Unequal Pollution Flows: Brazil's Role in Global Emission Trade (1995-2018)

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Abstract
This study quantifies the net balances of value-added, CO_2 emissions, and employment embedded in Brazilian international trade with the Global South and Global North from 1995 to 2018. It investigates the applicability of the Environmental Terms of Trade Deterioration Hypothesis, particularly in the context of Brazil's export reprimarization process. To test this hypothesis, the study uses the Pollution Terms of Trade (PTT) metric, assessing whether the environmental cost of Brazil's exports exceeds that of its imports. This approach offers a comprehensive evaluation of the sustainability of Brazil's trade patterns. Using a multi-regional input-output (MRIO) model, the study examines the direct and indirect effects of trade flows on value-added, CO_2 emissions, and employment, capturing global production network interdependencies. It relies on the OECD Inter-Country Input-Output (ICIO) database (1995-2018), disaggregated into 45 sectors for 66 countries and the Rest of the World (RoW). Countries are categorized into Global South (developing countries) and Global North (developed economies), allowing for a detailed sector-specific impact analysis. The findings reveal that emissions from Brazilian exports to the Global South are approaching those directed to the Global North, especially after 2010. Exports to the Global North are consistently more carbon-intensive, supporting the Environmental Terms of Trade Deterioration Hypothesis. This suggests that exporting primary products to developed economies results in higher environmental costs per unit of value added. The study also addresses the uneven distribution of environmental impacts, particularly regarding emissions responsibilities. It highlights the debate on whether the burden of emissions should lie with producing or consuming countries, which is critical for Brazil due to its growing specialization in primary product exports. This study provides empirical evidence on Brazil's export reprimarization and its implications for environmental terms of trade, offering insights for trade and environmental policy discussions.

Keywords: Brazil, international trade, CO_2 emissions, export reprimarization, Environmental Terms of Trade.

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1. Introduction

This study aims to analyze Brazil's position as a global exporter or importer of emissions, differentiating between the groups of countries with which Brazil engages in international trade. The rapid expansion of global trade and the increasing fragmentation of production processes have intensified the interdependence of production and consumption across geographically dispersed regions. This globalization of production networks has resulted in significant environmental consequences, including the transboundary transfer of pollutants embedded in traded goods.

However, the environmental impacts of international trade are distributed unevenly among countries, reflecting differences in trade patterns, production structures, and technological capabilities. These disparities raise important questions concerning the allocation of environmental responsibility: Should the burden of emissions be borne by the producing country or the consuming country?

This question has stimulated an extensive body of literature on emissions accounting, highlighting the complexities of attributing environmental responsibility in an interconnected global economy (Afionis et al., 2017; Lenzen et al., 2007; Kander et al., 2015; Caro et al., 2015). The debate is particularly pertinent for countries such as Brazil, which have experienced a shift towards primary product exports, rendering them more vulnerable to the environmental and economic consequences of international trade.

A central theoretical framework in this debate is the Pollution Haven Hypothesis (PHH), which posits that, under conditions of free trade, pollution-intensive and resource-heavy industries in developed countries (Global North) relocate to developing countries (Global South) to evade stringent environmental regulations (Copeland & Taylor, 1994). This geographical shift in environmental burdens occurs through both trade in goods and services and foreign direct investment (FDI). As a result, the Global South may experience increased environmental degradation, while the Global North benefits from lower domestic emissions.

In parallel, the Environmental Terms of Trade Deterioration Hypothesis posits that economies specializing in primary products are susceptible to long-term declines in the value of their exports relative to their imports (Pérez-Rincón, 2006; Røpke, 1994). This hypothesis builds on the Terms of Trade Deterioration Theory advanced by Prebisch (1950) and Singer (1950), which argues that developed countries specialize in the export of capital- and knowledge-intensive goods, while developing countries export resource-intensive and low-skilled labor products. Over time, this pattern of specialization leads to a decline in the terms of trade for developing countries, requiring them to export increasing volumes to maintain their import capacity.

The productive specialization between the Global North and Global South has profound economic and environmental implications. The Global South is not merely an exporter of goods but also a key supplier of energy and raw materials to the Global North. Consequently, the deterioration of environmental terms of trade suggests that countries in the Global South must intensify the extraction of natural resources or increase pollutant emissions to sustain their export volumes.

Brazil exemplifies this dynamic, having undergone a process of export reprimarization, characterized by an increasing share of primary products and a declining share of manufactured goods in its export basket (Alves-Passoni, 2023; Nassif et al., 2020). This structural transformation raises critical concerns regarding the long-term sustainability of Brazil's economic development and its environmental impacts.

This study seeks to quantify the net balances of value-added, CO_2 emissions, and employment embedded in Brazilian international trade with the Global South and Global North from 1995 to 2018. Furthermore, it investigates the evolution of these balances over time to assess the applicability of the Environmental Terms of Trade Deterioration Hypothesis to Brazilian international trade during the analyzed period, particularly in the context of the ongoing export reprimarization process (Alves-Passoni, 2023; Nassif et al., 2020).

To rigorously test this hypothesis, the study advances beyond conventional trade balance analysis by calculating the Pollution Terms of Trade (PTT), as formulated by Antweiler (1996). This metric evaluates whether the environmental cost of Brazil's exports exceeds the environmental cost of its imports, thereby providing a comprehensive assessment of the environmental sustainability of Brazil's trade patterns.

Methodologically, the analysis employs a multi-regional input-output (MRIO) model, enabling a detailed examination of the direct and indirect effects of trade flows on value-added, CO_2 emissions, and employment. This approach captures the complex interdependencies among countries and sectors within global production networks, offering a holistic perspective on the environmental and economic implications of international trade.

The empirical analysis is underpinned by the OECD Inter-Country Input-Output (ICIO) database, in its most recent version released in November 2021, which provides inter-regional input-output tables for 66 countries and an aggregated category for the Rest of the World (RoW). These tables disaggregate each region into 45 sectors, covering the period from 1995 to 2018.

By integrating OECD ICIO data with additional sources, the study estimates CO_2 emissions, employment, and value-added embedded in Brazilian international trade. For analytical rigor, countries are categorized into two distinct regions: Global South, encompassing developing countries, and Global North, comprising developed economies. Given the detailed sectoral disaggregation available in the OECD ICIO database, the study also investigates sector-specific impacts on the examined variables.

This study makes a significant contribution to the literature by providing empirical evidence on the environmental consequences of Brazil's export reprimarization and its implications for environmental terms of trade. By examining the evolving nature of Brazil's international trade and its environmental and economic impacts, the findings will offer critical insights for trade policy and environmental policy debates, highlighting the challenges and opportunities for reconciling international trade dynamics with sustainable development objectives.

2. Theoretical framework

Studies on embedded emissions in North-South trade (i.e., between developed and developing countries) suggest that there is a net transfer of carbon emissions from developed to developing nations (Grubb et al., 2022; Banerjee, 2019; Wang, Liu & Wang, 2019; Peng, Zhang & Sun, 2016; Wu et al., 2016). In contrast, emissions embedded in South-South trade have received less attention, although environmental imbalances in these exchanges have already been identified. This issue has gained prominence due to the rapid growth of trade among developing economies (Meng et al., 2018; Kim & Tromp, 2021; Wang & Yang, 2020; Lin & Xu, 2019).

The increasing fragmentation of production and the expansion of international trade, both consequences of globalization, particularly since the 1990s, have led to a growing separation between where products are manufactured and where they are consumed. This process has significant implications for embedded emissions and energy flows in global trade. As a result, several studies have sought to understand how international trade affects greenhouse gas (GHG) emissions, energy consumption, and how these effects are distributed across countries, regions, and economic sectors (Peters et al., 2011; Arto & Dietzenbacher, 2014; Duarte, Pinilla & Serrano, 2018; Wu et al., 2020). Peters et al. (2011) found that emissions from the production of exported goods accounted for 20% of global emissions in 1990 and increased to 26% in 2008. Wu et al. (2020) analyzed carbon transfers by differentiating between trade in intermediate and final goods and concluded that embedded carbon transfers in international trade represented approximately 40% of global direct carbon emissions. These findings highlight the significant role of international trade in global GHG emissions, underscoring the importance of considering trade-embedded emissions in climate change mitigation policies.

However, trade-embedded emissions do not affect all countries equally. The asymmetry in carbon transfers through trade raises debates over who should bear responsibility for these emissions and bear the costs of their reduction. Two primary approaches have emerged to address this issue: production-based accounting (PBA) and consumption-based accounting (CBA). PBA, also known as territorial emissions accounting, attributes emissions responsibility to the country where the production occurs. This is the standard method used in most climate agreements and organizations, including the Kyoto Protocol and the Paris Agreement. PBA's main advantage is that it is straightforward, relying on readily available national emissions data without requiring information on trade flows or emissions from other countries (Caro et al., 2015). However, PBA has significant limitations, as it excludes emissions from international transport, such as aviation and maritime trade, and fails to account for the offshoring of emissions-intensive industries from highly regulated countries to those with weaker environmental policies. As a result, developed countries that relocate polluting industries abroad still consume the same goods but no longer account for the associated emissions (Franzen & Mader, 2018). This phenomenon is known as carbon leakage.

In contrast, CBA, also referred to as the carbon footprint approach, addresses these limitations by attributing emissions to the country that ultimately consumes the goods rather than the one that produces them. Under CBA, the emissions embedded in imported goods are included, while emissions from exported goods are excluded. CBA is particularly useful for allocating emissions from international transport and provides a more comprehensive picture of emissions transfers through trade (Afionis et al., 2017). However, the main drawback of this approach is that it requires far more data than PBA, as it necessitates detailed information on emissions from all traded goods and international trade flows across all trading partners (Afionis et al., 2017). Despite PBA and CBA being the two dominant accounting methods for GHG emissions, Andrew & Forgie (2008) argue that each approach places responsibility solely on either producers or consumers, making it difficult for countries benefiting from one method to agree on a universal framework. As a result, recent studies have explored hybrid approaches that share responsibility between producers and consumers (Lenzen et al., 2007; Kander et al., 2015).

The calculation of trade-embedded emissions is often derived from the difference between PBA and CBA (Grubb et al., 2022). This distinction allows for the identification of net carbon exporters and net carbon importers. A country is a net carbon exporter when its PBA emissions exceed its CBA emissions, meaning it produces more emissions than it consumes. Conversely, a net carbon importer has higher CBA emissions than PBA emissions, meaning it outsources its emissions through trade. The literature on trade-embedded emissions has primarily focused on North-South trade, that is, exchanges between developed and developing countries (Wu et al., 2016; Peng, Zhang & Sun, 2016; Zhong, Jiang & Zhou, 2018; Wang, Zhao & Wiedmann, 2019; Wang, Liu & Wang, 2019; Banerjee, 2020). Overall, findings suggest that developed countries are net importers of GHG emissions, while developing countries are net exporters of GHG emissions (Grubb et al., 2022).

