Evaluating production processes and hydrogen supply routes for zero-emissions steelmaking in the EU

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Overview

Limiting climate change and reaching the Sustainable Development Goals and increasing well-being poses multifaceted challenges to all aspects of human activities. Historically, higher income levels and well-being have been correlated with an increase in the demand of material goods, more specifically of goods that are energy- and CO_2-intensive in their production. In particular, steel production is responsible for a sizeable share of global CO_2 emissions (about 6% of global CO_2 in 2018). Among the low-carbon options for steelmaking are electrification and the use of low-carbon hydrogen, which itself can be produced in a variety of manners with domestic resources or be imported.

Methods

This work presents on-going work on integrated hydrogen and steel demand and production within the energy system model POLES, for 66 world regions.

For each region, demand of steel is calculated with specific material contents of energy technologies or services in a bottom-up manner (buildings, road transport, power sector, other), relying on drivers from the rest of the modelling with a stock-based approach, ultimately relying on macro-economic development and living standards. The productions of hydrogen and of steel are calculated dynamically by representing the competition between multiple processes to satisfy demand. For hydrogen, these include CCS retrofit options on existing steam methane reforming and coal gasification; the use of new processes and infeeds (biomass, pyrolysis); the use of electrolysis (together with dedicated renewable capacities or making use of grid electricity in a flexible manner during non-peak load hours). For steel, these can include CCS retrofit options; new energy vectors (biomass, hydrogen); and electrification options.

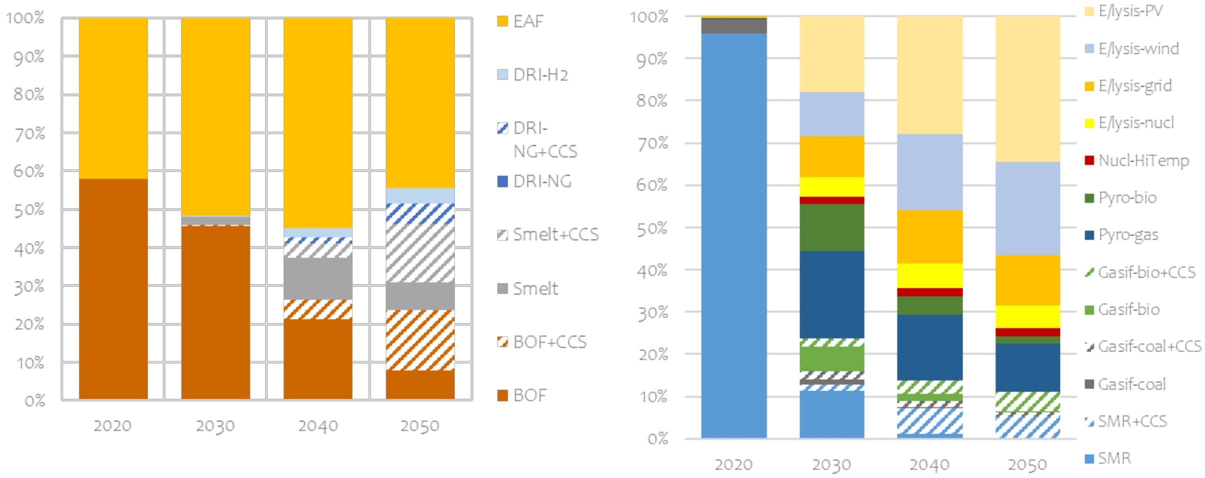
Hydrogen can be supplied domestically, taking into account a domestic distribution cost, or can be imported via ship in liquid form or via pipeline in compressed gas form, taking into account production cost, liquefaction/ regasification cost, travel distance and infrastructure cost. Imports are determined by production capacities of the exporting country and an Armington elasticity.

The evolution of energy and emissions and their implications on steel and hydrogen are studied in scenarios that put global emissions on a trajectory respecting the objectives of the Paris Agreement, resulting in global temperature change to 1.5°C at the end of the century (with limited overshoot to 2050). A global carbon price signal that grows in a sigmoid shape in all regions adjusts investment patterns and changes the relative competitiveness of technologies. Several scenario variants are produced to examine the relevance of key input parameters (macro-economic drivers, steel recycling rates, hydrogen storage costs).

