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International trade and greenhouse gas emission patterns between Brazil and the original BRICS countries

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Brasilia, May 2025

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CONTENTS

ABSTRACT

This paper aims to estimate the value added and greenhouse gas (GHG) emissions embodied in trade between Brazil and the original BRICS countries – China, India, Russia, and South Africa – for the year 2022. Based on data from Exiobase, the emissions indicator reveals that China is the main source of emissions embedded in Brazilian imports, while Russia records the highest emissions indicator among Brazilian export destinations – showing a greater emissions intensity relative to trade volume. The results show that China was the primary destination for Brazilian exports, absorbing approximately 23.1 million tons of CO_2, and also accounted for the largest share of emissions embedded in Brazil's imports, with around 52.8 million of TCO_2 – an outcome aligned with the trade volume between the two countries. Emissions associated with Brazilian exports were mainly concentrated in sectors such as food production and animal farming, whereas imports were dominated by intermediate and capital goods with high emission intensities.

Keywords: input-output analysis; greenhouse gas emissions; BRICS.

1 INTRODUCTION

With the intensification of international trade and the deepening of productive specialization among nations, production and consumption patterns have become increasingly decentralized, spanning multiple geographic regions. This phenomenon has led to integrating greenhouse gas (GHG) emissions into global value chains, as traded goods inherently carry the emissions associated with their production processes. Consequently, international trade facilitates the net transfer of GHG emissions, redistributing the environmental impacts of productive activities across countries.

However, the extent to which emissions embedded in trade affect different countries is highly asymmetrical. Variations in trade patterns, productive structures, and technological development significantly influence the magnitude of emissions transferred across borders (Caro et al., 2015; Afionis et al., 2017). Studies by Meng et al. (2018), Wu et al. (2020), and Liu, Lackner and Fan (2021) highlight the regional disparities in the economic and environmental consequences of international trade. Additionally, the literature underscores the link between pollution levels, economic growth, and institutional frameworks, showing that lower-income regions tend to become "pollution havens", where environmentally harmful activities are concentrated (Cole and Elliott, 2003; Duan, Ji and Yu, 2021). On the other hand, as Nunes et al. (2023) argue, international trade can also create opportunities for the external financing of climate mitigation projects, such as investments in renewable energy in developing economies.

Against this backdrop, the BRICS economies – Brazil, Russia, India, China, and South Africa – have gained increasing prominence in global economic dynamics. In 2022, these countries accounted for 26% of global gross domestic product (GDP) and 21% of international trade,[1] consolidating their role as key players in the world economy. However, this economic expansion has been accompanied by rising GHG emissions, with all five nations ranking among the world's top 20 emitters.[2] The accelerating pace of climate change demands a coordinated response aligned with the Paris Agreement and the Sustainable Development Goals (SDGs). Nevertheless, the unilateral adoption measures by developed economies, such as the European Union's Carbon Border Adjustment Mechanism (CBAM), pose additional challenges for emerging economies. By imposing tariffs on the carbon content of goods exported

1. In 2023, nine other members (Saudi Arabia, United Arab Emirates, Egypt, Ethiopia, and Iran) joined the group. With the new composition in 2024, the GDP reached 37% of global production, and international trade totaled 26%. In addition, in 2025, Indonesia joined the BRICS, and there are prospects for new partnerships.

2. Available at: https://unctadstat.unctad.org/EN/.

to the European Union, the CBAM[3] risks undermining the growth prospects of BRICS countries, adding another layer of complexity to their economic and environmental strategies (Thorstensen, Zuchieri and Mota, 2023).

In this context, the present study seeks to quantify the total GHG emissions embedded between Brazil's trade flows and the four BRICS countries. Given the bloc's economic significance and its members' commitments to emission reduction, a detailed understanding of these emissions' volume and sectoral composition is crucial for informing public policies. This objective is particularly relevant in light of the recent expansion of BRICS, which in 2023 welcomed five new members – Saudi Arabia, the United Arab Emirates, Egypt, Ethiopia, and Iran; in 2025 Indonesia came aboard – further strengthening the group and expanding opportunities for cooperation.