This general trend of carbon transfer from developing to developed nations raises concerns about carbon leakage. Carbon leakage can occur through three main channels. First, market-driven leakage occurs when climate policies in one region reduce fossil fuel demand, leading to lower global prices, which may then encourage other regions to increase fossil fuel consumption, offsetting the emissions reductions from the original policy. Second, relocation leakage occurs when higher energy prices in regulated regions drive energy-intensive industries to relocate to less regulated countries, effectively shifting emissions rather than reducing them. Third, policy spillover leakage occurs when emissions reductions in one region discourage other regions from adopting climate policies due to fears of competitive disadvantages (Jakob, 2021).

Although most research has focused on North-South carbon transfers, there is a growing interest in emissions embedded in South-South trade, that is, trade among developing nations (Meng et al., 2018; Lin & Xu, 2019; Wang & Yang, 2020; Kim & Tromp, 2021). Between 2005 and 2015, emissions embedded in South-South trade increased by 57%, surpassing the growth rate of overall international trade during the same period (Meng et al., 2018). With rising per capita incomes in developing nations and increased regional integration initiatives such as BRICS and China's Belt and Road Initiative, South-South trade is expected to continue expanding. This makes the environmental and socio-economic impacts of these exchanges increasingly relevant. While carbon transfers have historically been associated with North-South trade, recent research has identified environmental imbalances in South-South trade as well (Lin & Xu, 2019; Wang & Yang, 2020; Kim & Tromp, 2021). Furthermore, studies indicate that energy-intensive activities are also shifting among developing countries (Meng et al., 2018), emphasizing the need for further investigation into South-South trade dynamics and their environmental consequences.

3. Methodology

3.1 Multiregional input output model

To conduct an integrated analysis of the impacts of international trade on the flows under investigation—considering the increasing fragmentation of production across sectors and countries and the growing disconnect between production processes and the consumption of goods and services—we will employ a multi-regional input-output (MRIO) model.

In an MRIO model, national input-output tables, which capture the monetary transactions between economic sectors within a country, are linked to a trade flow table, detailing the export and import values between economic sectors across different countries. These two tables are interconnected to form a coherent accounting framework, enabling the tracking of direct and indirect impacts of production and consumption along global supply chains. These impacts can span multiple sectors across various countries and regions.

This methodological approach allows for a comprehensive assessment of trade flows by examining not only the final demand but also the entire production chain of goods and services. This is particularly relevant for accurately computing international trade flows and assessing the concept of pollution heavens, as it avoids the oversight of attributing environmental impacts solely based on production. Instead, this method follows a consumption-based accounting approach, which allocates emissions and resource use to the consuming country rather than the producing country. This approach provides a more accurate representation of the environmental and socioeconomic implications of global trade patterns, particularly in increasingly fragmented and interconnected supply chains.

Moreover, environmental and socioeconomic extensions can be incorporated into the MRIO structure, allowing for the calculation of pollutant emissions, water usage, land use, energy consumption, and other variables across different economic sectors and regions.

To operationalize this model, we will structure it with four countries/regions: Brazil (B), Global South (S), Global North (N), and Rest of the World (RoW). These regions are represented by the superscripts BBB, SSS, NNN, and RRR, respectively. This methodology follows the concepts applied by Grether and Mathys (2013) and adopts the notation system of Kim and Tromp (2021), ensuring consistency with established practices in the field of multi-regional input-output analysis.

The multiregional gross output can be expressed as the following equation:

$$\begin{pmatrix} \boldsymbol{x}^B \\ \boldsymbol{x}^S \\ \boldsymbol{x}^N \\ \boldsymbol{x}^R \end{pmatrix} = \begin{pmatrix} \boldsymbol{A}^{BB} & \boldsymbol{A}^{BS} & \boldsymbol{A}^{BN} & \boldsymbol{A}^{BR} \\ \boldsymbol{A}^{SB} & \boldsymbol{A}^{SS} & \boldsymbol{A}^{SN} & \boldsymbol{A}^{SR} \\ \boldsymbol{A}^{NB} & \boldsymbol{A}^{NS} & \boldsymbol{A}^{NN} & \boldsymbol{A}^{NR} \\ \boldsymbol{A}^{RB} & \boldsymbol{A}^{RS} & \boldsymbol{A}^{RN} & \boldsymbol{A}^{RR} \end{pmatrix} \begin{pmatrix} \boldsymbol{x}^B \\ \boldsymbol{x}^S \\ \boldsymbol{x}^N \\ \boldsymbol{x}^R \end{pmatrix} + \begin{pmatrix} \boldsymbol{f}^{BB} & \boldsymbol{f}^{BS} & \boldsymbol{f}^{BN} & \boldsymbol{f}^{BR} \\ \boldsymbol{f}^{SB} & \boldsymbol{f}^{SS} & \boldsymbol{f}^{SN} & \boldsymbol{f}^{SR} \\ \boldsymbol{f}^{NB} & \boldsymbol{f}^{NS} & \boldsymbol{f}^{NN} & \boldsymbol{f}^{NR} \\ \boldsymbol{f}^{RB} & \boldsymbol{f}^{RS} & \boldsymbol{f}^{RN} & \boldsymbol{f}^{RR} \end{pmatrix} \quad \textbf{\textit{(1)}}$$

where $\boldsymbol{x^r}$ is a 45×1 vector representing the total output of country r for each sector; $\boldsymbol{A}$ is the global direct input coefficient matrix that reflects the interconnections between different sectors of the economy, where $\boldsymbol{A^{rp}}$ is a 45×45 matrix symbolizing the intermediate input coefficient matrix. It indicates how much intermediate goods from country r are needed by country p to produce one monetary unit of output. In turn, $\boldsymbol{f^{rp}}$ is a 45×1 vector representing the final demand for products from country p by country r.

We can express the previous equation as the traditional input-output model, such as:

$$\boldsymbol{x = Ax + f} \quad \textbf{(2)}$$

Solving the system for x, we have

$$\boldsymbol{x = (I - A)^{-1} f} \quad \textbf{(3)}$$

Where $\boldsymbol{L = (I - A)^{-1}}$ is the Leontief inverse matrix, which indicates the direct and indirect connections between countries and sectors. Specifically, in a four-multiregion model, the Leontief matrix contain 16 submatrices, where L^{rp} represents the total output (both direct and indirect) of country r that is required to satisfy one unit of final demand from country p.

Since our objective is to analyze the flows in the Brazilian exports, we will now focus in this flows only. In an input-output model, a country's exports are driven by foreign demand. We will use the South as an example to derive all the equations, but it is similar for the other region.

For instance, to calculate Brazil's exports to the Global South (ET_{BS}), all L^{**} elements must be set to 0 except for L^{B*}, and all F^{**} elements must be set to 0 except forF^{*S}.

$$\boldsymbol{ET_{BS}} = \begin{pmatrix} \boldsymbol{L^{BB}} & \boldsymbol{L^{BS}} & \boldsymbol{L^{BN}} & \boldsymbol{L^{BR}} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \end{pmatrix} \begin{pmatrix} \boldsymbol{0} & \boldsymbol{f^{BS}} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{f^{SS}} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{f^{NS}} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{f^{RS}} & \boldsymbol{0} & \boldsymbol{0} \end{pmatrix} =$$

$$\boldsymbol{L^{BB} f^{BS} + L^{BS} f^{SS} + L^{BN} f^{NS} + L^{BR} f^{RS}} \quad (4)$$

The term $\boldsymbol{L^{BB} f^{BS}}$ represents the exports of final products from Brazil to the Global South; $\boldsymbol{L^{BS} f^{SS}}$ is the direct export of intermediates from Brazil to the Global South; while $\boldsymbol{L^{BN} f^{NS}}$ and $\boldsymbol{L^{BR} f^{RS}}$are, respectively, the exports of intermediates from Brazil to the Global North and RoW, which end up being processed in these countries and exported to the Global South. Thus, these flows represent Brazilian exports to the Global South that are embedded, as intermediate goods, in the products of the Global North and RoW.

To calculate the Brazilian imports, which are the exports from the Global South to Brazil, (ET_{SB}) the same logic is applied.

$$\boldsymbol{ET_{SB}} = \begin{pmatrix} \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{L^{SB}} & \boldsymbol{L^{SS}} & \boldsymbol{L^{SN}} & \boldsymbol{L^{SR}} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \end{pmatrix} \begin{pmatrix} \boldsymbol{f^{BB}} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{f^{SB}} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{f^{NB}} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{f^{RB}} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \end{pmatrix} =$$

$$\boldsymbol{L^{SB} f^{BB} + L^{SS} f^{SB} + L^{SN} f^{NB} + L^{RB} f^{RB}} \quad (5)$$

Similarly, $\boldsymbol{L^{SB}f^{BB}} + \boldsymbol{L^{SS}}$are the direct exports of intermediates from the Global South to Brazil, $\boldsymbol{L^{SS}f^{SB}}$ are the exports of final products from the Global South to Brazil, and the terms $\boldsymbol{L^{SN}f^{NB}}$ and $\boldsymbol{L^{RB}f^{RB}}$ are the indirect exports of intermediates from the Global South to Brazil.

To calculate the carbon emissions, employment, and value added embedded inthe trade flows of intermediate and final goods, we need to define intensity vectors for each of these variables.

Thus, let $\boldsymbol{\delta} = (\boldsymbol{\delta^B}, \boldsymbol{\delta^R}, \boldsymbol{\delta^N}, \boldsymbol{\delta^R})$ be the carbon emission intensity vector, which represents the carbon emissions per unit of gross output for each country; $\boldsymbol{\theta} = (\boldsymbol{\theta^B}, \boldsymbol{\theta^R}, \boldsymbol{\theta^N}, \boldsymbol{\theta^R})$ be the direct employment coefficients, which represent the employment created per unit of gross output for each country; and finally, $\boldsymbol{\tau} = (\boldsymbol{\tau^B}, \boldsymbol{\tau^R}, \boldsymbol{\tau^N}, \boldsymbol{\tau^R})$ be the value-added coefficients, which reflect the value added per unit of per unit of gross output for each country[**].

