The role of demand, recycling, CO2 capture and hydrogen in the global race for zero-emissions steel

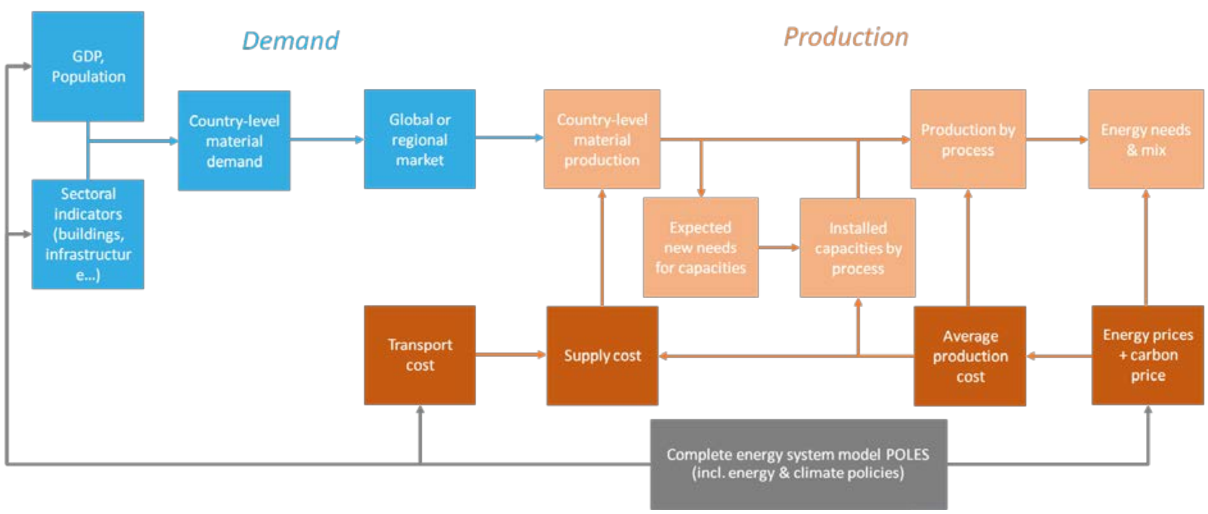
Kimon KERAMIDAS, Université Grenoble-Alpes, France, kimon.keramidas@univ-grenoble-alpes.fr
Silvana MIMA, Université Grenoble-Alpes, France, silvana.mima@univ-grenoble-alpes.fr
Adrien BIDAUD, Université Grenoble-Alpes, France, bidaud@lpsc.in2p3.fr

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).

Methods

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



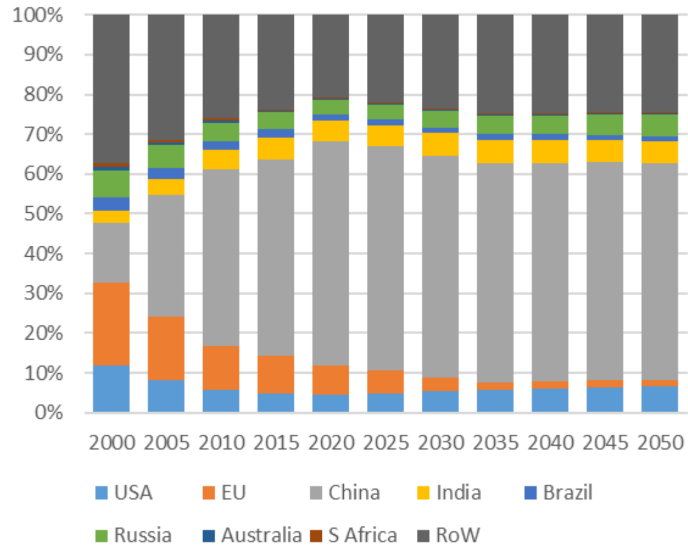
Demand for steel is calculated dynamically by associating specific material demand to energy technologies or services in a bottom-up manner, namely: buildings (for new and renovated surfaces for residential and commercial buildings); road transport (for light and heavy vehicles); power sector (for each power production technology and for transport and distribution grid). These rely on drivers from the rest of the modelling with a stock-based approach, ultimately relying on macro-economic development and living standards.