To achieve this, we employ an emissions decomposition analysis, mapping GHG emissions across interindustry production and consumption linkages within traditional international trade networks. Following the methodology proposed by Chen et al. (2021) and applied by Barcelos and Costa (2024), we use data from an environmentally extended multiregional input-output model, Exiobase (EE MRIO), to estimate the emissions embedded in trade flows between Brazil, China, India, Russia, South Africa, and the rest of the world (ROW) for the year 2022. This approach enables a detailed examination of emissions trade relations by economic sector, allowing for a more precise analysis of the origin and destination of Brazil's emissions to the BRICS. Moreover, Exiobase provides the most up-to-date database (2022) among available input-output models, with a detailed sectoral classification – covering 50 sectors compared to Eora's 26 – and a higher level of granularity. Notably, the six new BRICS members were not included in this analysis, as their accession to the bloc occurred only in 2023.

The structure of this study consists of six sections, including this introduction. The second section provides a literature review, followed by the third, which outlines the methodology. The fourth section describes the database used, while the fifth presents and discusses the results. The last section offers the concluding remarks.

2 LITERATURE REVIEW

Estimating emissions through a multiregional input-output (MRIO) matrix offers a robust methodology capable of capturing the complex and simultaneous interactions between

3. The aim is to prevent carbon leakage by applying a border tax. This is compensation for differences in production costs due to the price of carbon. The proposal is to replace the current system of free Emissions Trading System (ETS) licenses for industry, incentivizing GHG emissions reductions in the sectors covered by the ETS (see Thorstensen, Zuchieri and Mota, 2023).

productive sectors and geographic regions. This model not only enables the assessment of both direct and indirect emissions flows associated with international trade but also calculates interregional feedback effects, offering an integrated view of the dynamics of production, consumption, and emissions across different economies (Miller and Blair, 2009).

Studies such as those by Sato (2014) and Zhang et al. (2017) have demonstrated the effectiveness of using input-output matrices to estimate energy flows and emissions embedded in international trade, addressing key issues such as carbon leakage. This concept refers to the phenomenon where stringent environmental regulations in one country led to the relocation of carbon-intensive production to countries with weaker environmental policies, effectively shifting, rather than reducing, global emissions. These studies highlight how the relocation of emissions to countries with less stringent environmental regulations can undermine global efforts to mitigate climate change.

Su, Ang and Liu (2021) explore the spatial aggregation issues in MRIO analysis of regional emissions and intensities by linking regional and global datasets. The study examines four spatial aggregation schemes, using an empirical analysis of 30 Chinese regions and 43 countries for 2007 and 2012 to assess the impact of aggregation on embedded emissions and intensities. Findings reveal that spatial aggregation affects sectoral outcomes more significantly than regional ones, with important implications for regional emission studies.

In the Brazilian and Chinese context, Barcelos and Costa (2024) applied the MRIO model to analyze the relationship between international trade within global value chains (GVCs) and greenhouse gas (GHG) emissions. The results indicated that, in the case of China, emissions are predominantly associated with energy generation and energy-intensive industries, reflecting the country's heavy dependence on fossil fuels to sustain its industrial growth. In contrast, Brazilian emissions mainly stem from the service sector and traditional industries, underscoring the need to improve energy efficiency in key sectors of the Brazilian economy.

Zhang et al. (2019) analyze trade-related emissions using an MRIO model, focusing on transactions between BRICS (original formation) and non-BRICS countries. The study examines the flow of emissions embedded in trade, with particular emphasis on the energy sector. The results indicate that, within the BRICS group, the majority of emissions were embedded in intermediate goods rather than in final demand. China emerged as the dominant player in terms of traded emissions, acting as a key intermediary. Specifically, China facilitated the transfer of emissions embedded in Russian exports to other BRICS countries while also driving a significant inflow of emissions from major economies outside the bloc.

Building on these findings, Zhongxiu and Yunfeng (2014) utilized the World Input-Output Database (WIOD) to compare production-based emissions (PBE) and consumption-based emissions (CBE), defining emissions embedded in exports (EEE) and imports (EEI). The study revealed that BRICS countries were major CO_2 producers between 1995 and 2009, collectively emitting over 3.7 Gt of CO_2 under the CBE approach. To further understand the driving forces behind carbon flows in international trade, Xu et al. (2011) developed a novel structural decomposition analysis (SDA) method using the MRIO model, incorporating emissions from production. Their results showed a significant increase in embedded emissions, with EEE rising by 207% in China and 125% in India, while EEI surged by 330% and 338% for both countries over the same period.