Since the process for calculating these different flows is quite similar, we will calculate the carbon emission flows as an example. Thus, to calculate the carbon emissions embedded in international trade between Brazil and the Global South, we must combine the carbon emission intensity vector ($\boldsymbol{\delta}$), doing the correspondent multiplication $\boldsymbol{\delta^B}$ by $\boldsymbol{ET_{BS}}$ to obtain the Brazilian emissions when it exports to the Global South

$$\boldsymbol{CET_{SB}} = (\boldsymbol{0} \quad \boldsymbol{\delta^S} \quad \boldsymbol{0} \quad \boldsymbol{0})\begin{pmatrix} \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{L^{SB}} & \boldsymbol{L^{SS}} & \boldsymbol{L^{SN}} & \boldsymbol{L^{SR}} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \end{pmatrix}\begin{pmatrix} \boldsymbol{f^{BB}} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{f^{SB}} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{f^{NB}} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{f^{RB}} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \end{pmatrix} =$$

$$\boldsymbol{\delta^S L^{SB} f^{BB}} + \boldsymbol{\delta^S L^{SS} f^{SB}} + \boldsymbol{\delta^S L^{SN} f^{NB}} + \boldsymbol{\delta^S L^{RB} f^{RB}} \qquad (6)$$

and $\boldsymbol{\delta^S}$ by $\boldsymbol{ET_{SB}}$ to obtain the Brazilian emissions when the Global South exports Brazil

$$\boldsymbol{CET_{BS}} = (\boldsymbol{\delta^B} \quad \boldsymbol{0} \quad \boldsymbol{0} \quad \boldsymbol{0})\begin{pmatrix} \boldsymbol{L^{BB}} & \boldsymbol{L^{BS}} & \boldsymbol{L^{BN}} & \boldsymbol{L^{BR}} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \end{pmatrix}\begin{pmatrix} \boldsymbol{0} & \boldsymbol{f^{BS}} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{f^{SS}} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{f^{NS}} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{f^{RS}} & \boldsymbol{0} & \boldsymbol{0} \end{pmatrix} =$$

$$\boldsymbol{\delta^S L^{BB} f^{BS}} + \boldsymbol{\delta^S L^{BS} f^{SS}} + \boldsymbol{\delta^S L^{BN} f^{NS}} + \boldsymbol{\delta^S L^{BR} f^{RS}} \qquad (7)$$

Using these matrices, we can calculate the net flow of carbon emissions embedded in trade between Brazil and the Global South ($\boldsymbol{CLT_{BS}}$) by the difference, such as: $\boldsymbol{CLT_{BS}} = \boldsymbol{CET_{BS}} - \boldsymbol{CET_{SB}}$ *(8)*

By applying the same procedure for value added, using the value-added coefficients ($\boldsymbol{\tau}$), and for employment, using the direct employment coefficients ($\boldsymbol{\theta}$), we will determine the value added and employment embedded in international trade between two regions for both intermediate and final goods flows.

[**] The exported value-added amounts are calculated, they are deflated using the sectoral product deflator from the OECD database, the Database for Structural Analysis - Stan (Hórvat & Webb, 2020).

Anteweiler (1996) introduced the concept of Pollution Terms of Trade (PTT) as a means to measure the environmental gains that a country or region can obtain from trade. We will use the definition of PTT proposed by Grether and Mathys (2013), which defines it as the ratio of exported pollution per unit of exported value added to imported pollution per unit of imported value added. We will define PTT and the other indicators only for trade between Brazil and the Global South. Thus, the PTT for trade between Brazil and the Global South is defined as:

$$\boldsymbol{PTT_{BS}} = \frac{\left(\frac{CET_{BS}}{VAET_{BS}}\right)}{\left(\frac{CET_{SB}}{VAET_{SB}}\right)} \tag{9}$$

The Pollution Terms of Trade (PTT) eliminates the influence of trade scale between regions, measuring a country's participation in international trade in relation to its environmental impact, while also considering technological and compositional effects. If $PTT_{BS} > 1$, this indicates that Brazil's trade with the Global South deteriorates the environment of the Global South. If $PTT_{BS} < 1$, it indicates that Brazil benefits environmentally from trade with the Global South because the CO_2 intensity of Brazilian exports is lower than the intensity of Brazilian imports from the Global South.

Similar to PTT, we construct the relative jobs-carbon emission (RCE), as the ratio between CO_2 emissions per exported job and CO_2 emissions per imported job. These are defined as follows:

$$\boldsymbol{RCE_{BS}} = \frac{\left(\frac{CET_{BS}}{JET_{BS}}\right)}{\left(\frac{CET_{SB}}{JET_{SB}}\right)} \tag{10}$$

Thus, if $\boldsymbol{RCE_{BS}} > 1$, Brazilian jobs required to produce a unit of exports to the Global South are more CO_2 intensive than jobs in the Global South required to produce exports to Brazil. Notice that both PTT and RCE are a measure of intensity, which means they do not evaluate the magnitude of flows, only the "efficiency" of emission.

3.2 Database

To analyze the direct and indirect effects of trade flows on the variables under study, we will use a multi-regional input-output (MRIO) model. This research will utilize the latest version of the Organization for Economic Co-operation and Development (OECD) database, released in November 2021, known as the OECD Inter-Country Input-Output (ICIO). This database provides inter-regional input-output tables covering 66 countries and an aggregated Rest of the World (RoW) category for the remaining countries. Each region is composed of 45 sectors, covering the period from 1995 to 2018. By combining it with other data sources, it is possible to estimate indicators for carbon dioxide (CO_2) emissions from fuel combustion, employment, and value added. Thus, we will divide countries into two regions: the Global South, which consists of developing countries, and the Global North, which consists of developed countries.

We propose an aggregation of the 45 sectors to 12 sectors, considering the broad economic activities as the criteria. It consists in the following sectors: . The correspondence table is presented in Appendix A.

3.2.1 Group countries

The Global North will consist of the following 33 countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, South Korea, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, the United Kingdom, the United States, Cyprus, and Malta.
The Global South will consist of the following 17 countries: Chile, Colombia, Costa Rica, Hungary, Mexico, Poland, Turkey, Argentina, Bulgaria, China, Croatia, India, Indonesia, Romania, Russia, Saudi Arabia, and South Africa.
Due to the lack of available data on embedded employment, 16 regions will be aggregated into a fourth region called the Rest of the World (RoW), which includes: Brunei, Cambodia, Hong Kong, Kazakhstan, Laos, Malaysia, Morocco, Myanmar, Peru, the Philippines, Singapore, Taiwan, Thailand, Tunisia, Vietnam, and the RoW itself.

3.2.2 Employment

For the estimation of employment embedded in international trade (Trade in Employment Database - TiM), the indicators are calculated using the OECD ICIO combined with employment and labor compensation estimates by industrial activity. Various sources were used, such as the OECD Annual National Accounts and Structural Analysis (STAN) database and other official sources, including National Accounts, labor force surveys, and industrial surveys (Horvát, Webb, and Yamano, 2020).

Employment is defined as the number of people engaged in productive activities within national boundaries, including both employees and the self-employed. The estimates refer to the number of jobs sustained rather than jobs created, as the latter may have existed previously due to domestic demand (Horvát, Webb, and Yamano, 2020).

3.2.3 Value added

The value-added coefficients (Trade in Value Added Database - TiVA) are directly estimated from the OECD ICIO. The value-added flows are expressed in millions of dollars in the current year. For regional aggregates, such as the Global South and Global North, aggregation was performed before deriving the other indicators (Guilhoto, Webb, and Yamano, 2022).

3.2.4 Emissions

To estimate carbon emissions embedded in trade (Trade in Embodied CO_2 Database - $TECO_2$), it is essential to have emission factors, which indicate the proportion of carbon emitted relative to the output generated in each country and industrial sector. This estimation is carried out by integrating OECD ICIO data with databases from the International Energy Agency (IEA) on CO_2 emissions from fossil fuel combustion (IEA-CO_2) (Yamano and Guilhoto, 2020) and EDGAR (Emissions Database for Global Atmospheric Research) (Crippa et al., 2021).

EDGAR reports CO_2-equivalent emissions (CO_2eq) originating from industrial processes, land use and land-use change, and forests, including gases such as CH_4 (methane), N_2O (nitrous oxide), and F-gases (fluorinated gases), in addition to emissions from fossil fuel combustion, covering the period from 1970 to 2022. Similar to ICIO, the primary data source for fossil fuel-related emissions in EDGAR is the International Energy Agency (IEA). However, EDGAR follows the Intergovernmental Panel on Climate Change (IPCC) sectoral classification, requiring compatibility adjustments with the ISIC classification used in ICIO.

To ensure consistency between measurement units, Compatibility EDGAR values were converted from gigagrams of CO_2eq to million tons of CO_2eq, which is the unit used in $TECO_2$. Meanwhile, IEA-CO_2 embedded emissions flows are directly expressed in million tons of CO_2. The alignment between sectoral classifications was done by grouping ISIC sectors according to the IPCC categorization, as detailed in the Table of Between IPCC and ISIC Categories. Further details can be found in Appendix B.

3.2.5 Deflation

The conversion of monetary flows into real values is a fundamental procedure to ensure the temporal comparability of data and the accuracy of economic analyses. However, in the case of global matrices, this process presents methodological challenges and analytical limitations that must be carefully considered. The OECD-ICIO data is already provided in a common currency, the U.S. dollar, although it is originally reported by national statistical agencies in their respective local currencies. To deflate sectoral information, the gross product deflators of the United States, made available by the STAN Structural Analysis Database (Horvát & Webb, 2020), are used. These sectoral deflators, harmonized with the ISIC classification, allow the conversion of values originally expressed in nominal dollars into constant 2015 dollars, ensuring the elimination of inflationary effects and facilitating comparisons over time.

The estimation of deflated value-added is carried out using the double deflation method, which is widely adopted in economic literature. This procedure occurs in three main steps: first, the intermediate consumption matrix and final demand are adjusted using the U.S. product deflators. Second, deflated output is obtained by aggregating the rows of the input-output matrix. Finally, deflated value-added is calculated as the difference between deflated output and intermediate consumption. This approach allows for capturing relative price variations between sectors and improves the accuracy of estimates, providing greater robustness to comparative analyses over time.

However, this method presents some important limitations. Since the data is expressed in U.S. dollars, significant changes in exchange rates can lead to misinterpretations of structural changes in technical coefficients, when they may actually reflect only currency fluctuations. This effect can distort sectoral analyses and compromise the interpretation of results.

To assist with the analysis, we calculated standardized exchange rates using data from the World Economic Outlook (WEO). A sample was compiled containing observations for countries in the Global North, Global South, and Brazil, covering the period from 1995 to 2018. The GDP indicators were considered in local currencies, both at current prices and constant prices. Additionally, data on the Implied PPP conversion rate were used, which indicates the implicit conversion rate between the local currency and the international dollar. To construct standardized exchange rates, derived variables were created by dividing the aggregated GDP values (for both current and constant prices) by the implicit PPP conversion rate. This process converts GDP values from local currency into an international benchmark (the international dollar), facilitating the comparative analysis of exchange rate relationships among the country groups. Furthermore, the GDP deflator was calculated as the ratio of GDP in constant prices to GDP in current prices, providing a measure of price variation over time. The exchange rate values are available in Appendix C.

