one sector to another, we observe that the decarbonization of the industry sector by hydrogen may secure a small hydrogen niche in the bus transport sector.

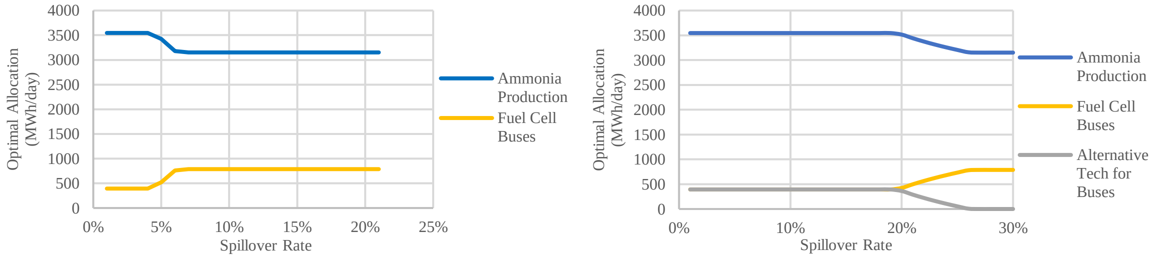

Figure 1. Optimal allocation of technologies with carbon price=200€/tCO_2 in the considered hydrogen valley with constraint on hydrogen supply and two existing local applications: *left*: with no alternative in transport sector. *Right*: with alternative in transport sector

Conclusions

In this paper, we propose a new methodology to define an optimal "Merit-Order for End-Uses of Hydrogen" based on the notion of MACC taking into account additional dimensions: the *constraint on hydrogen supply in short-term*, *competition among different zero and low-carbon technologies*, the *interactions and spillovers of various sectors*, as well as the *time perspective*. This approach is applied to define the optimal allocation of the renewable hydrogen in a hydrogen valley (or hydrogen hub) where co-location of large-scale renewable hydrogen production with multiple end-uses such as mobility and industrial feedstock can foster the development of low-cost hydrogen.

In the absence of the state intervention, this optimal allocation of hydrogen according to the order of merit that optimizes the total costs, might be different than the allocation in a free market that is ordinarily based on the equilibrium of supply and demand curves. In the later setting, applications with the highest willingness to pay, such as light mobility, are given priority for hydrogen use despite their low ranking in the optimal merit order. An efficient public policy should be designed to direct hydrogen to its most deserving applications based on the optimal allocation rather than the "free-market" ranking. A direct subsidy to hydrogen is not efficient as it only marginally increases the potential of the most deserving applications while it increases the competitive advantage of non-meritorious applications of hydrogen over alternative competitive low-carbon technologies.

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