STRATEGIES OF DECARBONATION. APPLIED INDUSTRIAL SYMBIOSIS TO LOW CARBON HYDROGEN

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Overview

Achieving global carbon neutrality will require removing fossil fuels and developing low carbon energy sources, on the supply-side, and improving process efficiency and decreasing consumption through sobriety, on the demand-side. Hydrogen has recently gained a lot of interest worldwide, as a key fuel of the energy transition in support to massive decarbonation for usages in transport, industry, heat and power (Ball & Weeda, 2015; Brandon & Kurban, 2017; Maggio et al. 2019). By 2050, the low carbon H2 demand is estimated at some 500 million tons (IEA, 2021). In Europe, the share of H2 in the energy mix is projected to increase at 14% by 2050, from the current 2% today (EC, 2020). At a country level, a set of national roadmaps include hydrogen in support to decarbonation of economies (Germany, United Kingdom, Russia, Australia, Korea, United States, etc). The French government as well enacted a low carbon hydrogen production Plan within a more global strategy of economy decarbonation (Ministry of Ecological Transition, 2020).This paper develops a methodology to study the deployment of hydrogen in France, based on projections of the national transmission system operator, of 35 TWh H2 in 2050 (RTE, 2021). Large uncertainties still remain whereas the H2 production potential is enough to meet the domestic demand and about the location of the H2 infrastructure, hence this research depicts those factors needed for the emergence of a large-scale hydrogen ecosystem. The starting point is firstly to replace the current brawn or grey hydrogen production based on fossil-fuels by green and yellow hydrogen produced with renewables and nuclear, i.e. 1 Mt of H2 consumed in France; and secondly to add new usages in transport and industry. We simulate a shock on gas import removing that is mainly used to produce grey hydrogen fueling three sectors, and we design a domestic low carbon hydrogen sector as the only alternative. We build an input-output model to highlight inter-industrial relationships of hydrogen sector, based on Leontief (1936), to further support economic industrial and innovation planning. Inter-industrial linkages are calculated by means of conventional indicators of input-output model such as the output multipliers, backward linkage index, and forward linkage index, which further contribute to assess industrial needs of hydrogen ecosystems. Global indicators (GDP, H2 volumes and costs) ultimately give an overview the hydrogen sector development.

Methodology

Step 1. IOT 19 sectors (2018 data)

Step 2. Gas shock. ↘ 25 TWh import (≈ 605M€) → ⇗ H2 domestic output (605 M€)

Step 3. $\mathbf{IOT_2}$ 20 sectors (19 + 1 H2)

Step 4. I-O open Leontief model

Step 5. $\mathbf{IOT_3}$ 20 sectors - with inter-industrial Relationships

Step 6. Output to Output model. H2 output = 4 587M€ = 0.8 MtH2 = 25 TWh

Step 7. $\mathbf{IOT_4}$

Step 8. Ranking: Backward Linkage, Foward Linkage. Multipliers.

Fig. 1. The flow chart of the methodological tool

We follow two main steps, one describing the shock on gas substituted by a new sector production of low carbon hydrogen; and one describing inter-industrial relationships among actors through input-output analysis. Once hydrogen sector is integrated, the conventional Leontief input-output approach applies first, together with the inverse matrix to get Leontief coefficients and inter-industrial relationships. We then apply output to output multiplier method (Miller & Blair, 2009) to model exogenous outputs for hydrogen sector and to further estimate hydrogen development impacts in terms of GDP, intermediate consumptions, multipliers, backward linkage and forward linkage. Data is documented by Eurostat for national input-output table, by academic research for elasticities of substitution between fossil fuels and hydrogen, and by reports on hydrogen key figures (IEA, RTE).