Another challenge arises from using a single country's deflators for the global matrix. While U.S. deflators were selected due to their availability and long-term consistency, they may not accurately capture relative price changes in other economies. Differences in inflation patterns, sectoral dynamics, and production structures across countries could lead to distortions in the analysis of real prices. Moreover, the use of the double deflation method can compromise additivity between aggregated and disaggregated deflators, potentially affecting the coherence of results in analyses based on chained national accounting systems.

To mitigate these effects, we estimated price indices for Brazilian exports to both the Global South and Global North using data from the BACI database. These sectoral price indices are expected to help interpret the results, as U.S. sectoral indices were used to deflate all countries. It is important to note that these price indices capture only direct exports and not all exports resulting from input-output matrix effects. The detailed procedures are outlined in Appendix D.

Given these limitations, the results presented in the following section should be interpreted with caution, considering the methodological challenges discussed. Whenever possible, adjustments will be made to the analysis to minimize the effects of these constraints and ensure a more accurate interpretation of the data.

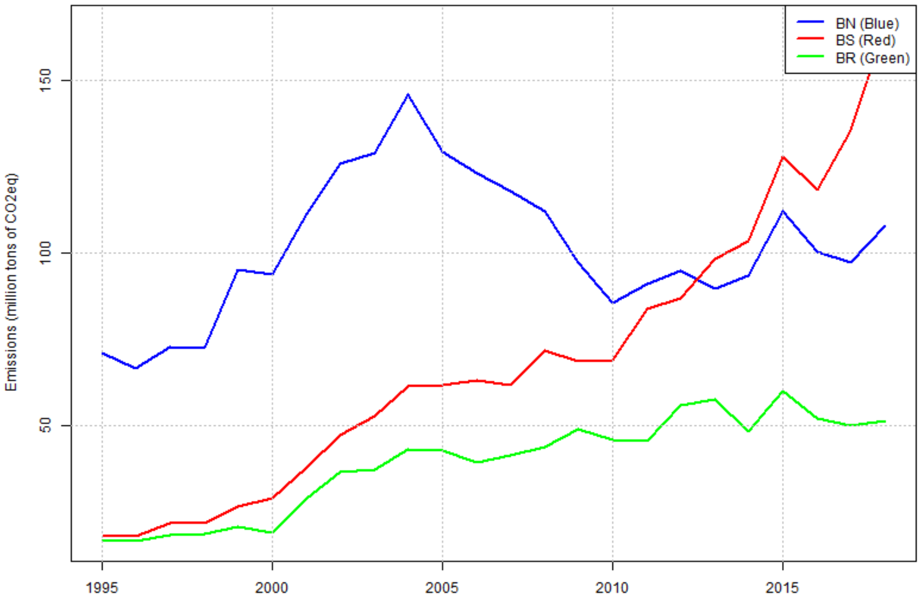
4. Results

Figure 1 illustrates the absolute CO_2 emissions associated with Brazilian exports to the Global North ($\boldsymbol{CET_{BN}}$), and Global South ($\boldsymbol{CET_{BR}}$) and Rest of the world ($\boldsymbol{CET_{BR}}$)

between 1995 and 2018. It provides a clear depiction of how the carbon footprint of Brazilian exports has evolved for these two regions, highlighting important trends in emission intensity and trade patterns.

The emission trajectories for the Global North show higher average values throughout the entire period. However, starting from 2010, there is a reversal in emissions directed to the Global South, with a more significant increase. This phenomenon is linked to Brazil's process of export specialization in primary products, as discussed by Alves-Passoni (2023, 2024) and Nassif (2020), which points to a greater focus on commodity markets.

Figure 1 – Emissions of Brazilian exports destine to the Global North, South and rest of the world, 1995 to 2008



Source: Authors' elaboration based on ICIO (OCDE, 2021), IEA-CO_2 (Yamano and Guilhoto, 2020) and EDGAR (Crippa et al., 2021).

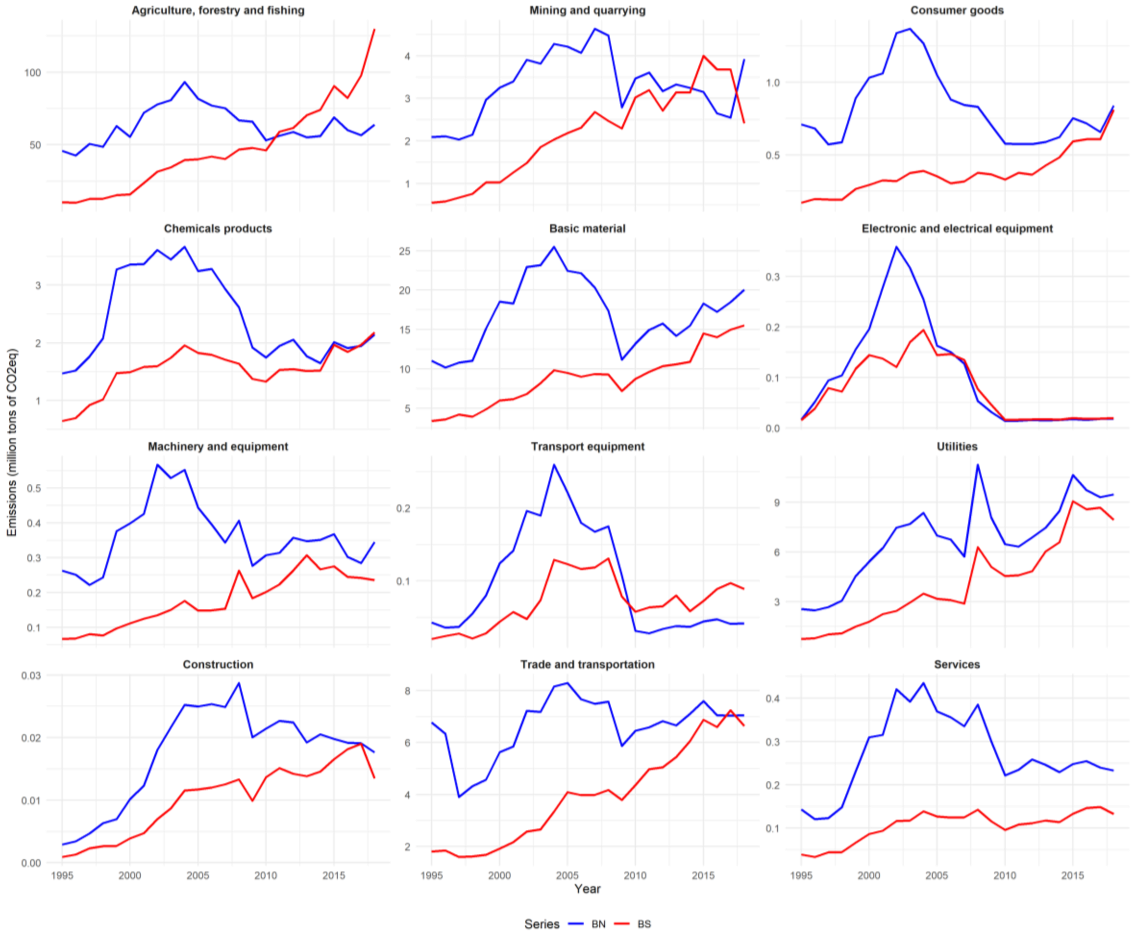
In the Brazil to Global North (BN) trajectory, an abrupt decline in emissions between 2005 and 2010 stands out. This shift should be observed with caution, as it may be attributed to changes in measurement methods or alterations in production or trade dynamics during that period.

Finally, emissions from Brazil to the Rest of the World also follow an increasing trajectory, though in a more gradual manner, reflecting a steady but moderate increase in Brazil's commercial relations with markets outside the Global North and South.

Analyzing the sectoral disaggregation of Figure 1 in Figure 2, we see that the Global south leads the flow of emissions because of Agriculture, Forestry, and Fishing sector, which shows a sharp and continuous rise in CO_2 emissions, especially after 2010.

Analyzing the sectoral disaggregation from Figure 1 in Figure 2, we observe that the Global South leads the flow of emissions primarily due to the Agriculture, Forestry, and Fishing sector, which shows a sharp and continuous rise in CO_2 emissions, especially after 2010. In fact, this sector is the one that, in absolute volume, exhibits the largest flow of emissions, reaching up to 130 million tons of CO_2 equivalent. In comparison, the second-largest sector contributing to emissions is Basic Materials, which reaches a flow of approximately 15 million tons of CO_2 equivalent in 2018 for the Global South—about 1/10th of the emissions from the Agriculture, Forestry, and Fishing sector.

Figure 2 – Total emissions of Brazilian exports to Global North, South and rest of the world, sectoral disaggregated, 1995 to 2008

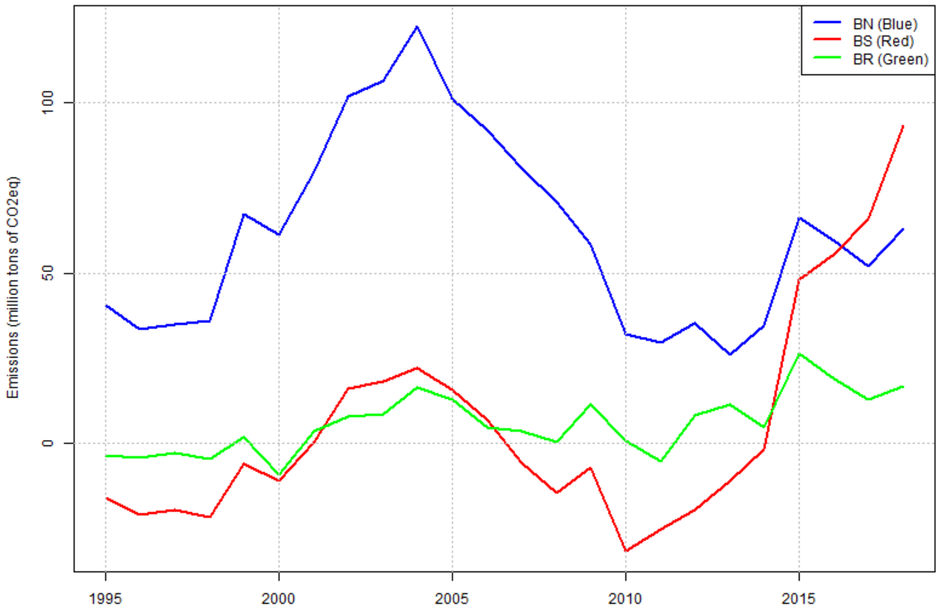


Source: Authors' elaboration based on ICIO (OCDE, 2021), IEA-CO_2 (Yamano and Guilhoto, 2020) and EDGAR (Crippa et al., 2021).