Despite this extensive literature, an integrated analysis of GHG and value-added flows embedded in BRICS economies remains scarce. This study aims to fill this gap by providing a sectoral analysis of emissions incorporated into BRICS trade flows, offering an overview of the dynamics of emissions related to trade within the bloc.

The main contribution of MRIO models is in the adequate understanding of the new pattern of international trade. Analyzing only gross export data can omit important information regarding the domestic production capacity of countries (Wang, Wei and Zhu, 2013). Moreover, one limitation of some MRIO databases – for example, Exiobase and Eora (Casella et al., 2019) and the Inter-country input-output tables (ICIO)[4] – is that they account only for the flow emissions, not able to account for stock emissions. It is the case of not accounting for emissions resulting from land-use changes and deforestation, which represented 48% of Brazil's total emissions in 2022 (Araújo, 2022). This gap is particularly relevant for countries with significant emissions associated with the conversion of forests and other biomes. Despite this limitation, the MRIO model remains highly appropriate as it provides a solid methodological framework and sufficient data to support the analysis of GHG emissions generated and embedded in international trade relations, which is crucial in the current climate crisis scenario.

3 METHODOLOGY

To estimate the input-output decomposition model, we start by following Leontief's (1936) methodology for a classical production system. First, by definition, it is assumed that inter-industry flows of i to j industries depend on the total output of the industry j. That relationship is measured by the technical coefficient $a_{ij} = {}^{z_{ij}}/_{x_j}$ (or $a_{ij}x_j = z_{ij}$), which given a fixed proportion of the intermediate consumption of industry i of j, z_{ij}, of total

4. Available at: https://www.oecd.org/en/data/datasets/inter-country-input-output-tables.html.

production of industry j, x_j, for a specific time period (Miller and Blair, 2009). Thus, applying the usual definitions of Leontief production system,

$$x_n = a_{n1}x_1 + \cdots + a_{ni}x_i + \cdots + a_{nn}x_n + f_n = \sum_{j=1}^{n} a_{ij}x_j + y_i \quad (1)$$

In matrix terms,

$$\mathrm{X} = \mathrm{AX} + \mathrm{Y} \quad (2)$$

In equation (2), the total production X is given by the technical coefficient matrix A and the final demand Y. In this sense, for an open economy, we include the foreign relationship in equation (2)

$$X = AX + Y = A^D X + Y^D + A^F X + Y^F = A^D X + Y^D + E \quad (3)$$

In equation (3), the A^D and Y^D denotes the domestic technical coefficient matrix and the domestic final demand, respectively, and *E* encompasses all external intermediate and final transactions (Miller and Blair, 2009). Therefore, the input-output analyses that incorporate these foreign relationships are applied to matrices MRIO, which present data on the flows of goods and services traded between industries in different countries (Johnson and Noguera, 2012). In this sense, in the MRIO framework, the domestic technical coefficient A^D is a block diagonal matrix (*N x N*), represented by (*k*) countries and (*m*) industries, such that (*k x m = N*), as follows.

$$\mathbf{A}^{\mathrm{D}} = \begin{bmatrix} \mathbf{A}^{\mathrm{rr}} & 0 & \cdots & 0 \\ 0 & \mathbf{A}^{\mathrm{ss}} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \mathbf{A}^{\mathrm{kk}} \end{bmatrix}$$

Similarly, we can define the matrix (A^F) which refers to imported goods, for the components that are off diagonal, as follows.

$$\mathbf{A}^{\mathrm{F}} = \mathbf{A} - \mathbf{A}^{\mathrm{D}} = \begin{bmatrix} 0 & \mathbf{A}^{\mathrm{su}} & \cdots & \mathbf{A}^{\mathrm{st}} \\ \mathbf{A}^{\mathrm{us}} & 0 & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}^{\mathrm{ts}} & \cdots & \cdots & 0 \end{bmatrix}$$

The subscripts denote: (*s*) the country of origin, (*r*) the trading partner, and (*t*) third-party countries. Thus, we can obtain the domestic and global inverse matrix of Leontief as follows.