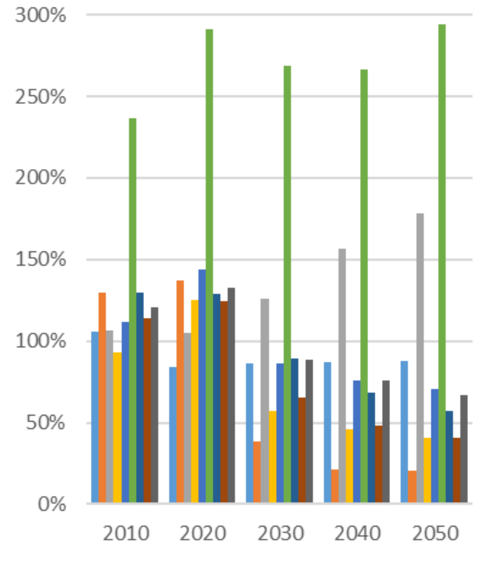
Production for steel is calculated dynamically by representing the competition between multiple industrial processes to satisfy the demand for physical goods. These can include retrofit options, new energy vectors (biomass, hydrogen) or electrification options. Emissions include direct (combustion and process) and indirect (power and hydrogen production) CO_2.

The evolution of energy and emissions and their implications on material cycles are studied in several scenarios, including no-policy; a global carbon price signal that brings the global economy on a pathway compatible with the Paris Agreement; announced policies on 2030 and long-term net-zero pledges; sensitivity analyses on SSP1-5 macro-economic parameters, on increased steel recycling rates, and on evolving specific material demand levels (changing relation between material use and energy service, reflecting material use efficiency and/or material substitution).

Results

Projections show that despite substantial increases in floor surfaces (x2.1 over 2019-2070, including a shift from informal to formal housing), vehicle fleets (x3.1) and power demand (x3.4), steel demand essentially flattens globally, with several regions continuing to increase their demand. Annual demand growth over 2019-2070 amounts to 0.4%/yr (compared to 5.5%/yr for 2000-2019), for both materials. The resulting over-capacity in certain regions redraws the map of potential importers/exporters. World steel production by region (left) and import/export status by region (right):





Climate policy feedback on electrification, power technologies mix and increased buildings renovation results in a 7% steel demand increase over 2019-2070, an increased burden on industry emissions while “enabling” significantly larger mitigation in other sectors.

The steel production mix evolves with the availability of new technologies such direct smelting reduction and hydrogen direct reduction and the possibility to retrofit CCS on existing capacities. The implementation of climate policies diversifies the production mix. Fossil fuel-based technologies without CCS become non-competitive from around 50 $/tCO2. Smelting reduction and direct reduction processes have the comparative advantage of not needing coking coal and can become as competitive as the EAF process. The direct reduction process using hydrogen gains advantage over its natural gas counterpart as the CO2 price increases.

Equipment end-of-lifetime raises the amount of steel available for recycling; with no changes in the recuperation rate, available scrap rises from a third to two thirds of annual demand. However, the competitiveness of other production routes, especially with CCS, does not allow the global market share of electric arc furnace to rise above 34%.

Several parameters are tested to obtain a more ambitious penetration of hydrogen direct reduction in steelmaking (costs of hydrogen production components costs, delaying the adoption of competitors to hydrogen, situating hydrogen production on the steel production site, enabling factors in investment environment), from 6% to as much as 23% of steel production by 2050. However, indirect land use requirements for hydrogen-electrolysis production could be potentially large.

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.

Globally, CCS technologies are found to contribute as much as 40% in steel production by 2050, leaving little space for hydrogen direct reduction (6%); several enabling factors would need to align to increase the contribution of hydrogen to as much as 23%, with potential land use implications for electrolysis.

Large material efficiency effects could be expected from the use of laminated timber materials to partially replace steel in construction. However, the land use trade-offs could be large.