The greater weight of the Agriculture, Forestry, and Fishing sector means that this sector largely determines the trajectory of the Global South's contribution to Brazil's total emissions. However, when analyzing emissions by sector, emissions from Brazil to the other groups of sectors are higher for the Global North in nearly all sectors, with the exception of the Transport sector, where emissions to the Global South exceed those to the Global North. Another interesting point is that the absolute values of emissions from the Global South are gradually approaching those of the Global North, with the trajectories becoming similar by the end of the period.

Figure 3 illustrates the net CO_2 emissions associated with Brazilian exports, calculated by subtracting the CO_2 embedded in imports from each region from the CO_2 embedded in exports to the Global North and Global South. A positive value indicates that Brazil is a net exporter of CO_2, meaning it is exporting more CO_2 than it is importing from that region. Conversely, a negative value indicates that Brazil is a net importer of CO_2. It shows very different trajectories between the groups. Brazil has traditionally been a net exporter of CO_2, particularly associated with goods from the Global North. The emissions linked to goods exported to the Global North represent only a small portion—about one-third of the total value—while the rest reflects positive emissions, indicating that Brazil remains a net exporter of CO_2.

Figure 3 – Liquid emission flows of Brazilian exports to the Global North, South and rest of the world, 1995 to 2008



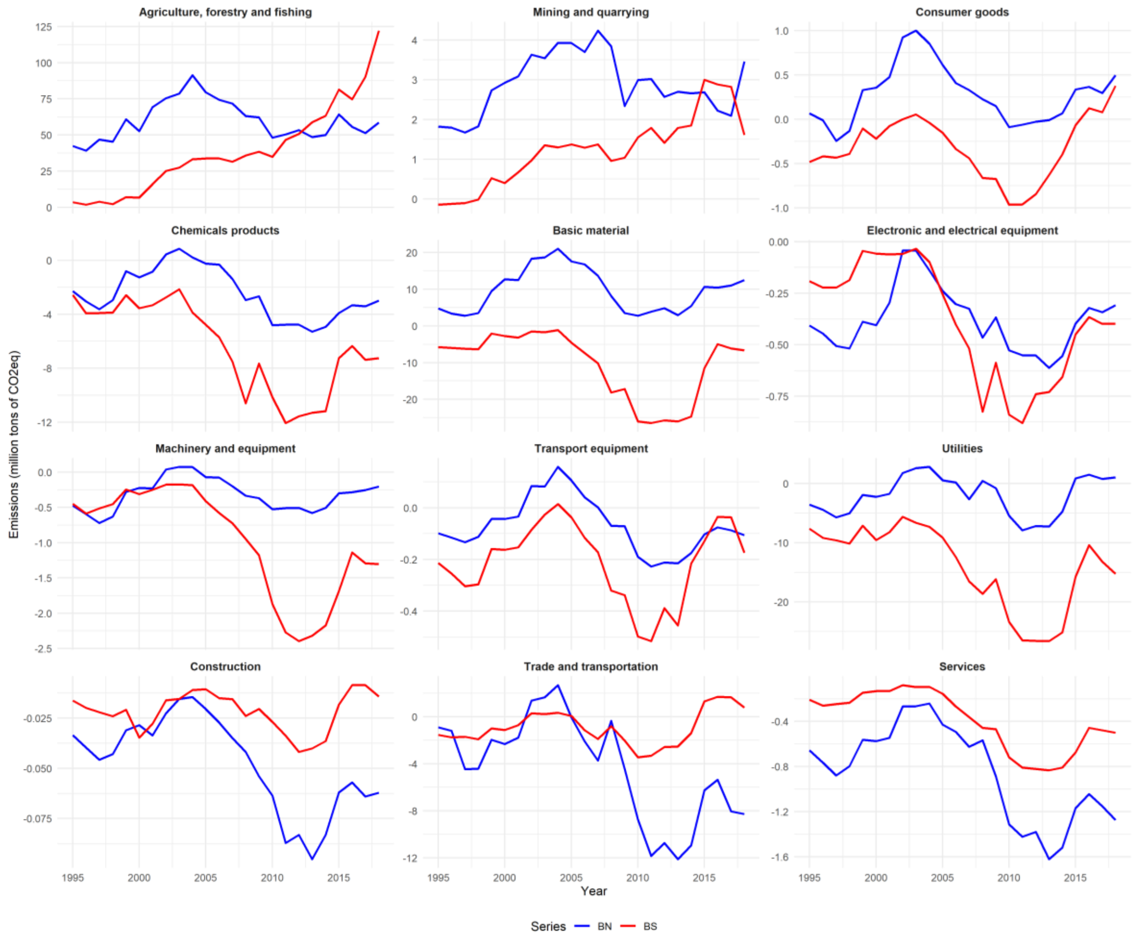
Source: Authors' elaboration based on ICIO (OCDE, 2021), IEA-CO_2 (Yamano and Guilhoto, 2020) and EDGAR (Crippa et al., 2021).

An interesting phenomenon is observed regarding the Global North. Brazil is a net exporter of CO_2 only in relation to products from Agriculture, Mining and Quarrying, Consumer Goods (Paper Products and Printing), and Basic Materials (Basic Metals and Fabricated Metal Products). For all other sectors, Brazil is a net importer of CO_2 equivalent, with notable magnitudes in Chemicals, Machinery and Equipment, and Electrical and Electronic Equipment.

An interesting phenomenon is observed regarding the Global North. Brazil is a net exporter of CO_2 only in relation to products from Agriculture, Mining and Quarrying, Consumer Goods (Paper Products and Printing), and Basic Materials (Basic Metals and Fabricated Metal Products). For all other sectors, Brazil is a net importer of CO_2 equivalent, with notable magnitudes in Chemicals, Machinery and Equipment, and Electrical and Electronic Equipment.

Between 1995-2002 and 2007-2014, the Global South was a net exporter of CO_2 equivalent. Notably, between 2003 and 2007, during the commodity boom, Brazil significantly increased the value of its exports, particularly in mineral and agricultural products (see Mining and Quarrying and Agriculture in Figure 4). From 2010 onwards, the balance gradually became less negative, until it turned positive in 2014, driven by the growth of emissions associated with the previous products.

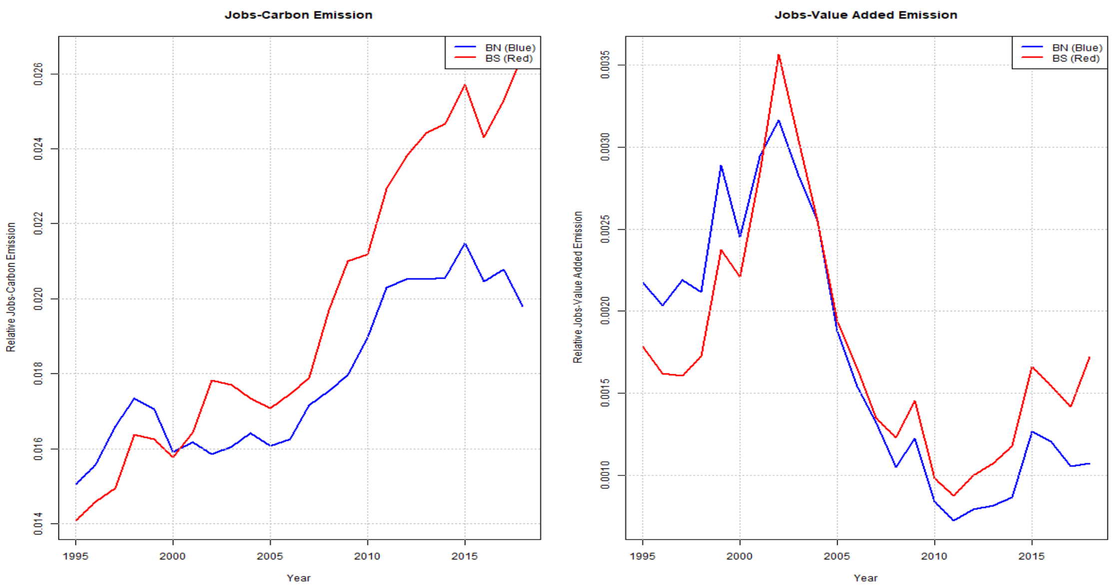
Figure 4 – Liquid emission flows of Brazilian exports to the Global North, South and rest of the world, 1995 to 2008



Source: Authors' elaboration based on ICIO (OCDE, 2021), IEA-CO_2 (Yamano and Guilhoto, 2020) and EDGAR (Crippa et al., 2021).

The analysis of the Jobs-Carbon Emission and Jobs-Value Added Emission can be seen in Figure 5. The first graph shows the Relative Jobs-Carbon Emission (RCE), and we see both lines remain below 1 throughout the observed period, indicating that the carbon intensity per job of Brazilian exports is consistently lower than that of its imports. This suggests that Brazil exports more carbon-efficient jobs compared to the jobs it imports. Although the Global South is consistently above the Global North especially after 2005, this shows that Brazilian exports to the Global South are relatively more carbon-intensive than those to the Global North.

Figure 5 – Pollution terms of trade and relative jobs-carbon emission between Brazil, the Global North, and the Global South, from 1995 to 2018



Source: Authors' elaboration based on ICIO (OCDE, 2021), IEA-CO_2 (Yamano and Guilhoto, 2020) and EDGAR (Crippa et al., 2021).