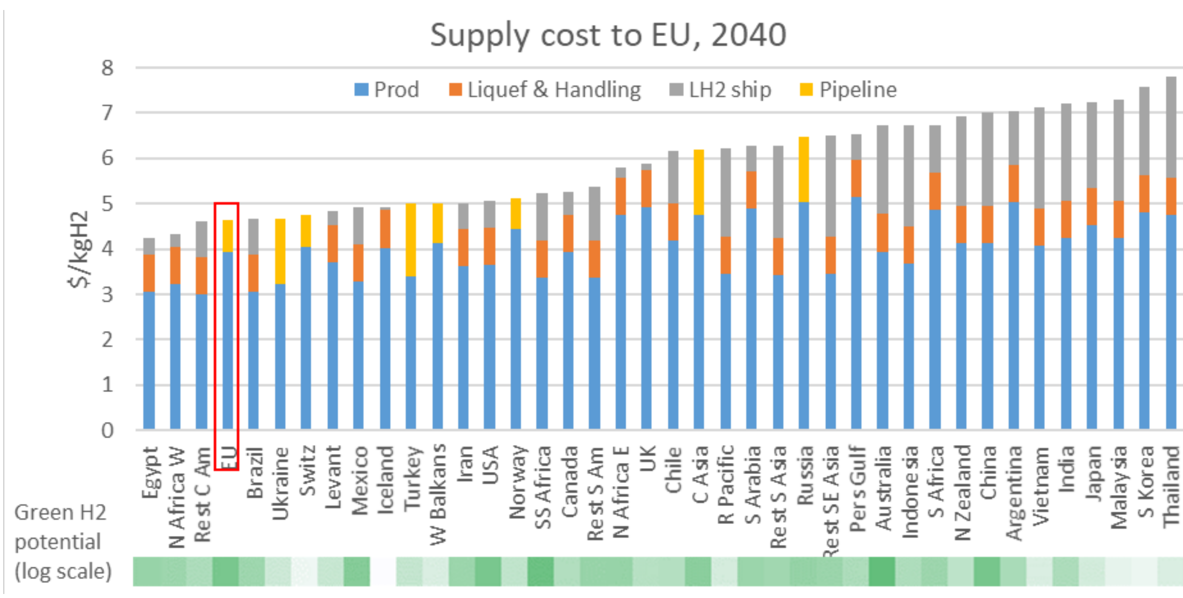
Results

The projected steel demand in the EU remains at roughly constant levels throughout 2050. Under the impetus to reduce emissions, steel production capacities diversify. The fossil fuel-based blast oxygen furnace (BOF) without CCS become non-competitive from around 50 $/tCO2. The smelting reduction and direct reduction processes have the comparative advantage of not needing coking coal and can become as competitive as the electric arc furnace (EAF) process. The direct reduction process using hydrogen gains advantage over its natural gas counterpart as the CO2 price increases. The competitiveness of other production routes does not allow the market share of EAF to rise further. The EU mix evolves from the current domination of BOF to one with BOF with CCS, direct smelting and direct reduction with natural gas and CCS or with hydrogen; electric arc furnace capacities keep their market share roughly constant (*figure below, left*).

EU hydrogen demand is projected to increase significantly due to many new uses, with demand for steelmaking being only a small part of the overall demand. The role of hydrogen in steelmaking is tested under several configurations, by changing the costs of hydrogen production components, delaying the adoption of competitors to hydrogen steelmaking (CCS), situating hydrogen production on the steel production site (bypassing certain transport costs but increasing strage costs), enabling factors in investment environment (early availability of alternative production processes). The share of hydrogen in steelmaking varies between 6% and 23% by 2050 in the EU.



Domestic EU production of hydrogen becomes dominated by electrolysis solutions (*figure above, right*). There is a significant potential for comparatively lower cost supply of hydrogen to the EU from imports from regions in the EU neighbourhood, in particular from North Africa and Middle East (abundance of solar resources with higher full load hours compared to EU for electrolysis) and from Eurasian countries (gas resources for reforming or pyrolysis). The provision of such imported low-carbon (green, blue and turquoise) hydrogen to the EU lowers the average hydrogen price, increasing its competitiveness. In turn, non-EU suppliers to EU could provide for up to 55% of domestic demand by 2050 (including hydrogen for steelmaking) and decrease the average domestic price for hydrogen by up to 10%. This new supply dependence comes while the decarbonisation effort decreases the volume of imports of fossil fuels to the EU. However, in monetary values, the increase in hydrogen imports are not sufficient to counter-balance the decrease in fossil fuel imports. There are still large uncertainties in the costs of the, yet inexistent, industrial-scale supply chain for international hydrogen trade, with significant implications in the terms of trade.



Conclusions

The demand and production of steel and of hydrogen is detailed in the global energy system model POLES. The mitigation options of the steel sector are studied in a scenario with a global carbon price signal that brings the global economy on a pathway compatible with the Paris Agreement. The steel sector has the potential to cost-efficiently reduce its emissions to net-zero by 2050. Several enabling factors would need to align to provide hydrogen direct reduction a significant market share (6%-23%), with a considerable potential for green, blue and turquoise hydrogen being sourced from non-EU imports.