Decarbonization Pathways and Value Chain Restructuring in the Global Iron and Steel Industry

Extended abstract

Introduction

The iron and steel industry serves as a fundamental cornerstone for economic development and plays a critical role supporting industrialization and modernization. It is also the second-largest consumer of industrial energy and the highest emitter of direct CO_2 among all industrial sectors in the world. Decarbonizing the iron and steel sector is pivotal to achieving the global carbon neutrality.

Blast Furnace - Basic Oxygen Furnace (BF-BOF), scrap-based Electric Arc Furnace (EAF), and Direct Reduced Iron (DRI) based EAF, as the main steel production technologies, exhibit distinct input requirements, emission characteristics, and cost structures. Their adoption rates also vary significantly across different countries. Increasing the share of EAF, implementing hydrogen-based ironmaking, and utilizing carbon capture and storage (CCS) are key strategies for emissions reduction in the iron and steel industry.

Research indicates that the green transition of the iron and steel industry requires more green DRI. Access to abundant low-cost renewable electricity, competitive green hydrogen, and high-quality iron ore are identified as key factors for producing green DRI (Devlin et al., 2023).Devlin and Yang (2022) and Lopez et al. (2023) suggest that reconfiguring steel production assets could reduce overall costs. Additionally, producing green DRI at iron ore production sites that have access to abundant and cheap renewable energy and hydrogen could replace iron ore exports, potentially transforming global steel trade, provided that it achieves economic cost advantages.

Research on decarbonization pathways for the iron and steel sector using Computable General Equilibrium (CGE) models often simplifies steel production as a single sector or divides it into BF-BOF and EAF sectors based on GTAP's power inputs, assuming EAF production relies entirely on scrap (Duscha et al., 2019; Nechifor et al., 2020). These approaches are unable to accurately reflect actual production and structures. Most studies treat ironmaking and steelmaking as a whole process, making it impossible to capture the output and emissions characteristics across different production stages and to consider the potential for future DRI trade. Furthermore, many models lack representation of advanced low-carbon technologies or high scrap utilization, both of which are critical to the low-carbon transition(Winning et al., 2017).

This study aims to develop a CGE model that incorporates both the upstream and downstream sectors of the iron and steel value chain. Emerging technologies such as hydrogen-based metallurgy and CCS are also integrated into the model. The study seeks to investigate: (1) the contributions of high scrap-based steelmaking, hydrogen-based ironmaking, and CCS to the low-carbon transition of the iron and steel industry across different countries and regions, and (2) how H_2-DRI could drive the restructuring of the global iron and steel value chain during this transition to a low-carbon economy.

Methods

We extended the China-in-Global Energy Model (C-GEM) to simulate the decarbonization pathways and their economic impacts. The model is a multi-sector, multi-regional, dynamic recursive CGE model that has been widely used in global energy and climate policy studies. We reaggregated this model into 24 countries and regions, with a detailed disaggregation of the main iron ore and steel producers. The model has been updated to employ the latest data from the Global Trade Analysis Project (GTAP) 11 database, and sectors within the iron and steel value chain are separated for more precise analysis.

Iron ore mining (ORE) was splitted from Mining sector (MINE) and coke making (COK) was splitted from Petroleum and Coke Making sector (P_C). The new sectors were modeled based on production and consumption volumes from UN energy statistics and USGS 2021 Minerals Yearbook, and international trade data from UN Comtrade.

Iron and Steel sector (I_S) was disaggregated into BF, DRI, BOF, EAF and Steel Processing sectors. Scrap was added as resources. The disaggregation of the iron and steel sector requires breaking down its inputs into individual stages and constructing an input-output relationship within the industry. The objective is to accurately reflect each country's steel production characteristics. The disaggregation is based on global steel statistics for national BF/BOF/EAF/DRI production from WSA, BF/DRI/Scrap trade volumes from UN Comtrade, and production characteristics derived from technical literature on ironmaking and steelmaking.

We will simulate the decarbonization pathways for the iron and steel sector in 3 global scenarios: a reference scenario, which assumes the current trends in policy setting; and a national net zero scenario, which assumes each country and region realizes its net zero target; and a steel net zero scenario, which assumes iron and steel sector of each country and region reaches net zero emissions.

Preliminary results

In the low-carbon transition of the iron and steel industry, the short-term focus is on improving energy efficiency, increasing the proportion of scrap used in EAF, and retrofitting blast furnaces for hydrogen injection (H_2-BF). In the long term, new steel production technologies will be adopted, with EAF replacing BOF as the primary method. Scrap-based EAF and H_2-DRI-EAF will become the dominant production technologies, alongside the partial implementation of BF-CCS.

Due to Australia's abundant and low-cost renewable electricity, local hydrogen production for DRI is more cost-effective compared to major steel-producing countries. Furthermore, the cost of transporting H_2-DRI is lower than that of transporting iron ore. In the long term, Australia's exports of H_2-DRI to China, Japan, and South Korea increase gradually, partially replacing iron ore exports.

References

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