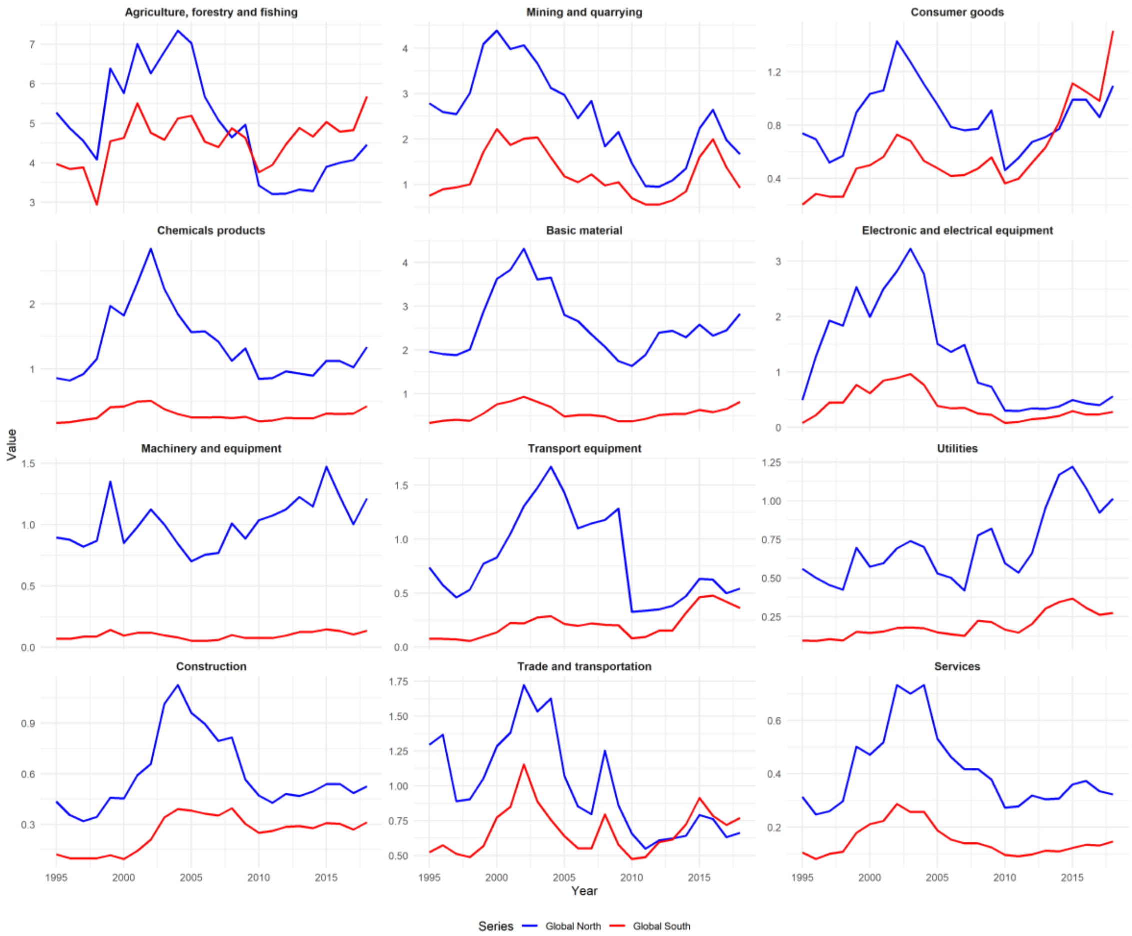
The second graph illustrates the Jobs-Value Added Emission, comparing the carbon intensity per unit of value added for Brazilian exports to the Global North and Global South. Similar to the Jobs-Carbon Emission graph, both lines remain below 1 throughout the period, indicating that the carbon intensity per value added of Brazilian exports is lower than that of its imports. This suggests that Brazil exports more carbon-efficient products with higher value added compared to the products it imports.

What is now observed is that the difference between the Global South and the Global North is smaller in terms of value than in terms of employment. It is important to note that these results represent relative measures of carbon intensity and do not account for the absolute volume of trade flows. Therefore, the analysis does not imply that Brazil exports more to the Global North than to the Global South.

Analyzing these results in aggregate terms masks the internal dynamics between sectors. In Figure 6, we observe that the sectors of Agriculture, Mining and Quarrying, Basic Materials, Chemical Products, and Electrical and Electronic Equipment have a PTT (Production-to-Trade ratio) greater than 1 for the Global North, meaning that the goods exported by Brazil to this group have a higher CO_2 equivalent emissions than those received for each unit of value added, in comparative terms. This phenomenon associated with the Global North is more pronounced than in the Global South.

For the Global South, a higher PTT is notably observed starting in 2010 for the Agriculture and Consumer Goods sectors (with the latter showing a significant rise starting in 2013, most likely due to processed goods related to agriculture, such as meat products).

Figure 6 – Carbon-Value added indicator between Brazil, the Global North, and the Global South, from 1995 to 2018

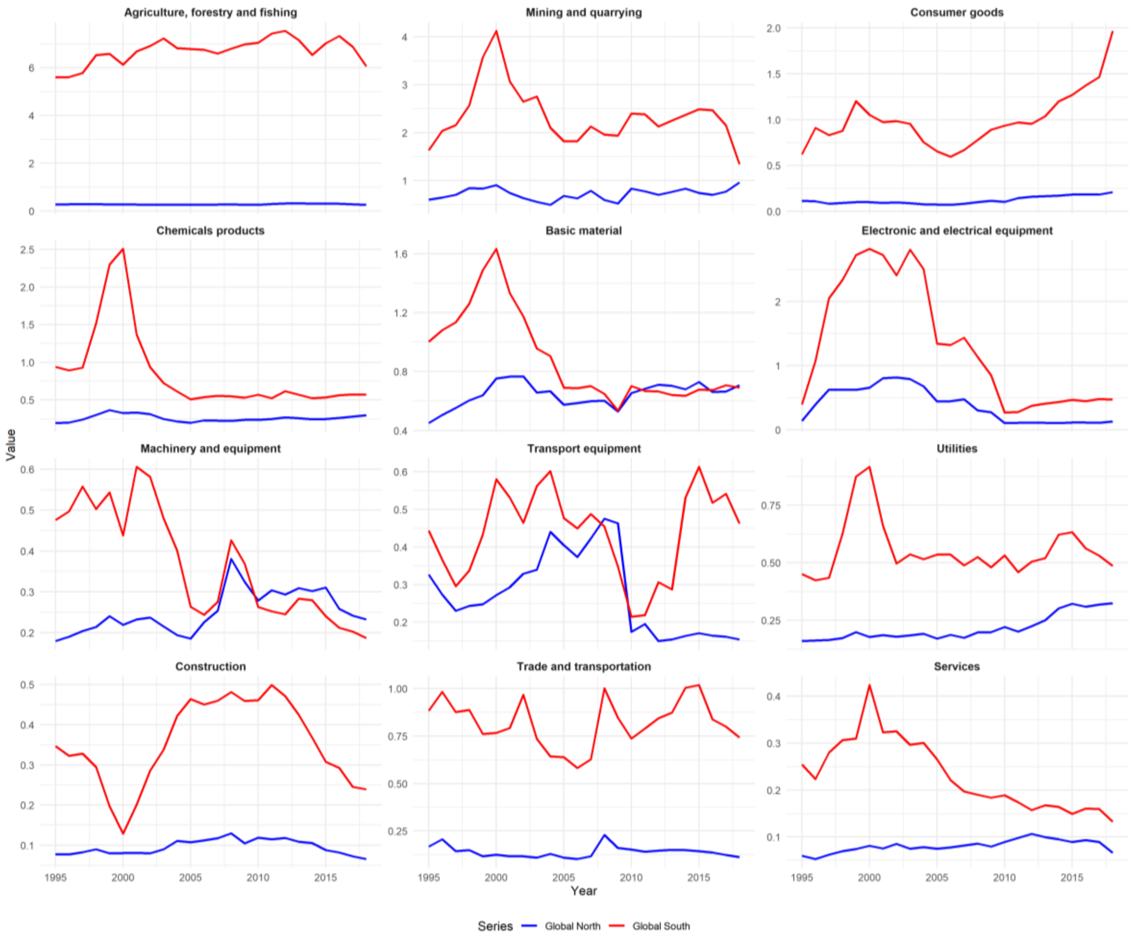


Source: Authors' elaboration based on ICIO (OCDE, 2021), IEA-CO_2 (Yamano and Guilhoto, 2020) and EDGAR (Crippa et al., 2021).

These findings suggest that Brazil is exporting more carbon-intensive products to developed economies, supporting the Environmental Terms of Trade Deterioration Hypothesis. The consistently higher BN values indicate that Brazil bears a higher environmental cost per job for exports to the Global North, whereas the lower BS values suggest a more favorable environmental trade balance with the Global South. This divergence highlights a carbon intensity disparity in Brazil's trade relations, where exports to the Global North are systematically more carbon-intensive compared to exports to the Global South. This dynamic is likely influenced by Brazil's export reprimarization process, with an increasing share of primary and resource-intensive products in its export basket.

Analyzing the sectoral relative carbon emission intensity per job for Brazilian exports (Figure 7) to the Global North (BN) and Global South (BS) reveals significant disparities when compared to the PTT. In most sectors, the CO_2 per job for the Global South is higher than that for the Global North, which contrasts with the findings from value-added emissions, where the opposite is observed—the Global North has higher value-added emissions per unit of value added. This allows us to conclude that the productivity of products exported to Global North has a higher value-added per unit of employment.

Figure 7 - Relative jobs-carbon emission between Brazil, the Global North, and the Global South, from 1995 to 2018



Source: Authors' elaboration based on ICIO (OCDE, 2021), IEA-CO_2 (Yamano and Guilhoto, 2020) and EDGAR (Crippa et al., 2021).

The analysis highlights notable sectoral differences in carbon intensity per job compared to carbon intensity per unit of value-added (VA) for Brazilian exports to both the Global North and Global South. These differences are particularly pronounced in sectors such as Agriculture, Mining and Quarrying, and Consumer Goods.

5. Final comments

This study has sought to provide a comprehensive analysis of Brazil's role as a global exporter and importer of emissions, focusing on the distinctions between the Global North and the Global South. It has highlighted the complex dynamics of international trade, where the globalization of production networks has created significant environmental consequences, notably the transboundary transfer of pollutants embedded in traded goods. As the findings suggest, Brazil's trade relationships reveal important patterns that reflect broader global trends, including the shifting environmental burden between developed and developing economies.

Methodologically, the use of a multi-regional input-output (MRIO) model enabled a detailed and dynamic assessment of the interdependencies between countries and sectors. This approach proved essential for capturing the complex effects of global trade on CO_2 emissions, value-added, and employment. By integrating the OECD ICIO database with other sources, the study was able to estimate the environmental and economic impacts of Brazilian trade, providing a comprehensive view of the country's position in the global trade network and its implications for sustainable development. The use of this model also allowed for a more accurate analysis of sector-specific impacts, providing a granular understanding of how different industries contribute to both emissions and economic value creation.

A central concern arising from this analysis is the uneven distribution of environmental impacts, particularly as they pertain to emissions responsibilities. The study highlights the persistent debate on whether the burden of emissions should lie with the producing countries or the consuming countries. The implications of this question are critical for nations like Brazil, which have seen a marked shift toward primary product exports, thereby exacerbating their vulnerability to the environmental and economic consequences of international trade. This growing disparity underscores the need for more nuanced discussions surrounding global responsibility for emissions and the effectiveness of trade-based emissions accounting methods.

