SYNERGIES AND TRADE-OFFS BETWEEN CLIMATE AND CIRCULAR ECONOMY POLICIES IN THE STEEL INDUSTRY

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Abstract

A pathway towards 1.5°C requires substantial economic, societal and technological transformations (IPCC 2018). All sectors require deep and immediate emissions reductions. Heavy industry (steel, cement and chemicals) and heavy-duty transport (trucking, shipping and aviation) are responsible for around one-third of global CO2 emissions (ETC 2018). However, reducing emissions in these hard-to-abate sectors requires policy makers to support the development and diffusion of carbon-neutral technologies and align decarbonisation strategies to global and regional sustainable development pathways. We use an updated version of the ENGAGE-Materials model to assess different strategies and technology options in the iron and steel sector to achieve decarbonisation and a sustainable use of resources. Our results show that an enhanced circularity and the availability of new low-carbon technologies in the steel sector help reduce the costs of decarbonisation. Furthermore, the introduction of a global carbon price that limits fossil fuel use and the associated greenhouse gas emissions motivates the steel industry to move towards a more circular use of steel.

Keywords: Computable General Equilibrium, Steel, Climate Policy, Circular Economy

JEL classification: D58, Q31, Q54, Q53

1 Introduction

The steel industry is vital to infrastructure and the manufacturing of a variety of finished goods, yet it is also a substantial consumer of primary materials and a source of greenhouse gas emissions. Steel also plays a key role in the global decarbonisation as an integral component of wind turbines, dams and electric vehicles (IEA 2020). In the last 50 years, the global demand

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for steel has increased more than threefold and over the coming decades it is expected to continue rising to support economic growth, urbanisation and the consumption of goods. Among heavy industries, the iron and steel sector ranks first in terms of CO2 emissions and second in terms of energy consumption (IEA 2020) with around half of global production occurring in China. The steel sector is currently the largest industrial consumer of coal, which provides around 75% of its energy demand (IEA 2020). Depending on the product, steel remains in use for including an average of 13 years in vehicles and around 50 years in construction, after which the steel may become available for reuse or recycling (Bleischwitz et al. 2018).

In this study, we explore the strategies and technology options in the iron and steel sector to achieve net-zero emissions, considering both the challenges of decarbonisation and a sustainable use of resources. We do this under the overall framework where the Paris Agreement is met across all sectors of the economy. Therefore, we focus on the trade-offs and synergies between climate policies, circular economy policies and technology development.

We use an updated version of the Environmental Global Applied General Equilibrium (ENGAGE-Materials) model, which is a multi-sector, multi-region, global economic model that accounts for circularity in the steel sector (Winning et al. 2017 and Nechifor et al. 2020). The steel version of ENGAGE is the most advanced global CGE model dealing with the steel sector in a circular economy context. ENGAGE-materials models iron ore, primary and secondary steel production technologies which take into account the possible pathways for steel production capacities across the electric arc furnace (EAF) and basic oxygen furnace (BOF) routes. Furthermore, the model represents the scrap treatment and recycling sector as a standalone economic activity producing treated scrap which can be used domestically or traded internationally. The model also considers the potential development and deployment of carbon capture and storage (CCS) and hydrogen-based direct reduced iron used in electric arcs (H-DRI-EAF).

2 Towards the decarbonisation and circularity of the steel industry

2.1. Decarbonisation challenges in harder-to-abate-sectors

Carbon emissions from heavy industry are often referred to as hard-to-abate due to the lack of technological options to decarbonise sectors such as steel, cement and chemicals. While commercialised substitution possibilities exist for production in other carbon-intensive sectors e.g., renewables in power and electric vehicles in transport, the same cannot be said for much of industry where low-carbon technological have, until recently, either non-existent or still in their infancy, although these are now emerging (Material Economics, 2019). Often it is the requirement for high-temperature heat for these industrial processes that necessitates fossil fuels, as electrification cannot meet that heating demand, and also chemical reactions create unavoidable process emissions in certain instances. Despite these difficulties, under the Paris Agreement these industrial sectors are an essential part of a global solution to move "well-below 2°C and towards 1.5°C" and become net negative sometime between 2050 and 2070. These goals can also be achieved through material efficiency solutions and improved recycling possibilities, as well as decarbonising production.

At present, there are no specific industrial climate policies that apply across these sectors at a global level, although some have called for regional and sectoral transition plans as a solution (Bataille 2020). Some progress has been made in this regard with the COP26 announcements of sectoral breakthroughs and a potential EU-US trade agreement on steel and aluminium. Countries may therefore introduce their own industrial policies which may be reflected in targets aligned to the Nationally Determined Contributions. Policies which can assist in achieving this sectoral transition include carbon pricing (taxes or permits), border adjustments (see below) and contracts for difference, among others.

Another reason why these sectors are often considered difficult to decarbonise from an economic and political perspective is because many of these sectors operate across international markets, again unlike the power sector. Therefore, any unilateral climate policy raises carbon leakage concerns. One option is introducing Carbon border adjustment mechanisms (CBAM), a policy solution which can help avert negative economic impacts for domestic industrial climate policy by taxing imports of carbon-intensive products too. The EU is introducing such a measure over the coming five years.

