

Low-carbon hydrogen imports to Europe as a new pillar to achieve carbon neutrality - An economic analysis of potential hydrogen import pathways to 2050

[Johannes Brauer, MINES ParisTech, PSL University, Centre for industrial economics (CERNA),
i3 UMR CNRS, 60 Bd St Michel 75006 Paris, France, +4915788851130, johannes.brauer@mines-paristech.fr]

[Cabot Clément, MINES ParisTech, PSL University, Centre for industrial economics (CERNA),

i3 UMR CNRS, 60 Bd St Michel 75006 Paris, France, +33669011176, clement.cabot@mines-paristech.fr]

[Villavicencio Manuel, Research associate, Chaire European Electricity Markets, PSL Research University, LEDa [CGEMP], Place
du Maréchal de Lattre de Tassigny, 75775 Paris, France. +33666623523, manuel.villavicencio@dauphine.psl.eu]

[Pierre Guilloteau, CentraleSupélec, Paris-Saclay University, 9 Rue Joliot-Curie, 91192 Gif-sur-Yvette, pierre.guilloteau@supelec.fr]

Overview

With the European hydrogen strategy, the European commission has set low-carbon hydrogen as a pillar of the energy transition alongside the direct usage of renewable energies through massiv electrification. Consequently, with the objective to contribute to a deep-decarbonization and to meet climate neutrality in 2050 the way is paved for a widespread usage of hydrogen in the coming decades. However, increasing missing public acceptance for the tremendous local exploitation of renewable energies ("Not in My Backyard") and possibly constrained domestic natural resources limit the potential of an entire domestic supply of low-carbon hydrogen. This suggests to take advantage of the chemical characteristics of hydrogen (e.g. transportation over long distances), to produce it in other parts of the world where the potential and the acceptance is higher and to then ship it to Europe. This is also confirmed by the strategy of the European Commissions that aims at partnering with non-EU countries to establish cooperations and trade of low-carbon hydrogen. It is now to be understood what the drivers are and to identify potential countries to engage with in cooperations that lead to low-carbon hydrogen imports in an economic manner. However, due to significant techno-economic uncertainties of different technologies and the potential repurposing of exiting natural gas infrastructure for handling hydrogen, a variety of import options exist that might vary over the coming decades and that consequently could impact the economics of imports. Therefore, the consideration of a wide range of possible options is suggested for obtaining meaningful insights on low-carbon hydrogen import possibilities to Europe. To the best of our knowledge this has not been addressed sufficiently yet. By focusing on the time horizon from 2030 to 2050 this study contributes to the exiting literature by providing a profound analysis that aims at answering the following research questions:

- How do the different exporting regions compete in terms of costs and volumes of hydrogen exports to Europe?
- What are the most economical pathways considering the different upstream and midstream activities to bring low-carbon hydrogen to Europe and what could be their development over time?

Methods

We develop a modelling framework that consists of a geospatial analysis and a supply-chain optimization model. This framework allows to assess potential low-carbon hydrogen exports from all parts of the world for imports to Europe with high spatial granularity and on an annual basis between 2030 and 2050.

The development of the modelling framework is composed of various substeps:

(1) Focus on the production of low-carbon hydrogen – The Upstream of the hydrogen value chain– and derivation of all required parameters namely the potential volumes and the corresponding prices for the individual exporting countries. In the analysis low-carbon hydrogen is considered to be produced either from offgrid renewable electricity (solar PV and onshore wind) through the electrolysis process (green hydrogen) or from natural gas through the reforming process combined with carbon capture and storage (blue hydrogen) as well as through the pyrolysis process (turquoise hydrogen).