Domestic matrix: $L = (I - A^D)^{-1}$ (4)

Global matrix: $B = (I - A)^{-1}$ (5)

Following the methodology of Chen et al. (2021), by decomposing (A^D) and (A^F) , we could achieve the simultaneous decomposition of production into intermediate and final goods, as well as the localization of production and consumption. Thus, the value-added

(VA) incorporated into the production of countries can be defined using the VA estimation method (Johnson and Nogueira, 2012; Timmer et al., 2014).

$$\hat{V}\hat{Y} + \hat{V}A\hat{Y} + \hat{V}AA\hat{Y} + \cdots = \hat{V}(I + A + AA + \cdots)\hat{Y} = \hat{V}(I - A)^{-1}\hat{Y} = \hat{V}B\hat{Y} \quad (6)$$

In equation (6), $\hat{V}$ is a diagonalized matrix of the value-added coefficient vector, $\hat{Y}$ is a diagonalized matrix of the global final demand vector and B is the global inverse matrix of Leontief. Each element of the matrix ($\hat{V}B\hat{Y}$) represents the VA of an industry in its country of origin that is directly or indirectly involved in the production of final goods and services in a given country/industry. The sum of the row and column elements of the matrix represents the total VA of the sector (both direct and indirect) within the country, incorporated into the final products produced by industry (*i*) in the country (*k*).

The summation of rows and columns in this interaction provides: i) backward linkages: the column sum equals the value of final goods produced by industry (*j*) in the country (*r*), which reflects purchases made by this industry/country from another industry/country; and ii) forward linkages: the row sum equals the total value added imputed by industry (*i*) in country (*s*), demonstrating sales from this industry/country to another industry/country.

Further, this analysis is conducted in two steps. The first step involves replicating this methodological exercise to investigate the trade linkages between Brazil, the BRICS countries, and the rest of the world (ROW) in terms of value added. Once the value-added results are obtained, the second step translates this distribution into GHG emissions. For this, we consider the emissions coefficient as follows (Chen et al., 2021).

$$C = \{C_i^S\} = \left\{\frac{C_i^S}{X_i^S}\right\} \quad (7)$$

In matrix terms, we obtain the emissions coefficient matrix (*C*) about total output (*X*). By substituting the diagonal value-added coefficient matrix ($\hat{V}$) with the emissions coefficient matrix ($\hat{C}$) we can estimate GHG emissions resulting from sectoral interactions in the production of goods and services between the two countries. Applying the necessary substitutions, we derive:

$$\hat{\mathrm{C}}\mathrm{B}\hat{\mathrm{Y}} = \hat{\mathrm{C}}(\mathrm{I} - \mathrm{A})^{-1}\hat{\mathrm{Y}} \quad (8)$$

Finally, we calculated the backward and forward linkage metrics for the $\hat{\mathrm{C}}\mathrm{B}\hat{\mathrm{Y}}$ matrix, where the sum of the rows and columns indicates the sectoral GHG emissions that have been incorporated into interindustry buying and selling relationships between the two countries.

Therefore, the analysis enables the mapping of value-added and GHG emissions linked to the trade flows of goods and services between Brazil and the BRICS countries. This allows for an assessment of the economic and environmental impacts of international trade transactions.

4 DATABASE

The matrix analysis is conducted using the Exiobase Global Supply Chain database, a comprehensive dataset that provides a Multi-Regional Environmentally Extended Supply-Use Table (MR-SUT) and a Multi-regional input-output table (MR-IOT). Exiobase was developed by standardizing and refining supply-use tables for 44 countries and five ROW regions, along with estimating emissions and resource extraction across 50 economic sectors – descriptions of the sectors, production factors, and satellite accounts are in appendix A. These national tables were then interconnected through international trade, forming the MR-SUT and, subsequently, the MR-IOT. This framework facilitates the analysis of environmental impacts associated with the final consumption of various product groups.

A key feature of the database is the *Satellite Accounts* quadrant, which integrates non-monetary inputs into the production relationships of each sector, making Exiobase an MRIO model with social and environmental extensions. The data within the Satellite Accounts enable the estimation of GHG emissions linked to intersectoral and cross-country trade flows. It records emissions from primary GHG sources – carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) – using gigagrams (Gg) as the standard unit (1 Gg = 1 kiloton of CO_2 equivalent). This detailed structure and extensive coverage justify the selection of Exiobase for the present analysis. From these satellite accounts, it is possible to calculate the ($\hat{C}$) matrix, as described in the previous session, in which the emissions coefficients between Brazil and the four BRICS countries are calculated.

5 DISCUSSION OF RESULTS

5.1 Descriptive analysis of commercial relations between Brazil and BRICS in 2022

Before presenting the results of the matrix estimates, we provide a brief descriptive analysis of Brazil's total exports and imports with its BRICS partners in 2022. Subsequently, we examine the composition of this trade, an essential step for a more comprehensive understanding of the results obtained from the MRIO matrix.