2.2. Demand and production outlooks

Steel is utilised in a variety of downstream economic areas including construction (53%), industrial equipment (20%), consumer products (18%), and vehicles (10%) in terms of volume (Bataille. 2020). How these industries develop in the future will determine the demand for steel, as will new products and markets including low-carbon technologies such as wind turbines. It is also likely that the level of ambition of material efficiency strategies can play an important role in determining overall demand for steel.

According to the IEA's Steel Roadmap the global end use demand for steel in their Stated Policies Scenario (STEPS) is almost 40% higher in 2050 compared to 2019 levels (IEA 2020). In this instance, global steel stocks per capita are expected to rise to 6.5 t/capita in 2050 compared to stocks of 4.2 t/capita in 2019. Another OECD study modelled a doubling of steel demand by 2060 in a business-as-usual instance without additional climate policy (OECD. 2019.) In the IEA's more ambitious Sustainable Development Scenario (SDS) global demand for steel is only 10% higher than in 2019 due to both demand reduction and material efficiency can play an important role in determining how much steel is required through methods such as extending building lifetimes, improved building design and construction, improving manufacturing yields, reuse, light weighting vehicles, and reduction in vehicle use. Although, in this instance, power sector infrastructure demand, in the form of crude steel production, is three times higher than in the STEPS scenario due to build out of more low-carbon electricity. In both the STEPS and SDS scenarios scrap accounts for 45% of inputs to the steel produced in 2050 as there is obviously a trade-off whereby greater demand reduction/material efficiency also means less scrap availability in the future.

At present about half of global steel production occurs in China. It is expected that China's share of production will decrease somewhat over the next decades to about a third, but may be replaced by production elsewhere, such as India which is likely to increase to around 17% in both STEPS and SDS (IEA, 2020). Other regions like the Middle East, Latin America, and other parts of Asia will also likely see increased production too, whereas much of the advanced economies will see similar levels of steel production as today.

2.3. Technology and other options for steel decarbonisation and circularity

The main method to produce steel today globally is via the primary Blast Furnace and Basic Oxygen Furnace (BF-BOF) method. This approach takes place in large integrated mills using significant mining inputs of coking coal and iron ore. In the first step, the oxygen in the iron ore is removed ("reducing") in the Blast Furnace when mixed with coking coal and other materials to produce pig iron. The coke acts as a reducing agent as well as an energy source for the BF-BOF. The iron is then turned into steel. Here the molten iron is combined with other materials such as scrap steel to give the required carbon content, and then blasted with pure oxygen. This ore-based production process is carbon-intensive due to the chemical reactions in the reduction process and the significant heat required.

There is also Direct Reduced Iron whereby a reducing agent, usually fossil gas, is utilised to make iron, which can then be transformed to steel similar to what is described below for scrap. At present, DRI is about 5% of global production but is only really undertaken in places with access to inexpensive gas.

Secondary steel can be produced in an electric arc furnace using scrap steel and electricity as the main inputs, and is thus a circular method to achieve steel production. In 2019 there was an estimated 865 Mt of scrap steel available for use globally (IEA. 2020). At present about half of the scrap used in secondary production comes from offcuts from the production process itself rather than end-of-life products. In particular, 20% comes from 'home scrap' which occurs from initial steel production, 30% from 'prompt scrap' which are offcuts returned by metal fabrication industries, and 50% end-of-life scrap which is situated in products and buildings. Also, the fact that electricity can be decarbonised leaves significant scope for further emissions reductions. However, there are issues around contamination of scrap steel which make its use limited in certain downstream sectors. Therefore, due to availability and useability issues, secondary production can play a significant role but cannot meet the entire steel demand over the coming decades.

There have been significant improvements in the thermodynamic efficiency of production in industrial sectors over the last several decades. Therefore, reaching frontiers in efficiency improvements, and stricter climate change targets mean that entirely new approaches to making steel are required.

It is possible to produce direct reduced iron from hydrogen made from electrolysis i.e., green hydrogen, using low-carbon electricity and water as inputs. Estimates suggest that this approach can become competitive with BF-BOF in instances of low electricity costs, with production cost ranging between 361 and 640 per tonne of steel for electricity costs of 20-100 EUR/MWh (Vogl et al., 2018). If produced via electrolysis, it would require around 3 to 4 MWh of low-carbon electricity to produce a tonne of steel (Material Economics, 2019). As hydrogen is an energy carrier, it would also be possible to produce this in a low-carbon way using other methods such as fossil gas with carbon capture. The production of such large-scale hydrogen for use in steel will require significant infrastructure expansion with storage and/or transport as well as sources of cheap low carbon electricity. For H-DRI-EAF steelmaking in Europe, it has been suggested that contracts for difference are the most promising policy option (Vogl et al., 2021).

Other options include combining the traditional BF-BOF process directly with carbon capture utilisation and storage (CCUS) technology to allow existing to continue operating if retrofitted, although this method is dependent upon there being options for utilisation and storage nearby as otherwise it would be prohibitively expensive, and potentially using bioenergy with CCUS for steelmaking (Mandova et al. 2019).

