Metal footprint and greenhouse gas emissions embodied in South-South trade: a study about the Brazil and China bilateral trade (2000-2019)

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The effects of climate change on production and international trade have become a constant concern for policymakers. According to the Intergovernmental Panel on Climate Change (IPCC, 2023), the substantial impacts estimates of climate change on the global economy are the occurrence of the water drawdown, which difficult the food production; the cities and transportation infrastructure, mainly on the cost area, that difficult the economic activity dynamism; and the impact on the health and well-being.

In the last decade, the implementation of policies to mitigate greenhouse gas (GHG) emissions - that is, the greater responsible for the increase in the global average temperature (IPCC, 2018) - has increased, corresponding to the productive decarbonization and energy transition. The Paris Agreement (UN, 2015) has formally attached this compromise through the coalition regime of National Developing Countries (NDC), which aims to reduce emissions and promote more transparency of climate actions. The positive results are observed through the creation of regulatory and economic instruments to increase energy efficiency, the reduction of deforestation levels, and the rapid development of technologies for emissions reduction (IPCC, 2023).

In this sense, countries have implemented strategies to build a low-carbon economy, accelerating the process of energy transition to renewable energy systems. However, as renewable energy is mineral intensive, the process has highlighted the environmental impacts associated with the increase in raw materials and minerals demand (Hund et al., 2020). As each country plays a different role in renewable energy value chains, the growth of renewable power plants has been a another driver of environmentally unequal exchange (Fu er al., 2023).

The environmental extended multiregional input-output (EE MRIO) analysis has been used as an important tool for understanding pollution transfer through trade flows (Steinberger et al., 2012; Grubb et al., 2022) and for the attribution of responsibility (Lenzen, Murray, 2010; Zhang et al., 2020).

Therefore, this paper proposes to use this tool to investigate the pattern of greenhouse gas (GHG) emissions and metal footprint (MF) associated with the bilateral trade pattern between Brazil, China and the Rest of the World (ROW) in the period 2000-2019. Since 2004, China's dynamism has influenced Brazil's export structure, increasing demand for commodities such as mining, livestock, and cereals. On the one hand, Chinese demand contributed to a trade surplus, with export growth averaging 15% since 2010. On the other, this rise in commodity exports led to the "re-commoditization" of Brazil's export structure (Bertola, Ocampo, 2012). Additionally, the growth of Brazilian agriculture has been linked to deforestation, raising GHG emissions through land-use change.

In general, the results show that bilateral trade between Brazil and China follows a North-South pattern, with Brazil being the larger supplier of raw materials and commodities, and China being the larger supplier of industrialized and higher value-added goods and services. The trade pattern is reproduced on the environmental dimension, where agriculture and food production are more CO2e-intensive in Brazil's exports to China, while manufacturing, machinery and equipment are more CO2e-intensive in China's exports to Brazil.

In the total consumption emissions indicator (domestic and foreign) and emissions on international trade (foreign), we observed that Brazil was a greater production-based emissary, while China evolved to a consumption-based with developing economies. In this sense, the results of Net Emissions Carbon demonstrate that Brazil has had a surplus of GHG emissions on its transactions with China. This result is related to the export volume, the energy efficiency, and the emission

intensity of Brazil's export structure.
Finally, in the material footprint analysis, the results indicate that Brazil's role in renewable electricity value chains is in the mining stages, in the categories of bulk and scarce metal ores. On the one hand, these sectors are positively affected by the low-carbon electricity system, which requires more material components than fossil-fuel electricity. On the other hand, the mining sectors generate the largest number of negative environmental externalities.Therefore, based on this analysis and considering the strategic partnership between Brazil and China, we pointed out the principle of shared responsibility (Rodrigues et al., 2006; Zhang et al., 2020) as a reference to design trade policies for these countries.