This study has provided an in-depth analysis of Brazil's environmental impact as an exporter of CO_2 emissions, with a focus on its trade relations with the Global North and Global South. The findings reveal significant disparities in emissions between these regions, with the Global North consistently having higher average CO_2 emissions throughout the period analyzed. A key observation is the reversal of emission flows from Brazil to the Global South starting in 2010, driven by Brazil's increasing export specialization in primary products. This shift aligns with the broader trend of export reprimarization, which is associated with higher emissions, particularly from resource-intensive sectors such as Agriculture, Forestry, and Fishing.

The study also highlights the changing dynamics of Brazilian exports, where emissions associated with products exported to the Global South are gradually approaching those directed to the Global North. This trend indicates a closer alignment in terms of environmental impacts between these two regions, particularly after 2010. Moreover, the analysis of the Jobs-Carbon Emission and Jobs-Value Added Emission reveals that Brazilian exports to the Global North are systematically more carbon-intensive compared to exports to the Global South. This dynamic reinforces the Environmental Terms of Trade Deterioration Hypothesis, suggesting that the export of primary products to developed economies results in higher environmental costs per unit of value added.

In conclusion, while the data provides valuable insights, caution is needed in interpreting it as absolute truth due to several limitations. First, using U.S. deflators for all countries may not accurately capture price variations in economies with distinct inflation dynamics, particularly in developing countries like Brazil, which can distort real price and environmental impact assessments. Additionally, the deflation approach may compromise the additivity between aggregated and disaggregated deflators, affecting the coherence of results in national accounting systems.

Another limitation is the focus on direct exports, which overlooks the broader impacts of global supply chains captured in input-output matrices, potentially underestimating environmental and economic effects. Finally, the regional and sectoral data segmentation challenges the full understanding of trade relations and their environmental consequences in emerging economies. However, this line of research holds significant promise, and much more remains to be analyzed, which will be addressed in future stages of the research, as this is an ongoing study.

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Appendix A: Correspondence table

ICIO Code	ICIO Industries	Code	Aggregated sectors
D01T03	Agriculture, forestry and fishing	S01	Agriculture, forestry and fishing
D05T06	Mining and extraction of energy producing products	S02	Mining and quarrying
D07T08	Mining and quarrying of non-energy producing products	S02	Mining and quarrying
D09	Mining support service activities	S02	Mining and quarrying
D10T12	Food products, beverages and tobacco	S03	Consumer goods
D13T15	Textiles, wearing apparel, leather and related products	S03	Consumer goods
D16	Wood and products of wood and cork	S03	Consumer goods
D17T18	Paper products and printing	S03	Consumer goods
D19	Coke and refined petroleum products	S04	Chemicals products
D20T21	Chemicals and pharmaceutical products	S04	Chemicals products
D22	Rubber and plastic products	S05	Basic material
D23	Other non-metallic mineral products	S05	Basic material
D24	Basic metals	S05	Basic material
D25	Fabricated metal products	S05	Basic material
D26	Computer, electronic and optical products	S06	Electronic and electrical equipment
D27	Electrical equipment	S06	Electronic and electrical equipment
D28	Machinery and equipment, nec	S07	Machinery and equipment
D29	Motor vehicles, trailers and semi-trailers	S08	Transport equipment
D30	Other transport equipment	S08	Transport equipment
D31T33	Other manufacturing; repair and installation of machinery and equipment	S07	Machinery and equipment
D35T39	Electricity, gas, water supply, sewerage, waste and remediation services	S09	Electricity, gas, water supply, sewerage, waste and remediation services
D41T43	Construction	S10	Construction
D45T47	Wholesale and retail trade; repair of motor vehicles	S11	Trade and transportation
D49T53	Transportation and storage	S11	Trade and transportation
D55T56	Accommodation and food services	S12	Services
D58T60	Publishing, audiovisual and broadcasting activities	S12	Services
D61	Telecommunications	S12	Services
D62T63	IT and other information services	S12	Services
D64T66	Financial and insurance activities	S12	Services
D68	Real estate activities	S12	Services
D69T82	Other business sector services	S12	Services
D84	Public admin. and defence; compulsory social security	S12	Services
D85	Education	S12	Services
D86T88	Human health and social work	S12	Services
D90T96	Arts, entertainment, recreation and other service activities	S12	Services
D97T98	Private households with employed persons	S12	Services

Appendix B: Database on emisisons of CO_2 equivalent

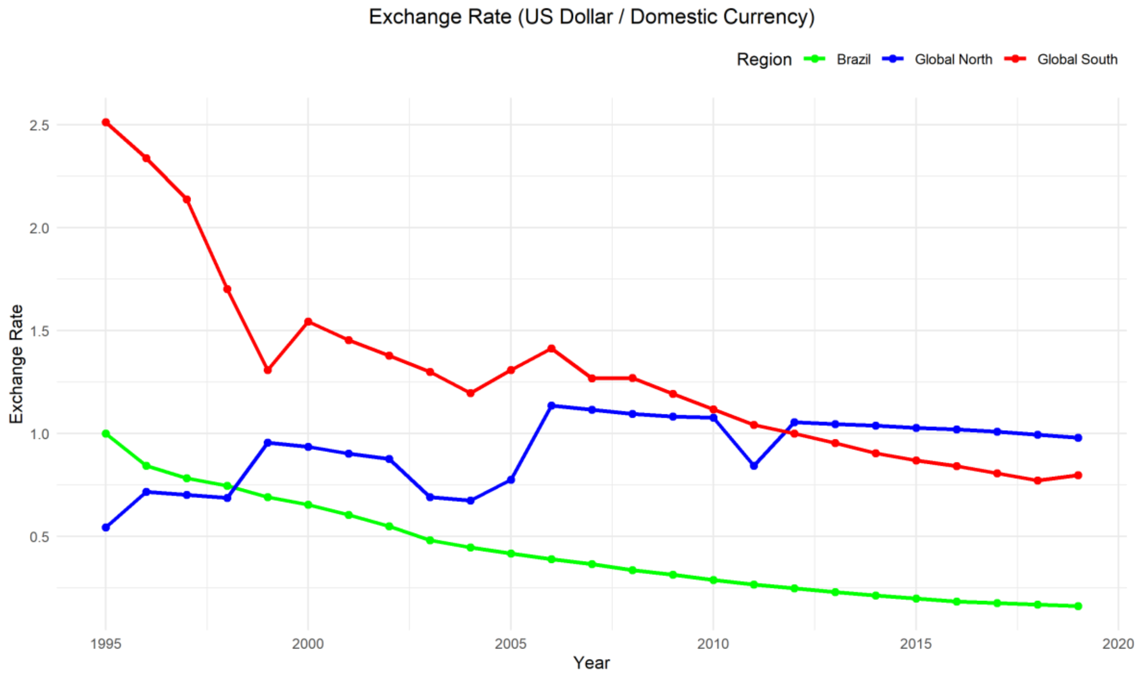
TECO2 presents data on emissions from fossil fuel combustion. To broaden the scope of the analysis, it was decided to add the CO_2eq emissions from EDGAR (Emissions Database for Global Atmospheric Research) (Crippa et al., 2021) to TECO2. EDGAR reports CO_2eq emissions from processes, land use, land use change, and forestry, including emissions of CH_4 (methane), N_2O (nitrous oxide), and F-gases (fluorinated gases), as well as fossil fuel combustion emissions from 1970 to 2022. As in the ICIO, the fossil fuel combustion emissions in EDGAR are primarily based on data from the International Energy Agency (IEA) database. However, EDGAR employs the sectoral classification of the Intergovernmental Panel on Climate Change (IPCC).
We will reconcile the sectors in EDGAR, which uses the IPCC classification, with those in the ICIO, which uses the ISIC classification. Since both EDGAR and ICIO include fossil fuel combustion emissions based on IEA data, only the EDGAR emissions not related to these are considered. Therefore, categories 1 and 5.B will not be included in the TECO2 emissions database, as they correspond to fossil fuel combustion emissions. Additionally, EDGAR's international aviation and international shipping emissions are not considered, because TECO2 already incorporates these emissions. The remaining IPCC categories and their correspondence with the ISIC sectors are summarized in the table below:

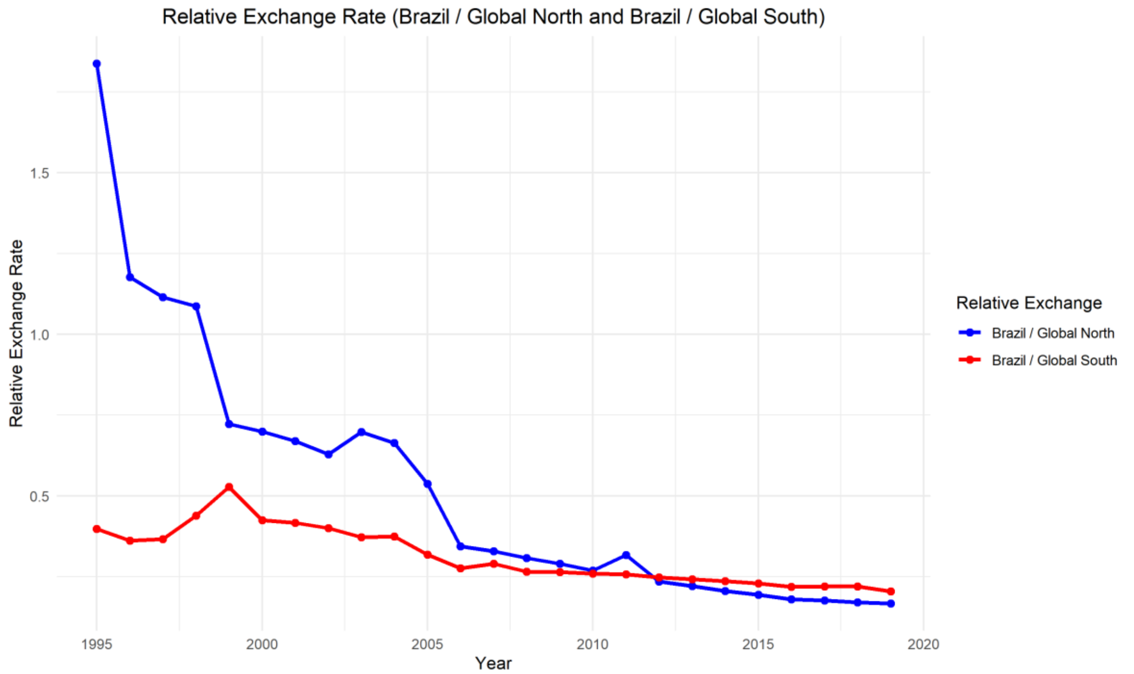
Correspondance Table: Mapping of IPCC Categories to ISIC

IPCC	ISIC
2.A.1, 2.A.2, 2.A.4	D23
2.A.3, 2.E	D26
2.B	D20 + D21
2.C	D24 + D25
2.D	D19
2.F	D35
2.G	D3133
3.A.1, 3.A.2, 3.C.1, 3.C.2, 3.C.3, 3.C.4, 3.C.5, 3.C.6, 3.C.7, D5.A	D01T02 + D03
4.A, 4.B, 4.C, 4.D	D36T39

Thus, to align the IPCC categories with those of ISIC, three pairs of ISIC sectors (D20 + D21, D24 + D25, D01T02 + D03) are aggregated, resulting in 42 sectors in the interregional input–output model.
Finally, to harmonize the emission units between EDGAR and TECO2, a division by 1000 is applied to convert EDGAR's units from gigagrams of CO_2eq to million tonnes of CO_2eq, which is the unit used in TECO2.
Comparing the most comprehensive CO_2 emission data (i.e., the total CO_2 emissions from EDGAR) with the reconciled CO_2 emissions, the latter represent 84% of EDGAR's total emissions in 2018. When the same comparison is made for the aggregated groups analyzed, the reconciled emissions for Brazil, Global South, Global North, and Others in 2018 correspond to 87.3%, 88.3%, 81.8%, and 77.7%, respectively.