Results

We simulate a 5% gas quantity shock (25,5 TWh). Under electrolysis efficiency assumption of 70%, it represents 0.8 Mt of low carbon hydrogen in volume and 4,587 M€ in value, at the assumption of 6 €/kg of H2. The GDP generated amounts to 3,961 M€, out of which 2,414 M€ in the hydrogen sector only. Low carbon hydrogen has an output **multiplier** of 1.879 and ranks first, which means that the hydrogen represents the highest growth potential sector in the economy, due here the methodological approach and to the assumption that all the process is domestic. According to **Backward Linkage Index (BLI)**, results show that H2 ranks first as well, and **Forward Linkage Index** confirms this trend as well. High BLI obtained here indicates the significant potential of H2 to pull other industries upward based on high level of intermediate consumption of a domestic H2 sector. As for FLI, high levels obtained mean that the H2 output serves entirely as intermediate consumption to other sectors. These results are mainly the consequence of model assumptions on the H2 sector. On one hand, low carbon hydrogen sector does not import any intermediate consumption to produce and needs domestic intermediate consumption only, which naturally leads to a high BLI. On the other hand, H2 output substitutes 100% gas from imports reduced through shock. Finally, there is no export, the entire hydrogen is consumed domestically. The top three sectors the most affected by a domestic hydrogen sector, as the main suppliers of intermediate consumption for the H2 sector, are as follows: Electricity, gas, steam and air conditioning supply (DZ), Scientific and technical activities; administrative and support services (MN) and Manufacture of other industrial products (C5). This dependence represents in the same time a source of fragility, in case of unexpected drop in their production. For example, at the moment, the French electricity production sector is subject to tensions, partly due to a lower availability of nuclear power. As hydrogen is produced here by electrolysis, a lower production in the DZ sector could strongly impact H2 sector and by domino effect all the depending sectors such as industries consuming hydrogen into their process, and their respective upward connected industries.

Conclusions

This paper provides a first methodological framework for the assessment of the energy security issue. In line with the French strategy of low carbon industrial development, it is estimated an energy policy of gas import removal, entirely replaced by domestic low carbon hydrogen. We use input-output model to identify the way that the hydrogen sector is linked to the other industries in the economy. Results show that the H2 domestic production can be considered as a leading sector with a significant economic potential, as shown by high output-to-output multiplier, and this leader position is further confirmed by high levels of BLI and FLI obtained for the H2 sector. This research opens further work perspective, related to the hydrogen infrastructure necessary to build a national industry made of local clusters of hydrogen production and transport and distribution points. Additional documentation is needed in order to finely model those H2 consuming sectors which already have the infrastructure ready to consume the hydrogen in priority in order to limit the switching costs of the energy transition. Next model development will extend the demand for hydrogen to the final user and to exports, where additional cost will be accounted for the distribution infrastructure in case of mass deployment of end-user engines, such as the heavy mobility. Sensitivity will be run to test the resilience of the economy to the hydrogen cost, here set at 6 €/kg H2, whereas in practice it might decrease due to electrolyser technological progress or it might increase due to electricity cost increase. Finally, input-output models contain intrinsic limitations due to linear calculation, static representation of impacts of the transition, and exogenous innovation. Yet the model gives useful insights into the energy role in the economy, in the costs and benefits structure from producing domestic source (electricity) and vector (hydrogen) of energy that reduce the country dependence. As any industrial development, the State intervention is crucial at this stage and the French government has already designed massive support initiatives that amount to 7 Bln € (NHS, 2020), with milestones of 10% clean hydrogen for 2023 and 20-40% for 2028.

References

Ball M. & Weeda M. (2015) The hydrogen economy – Vision or reality?, International Journal of Hydrogen Energy, Vol 40, Issue 25, P 7903-7919, https://doi.org/10.1016/j.ijhydene.2015.04.032

Brandon N. P. & Kurban Z. (2017) Clean energy and the hydrogen economy, Philosophical transactions of the royal society A Mathematical Physical and Engineering Sciences, 375, 20160400, https://doi.org/10.1098/rsta.2016.0400

European Commission, 2020. A hydrogen strategy for a climate-neutral Europe.

IEA, 2021. Net Zero by 2050. Paris.

Leontief W. (1936). Quantitative input–output relations in the economic system of the United States, Rev. Econ. Stat., 18 (3):105-125.

Maggio G., Nicita A., Squadrito G. (2019) How the hydrogen production from RES could change energy and fuel markets: A review of recent literature, International Journal of Hydrogen Energy, Volume 44, Issue 23, Pages 11371-11384, https://doi.org/10.1016/j.ijhydene.2019.03.121

Miller R.E., Blair P.D. (2009), Input-Output Analysis: Foundations and Extensions. Cambridge, Cambridge University Press, second edition.

Ministry of Ecological Transition, 2020. National low-carbon strategy. In French.

NHS National Hydrogen Strategy, 2020. French Ministry of ecology, transition and solidarity In French

RTE, 2021. Report on future perspectives in 2050, Chapter 9. The role of hydrogen and cross-sector coupling.