The determination of the potential volumes of blue and turquoise hydrogen is based on both historical and on forecasted natural gas production capacities, wellhead breakeven prices and the corresponding trades with Europe. For green hydrogen we set up a geospatial analysis in a geographical information system (GIS) to derive the potential exploitation of onshore wind and solar PV in the individual countries that allow us to consider both local resources (e.g. solar radiation and wind conditions) and local landuse restriction (e.g. proximity to settlements, landuse, terrain slope and altitude, protected areas). The corresponding hydrogen production costs for all production alternatives are expressed though the levelized cost of hydrogen (LCOH) that is calculated based on the required CAPEX and OPEX

as well as based on other influencing factors such as financing costs and the local renewable potential for every geographical point (e.g. either at country level for hydrogen from natural gas or at a rastered 2.5 degree grid geographical location for renewables). Moreover, for the production of green hydrogen the calculation of an optimized sized hybrid system that consists of three the elements – electrolyser, onshore wind, PV plant - is considered at every location.

(2) Secondly, all required data for the transportation of hydrogen are derived – The Midstream of the hydrogen value chain. It is distinguished between three transportation modes that together build the entire transportation need per supply route: (i) transport in the country of origin from the production site to the export hub, (ii) transportation between the exporting country (hubs) and the importing country (hubs) as well as (iii) transportation from the importing country (hub) to the country of final hydrogen usage within Europe. Therefore, extensive data on existing infrastructure (e.g. deep water ports, LNG port and natural gas pipeline facilities, sea route and pipeline distances) as well as data on the main potential transportation technologies and routes that are currently discussed are collected (e.g. ammonia, liquified hydrogen, liquified organic hydrogen carrier transport via road, pipeline and seaborne). The midstream also includes information on all the conversion/reconversion steps between the individual transportation modes.

(3) The supply-chain optimization model is formulated as a linear programming problem with the objective to minimize overall annual hydrogen supply costs (composed of costs for the hydrogen production, transportation and conversion/reconversion steps) for a given European demand that is considered at a national level. The obtained data from step (1) and (2) build the data foundation of the supply-chain optimization problem. The corresponding decision variables within the problem represent among other the volumes of all individual hydrogen supply routes. For the years between 2030 and 2050 the hydrogen supply chain is optimized. The model captures the main techno-economic drivers and their influence on the potential trade. An extensive sensitivity analysis of input assumptions is carried out.

Results

A variety of insights result from the analysis. One can state that hydrogen imports are subject to substantial techno-economic uncertainties as various parameters can significantly change the outcome of the optimized supply. Most notable are the exploitation of hydrogen production potential of both natural gas and renewable energies in exporting countries as well as the availability of exiting natural gas infrastructure to become hydrogen-ready. Furthermore, the results demonstrate that transportation costs and especially also the costs for the conversion/reconversion between the individual hydrogen forms can contribute significantly to the overall hydrogen supply costs. Moreover, the analysis shows that favorable exporting countries are located mainly in proximity of Europe (e.g. North Africa, Russia, Middle East). The potential repurposing of the exiting cross-border natural gas pipelines provides an important competitive advantage for the interconnected countries. Nevertheless, due to their favourable natural resources and/or their attractive financing conditions other countries such as South Africa, Australia and Chile also show interesting export possibilities mainly for shippable hydrogen products, such as ammonia.

Conclusions

Low-carbon hydrogen imports from other parts of the world to Europe seem to be a key lever to meet carbon emission targets. However, significant techno-economic uncertainties remain. The repurposing of exiting natural gas infrastructure is identified as an economic key driver for hydrogen imports as investment costs for new infrastructure can be reduced while at the same time the risk of stranded assets in the natural gas sector can be avoided. A repurposing decision also requires then to engage with the connected exporting countries in partnerships to develop a corresponding widespread exploitation of renewable energies and hence, to ensure a sufficient economic utilization of the dedicated infrastructure. Therefore, the resulting key policy recommendation is to ensure a long-term planning for the usage of the exiting natural gas infrastructure that includes an assessment of its repurposing potential that is aligned to security of supply aspects. Partnerships with potential involved non-EU countries should be established soon so that private investments in hydrogen production facilities can develop to ensure a timely development of the cross-border hydrogen trade that contributes to the ambitious carbon emission reduction targets.