3 Modelling framework

3.1. Global energy modelling and decarbonisation pathways

TIAM-UCL is the TIMES Integrated Assessment Model (TIAM) version developed at University College London. It is a global multiregional technology-rich bottom-up cost optimisation model. It is a whole system model that incorporates energy resource extraction through to conversion, infrastructure, and finally to sectoral end-use including renewables, other low-carbon and fossil fuel technologies. The 16 geographic regions are linked through trade in crude oil, hard coal, pipeline gas, LNG, petroleum products (diesel, gasoline, naphtha, heavy fuel oil), biomass, and emission permits. On the resource side, a total of eleven conventional and unconventional oil resource categories, eight conventional and unconventional gas resource categories, and two coal resource categories are specified. Each of these categories is specified with an individual supply cost curve within each region.

Base-year energy-service demands are defined exogenously and are projected for the future using drivers such as GDP, population, household size, and sectoral outputs; in this study, the SSP2 socioeconomic pathway has been used. The base-year (2005) primary energy consumption, energy conversion, and final consumptions are calibrated to the latest IEA Energy Balance at sector and sub-sector levels. The power generation mix and end-use sector fuel consumption are in line with the past data (until 2015).

TIAM-UCL also includes a climate module, which calculates changes in atmospheric greenhouse gas concentrations, radiative forcing and global temperature. We can constrain the climate module to limit temperature rise to a particular target such as 2°C. The module has been previously calibrated to represent a 60% chance of staying below the chosen target. This module is used in this study to achieve the various temperature targets.

3.2. Global economic and circular economy modelling

The Environmental Global Applied General Equilibrium (ENGAGE) model is a standard multi-sectoral, multi-region, dynamic computable general equilibrium model. The ENGAGE model was developed at UCL for the analysis of energy, environmental, resource and economic policies (Winning et al. 2017; Nechifor et al. 2019). ENGAGE is based upon standard Walrasian general equilibrium assumptions such a market clearance, zero profits, and utility maximisation/cost minimisation of representative agents. All industries are modelled through a representative firm, which maximizes its profits in perfectly competitive markets. The production functions of each economic sector to create a level of sectoral output are specified using a series of nested constant elasticity of substitution (CES) functions. Domestic and foreign inputs are not perfect substitutes and therefore are modelled using the "Armington assumption", which accounts for product heterogeneity between different world regions. A representative consumer in each region receives household income, defined as the service value of national primary factors. The national income is allocated between aggregate household consumption, public consumption and savings. A money metric measure of economic welfare, the equivalent variation, can be computed from the model output.

ENGAGE uses national accounts data and a system of non-linear equations to solve for a baseline equilibrium against which policy shocks can be implemented. ENGAGE uses the latest GTAP database as a main data source, which is combined and enhanced with other databases (e.g. EXIOBASE, FAO). The ENGAGE model is written in GAMS and based upon the GTAP9inGAMS model in MPSGE developed by Lanz and Rutherford (2016).

4 Scenarios for decarbonising the iron and steel sector

Our simulations utilise global decarbonisation scenarios consistent with the Paris Agreement. To assess the contrast between current commitments that follows global NDC pledges and a world which achieves a 1.75^{o}C target by 2100. Thus, global decarbonisation pathways produced by global energy system model TIAM-UCL are used in ENGAGE to replicate the regional emission reduction pathways and electricity mix in 2050. We combine the global decarbonisation scenarios with different circular economy policies and technology deployment scenarios in the steel sector to contrast alternative pathways for the steel industry towards net-zero emission in 2050. We explore a *current policy scenario*, where current trajectories are shaped by existing or announced policies, a *sustainable scenario*, where circularity in the steel sector is boosted by an accelerated adoption of secondary steel by downstream sectors, and a *new technology scenario*, where CCS and DRI technologies are deployed and upscaled at the global level.

5 Results

Our results show that an enhanced circularity and the availability of new low-carbon technologies in the steel sector help reduce the costs of decarbonisation. Moreover, the introduction of a global carbon price that limits fossil fuel use and the associated greenhouse gas emissions motivates the steel industry to move towards a more circular use of steel. In fact, circular economy policies and climate policies complement each other. However, to fully take advantage of the circular economy in the steel industry, policies and technological changes in downstream sectors are needed to increase the demand and use of secondary steel. Moreover, polices to promote a circular economy need to be aligned to the provision of green power, as the high electricity demand for secondary steel production could potentially result in an increase in associated emissions. The provision of low-carbon electricity and green hydrogen is key to avoid direct and indirect emissions.

While a circular steel sector can reduce both emissions and resource use in the short-term, it is evident that without CCUS and DRI the steel industry will not reach net-zero emissions in the long term. There is, therefore, a potential trade-off between resource use and carbon emission when selecting the optimal technology mix. This decision will also be highly dependent on the expected availability of scrap at the regional level and the evolution of the international trade. Policies enabling a circular economy and low-carbon transition should differentiate in their support for short, medium and long-term challenges.

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