Appendix C: Exchange rates





Appendix D: Fisher index prices for exports

The Fisher index is derived from the geometric mean of the Paasche and Laspeyres indexes. While in the former the quantities are held fixed in the most recent (reference) period, in the latter the basket of the previous period is kept fixed. This type of index possesses important ideal properties, such as temporal reversibility, factor reversibility, circularity, determination, and consistency in aggregation, as argued by the UN (2008), Silva, Prado and Torracca (2017), and Gameiro and Caixeta-Filho (2010).

The Fisher index ($f_{i,j,h}^{t,t+1}$) for a pair of years (t and t+1) can be expressed as:

$$f_{i,j,h}^{t,t+1} = \sqrt{\frac{\sum_{i=1}^{n} p_{i,j,h}^{t+1} q_{i,j,h}^{t}}{\sum_{i=1}^{n} p_{i,j,h}^{t} q_{i,j,h}^{t}} \times \frac{\sum_{i=1}^{n} p_{i,j,h}^{t+1} x_{i,j,h}^{t+1}}{\sum_{i=1}^{n} p_{i,j,h}^{t} x_{i,j,h}^{t+1}}}$$

in which $p_{i,j,h}$ expresses the unit price and $q_{i,j,h}$. the quantity for the i products, the j countries and for h trade flow (exports and imports). Note that each price index is calculated for a pair of years and to obtain a series for a long period of years it is necessary to chain the price indices through the multiplication of the annual indices, as described below:

$$F_{i,j,q}^{t^*,\tau} = \prod_{t=2000}^{T} f_{i,j,q}^{t,t+1}$$

where t is the initial year of the series, T the final year, τ represents the cumulative price index, and t^* the base (reference) year. A chained Fisher index produces transitive indices (UN, 2009), which broadens its coverage and reduces the bias of sequential comparisons due to changes in basket composition (the reference period relative to the other periods).

With the price indices in hand, it is now possible to calculate the volume value of exports and imports ($V_{i,j,q}^{t^*,\tau}$) for each product category by dividing the nominal value by ($x_{i,j,q}^{\tau}$) the Fisher price index ($F_{i,j,q}^{t^*,\tau}$):

$$V_{i,j,q}^{t^*,\tau} = \frac{x_{i,j,q}^{\tau}}{F_{i,j,q}^{t^*,\tau}}$$

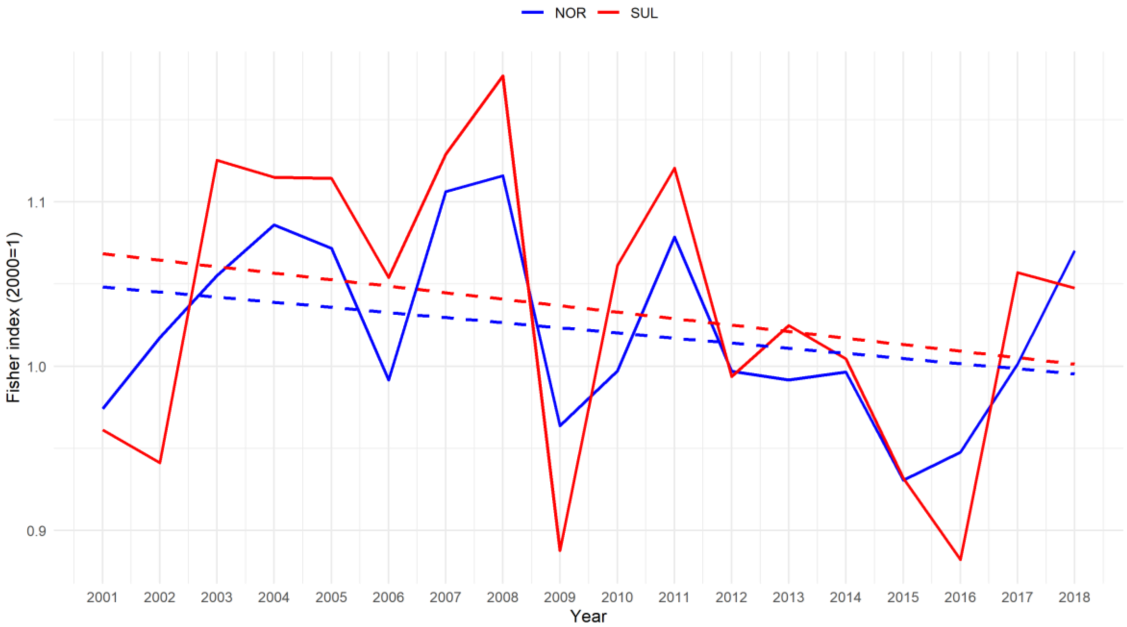
The total value for each category tends to be non-additive—that is, it does not equal the total deflated exports/imports when using its own deflator (UN, 2009). However, we chose to create an overall volume measure by summing the deflated categories, which facilitates comparison with the schedule of exports/imports at current prices (where the sum of all components equals 100%).

The database used was BACI, which compiles product-level international trade data published by CEPII (Centre d'Études Prospectives et d'Informations Internationales) and follows the methodology outlined in Gaulier and Zignago (2010). It provides annual quantities and values for each exported and imported product by origin and destination and is available in several versions of the Harmonized System (HS).

Several data screening adjustments were made. First, products with zero export or import values or quantities in any year were excluded. Second, products that did not appear as exported/imported goods in every year of the analyzed period were omitted, since annual prices and quantities are essential for constructing the baskets and performing the appropriate deflation. Next, unit prices for each product were calculated by dividing the value by the quantity. Finally, only products with price indices ranging between 40% and 250% were retained to prevent extreme fluctuations from distorting the analysis.

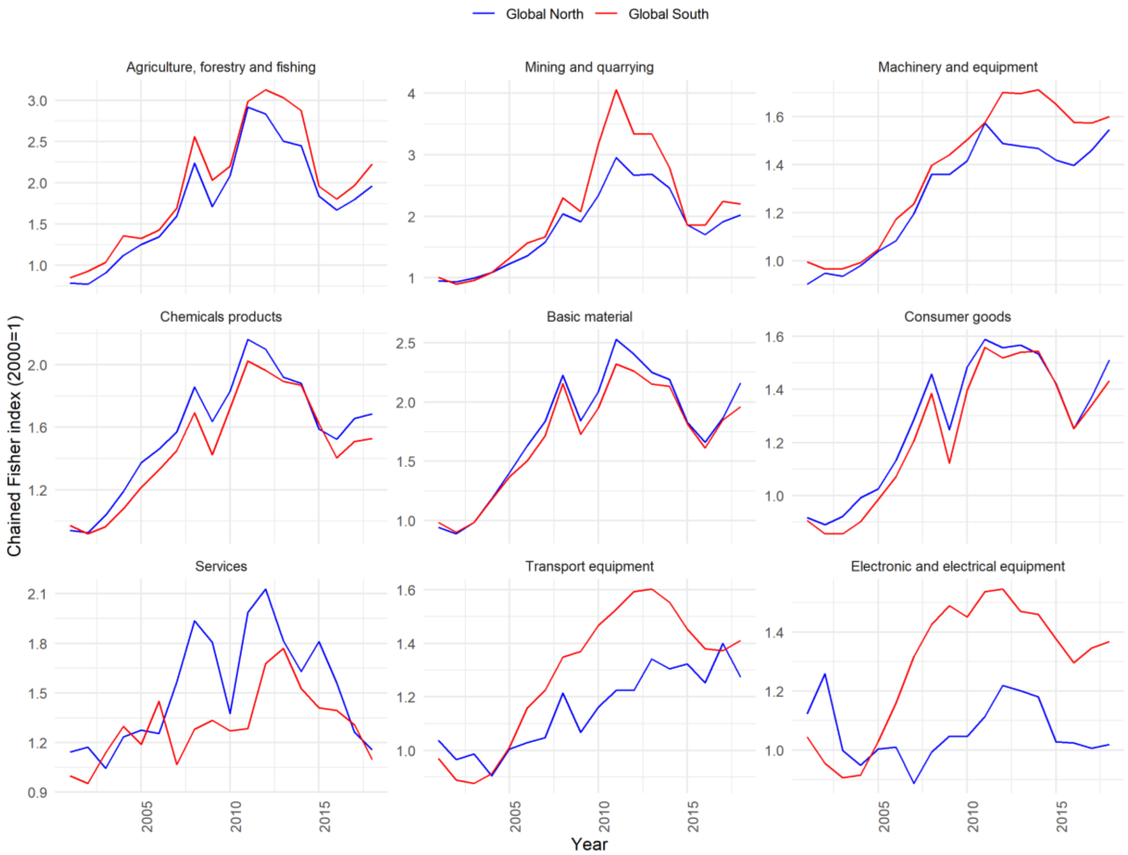
We opted for the 1996 HS version, which provides data from 1996 to 2019, ensuring that at least 70% of the data is maintained for each country. Nevertheless, the years prior to 2000 were excluded due to high volatility, in order to enhance the number of reliable observations in the sample.

Figure 8 - Fisher index of products exported by Brazil to Global North and Global South, 2001 to 2019 (2000=1)



Source: Own elaboration based on Gaulier and Zignago (2010).

Figure 9 - Fisher index of products exported by Brazil to Global North and Global South, 2001 to 2019 (2000=1)



Source: Own elaboration based on Gaulier and Zignago (2010).

Note: There are some sectors that are not included because we did not found and correspondence in the CEPII database.