Table 1 presents Brazil's total exports and imports to the four BRICS countries in 2022. China stands out as the dominant trade partner, accounting for 26.8% of Brazil's exports and 23.2% of its imports. The other three countries play a significantly smaller role in Brazilian trade. India ranked as the second-largest destination, receiving 1.9% of exports and supplying 3.3% of total imports. Russia followed with 0.6% of exports and 3.0% of imports, while South Africa accounted for 0.5% and 0.3%, respectively. The remaining countries outside the BRICS bloc collectively represented over 70% of Brazil's total trade in 2022.

TABLE 1
Total exports and imports between Brazil and the BRICS members (2022)

	2022		2022	
BRICS and ROW	Total exported (US$)	Total exported (%)	Total imported (US$)	Total imported (%)
China	89,718.9	26.8	67,767.8	23.2
India	6,340.5	1.9	9,602.1	3.3
Russia	1,973.6	0.6	8,630.0	3.0
South Africa	1,725.3	0.5	951.6	0.3
ROW	234,704.80	70.2%	205,392.16	70.3
Total	**334,463.08**	**100.0**	**292,343.73**	**100.0**

Source: World Integrated Trade Solution (WITS). Available at: https://wits.worldbank.org/reference-data.html.
Authors' elaboration.

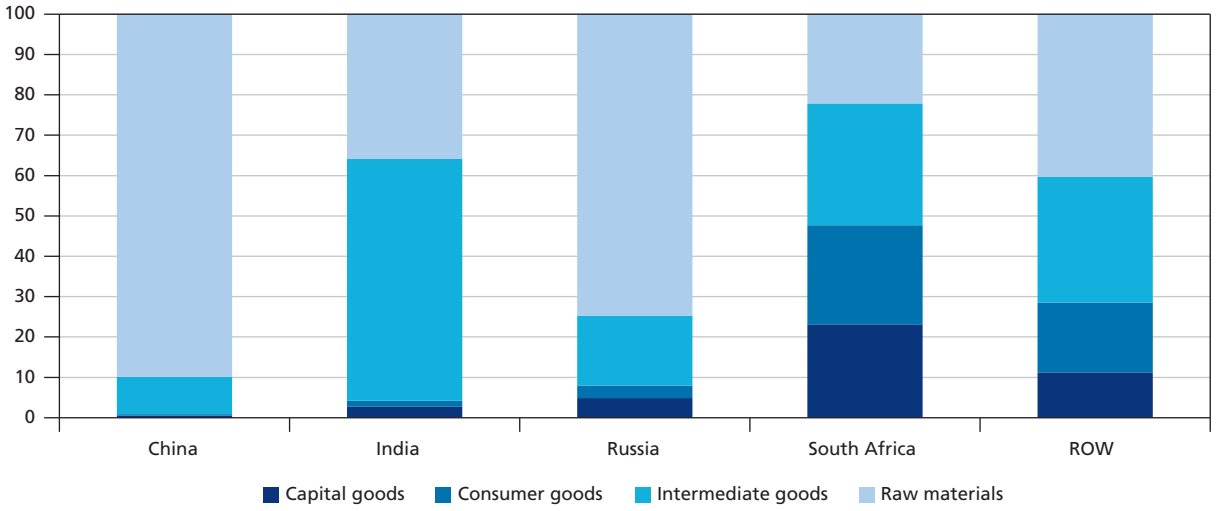
Figures 1 and 2 illustrate the sectoral composition of Brazil's exports and imports with BRICS partners. Exports to China were predominantly *raw materials*, making up 89.89% of total shipments, while imports from China were largely concentrated in *capital goods* (42.31%). Trade with India was characterized by a predominance of *intermediate goods*, representing approximately 59.93% of exports and 42.60% of imports. In transactions with Russia, *raw materials* constituted the bulk of Brazil's exports (74.73%), whereas *intermediate goods* dominated imports, comprising 75.21% of the total. Lastly, trade with South Africa exhibited a different pattern: *capital goods* accounted for 29.78% of Brazil's exports, while *raw materials* represented the largest share of imports (24.22%).[5]

5. The product classification can be found at https://wits.worldbank.org/referencedata.html.

FIGURE 1

Composition of total exports between Brazil and the BRICS members (2022)

(In %)

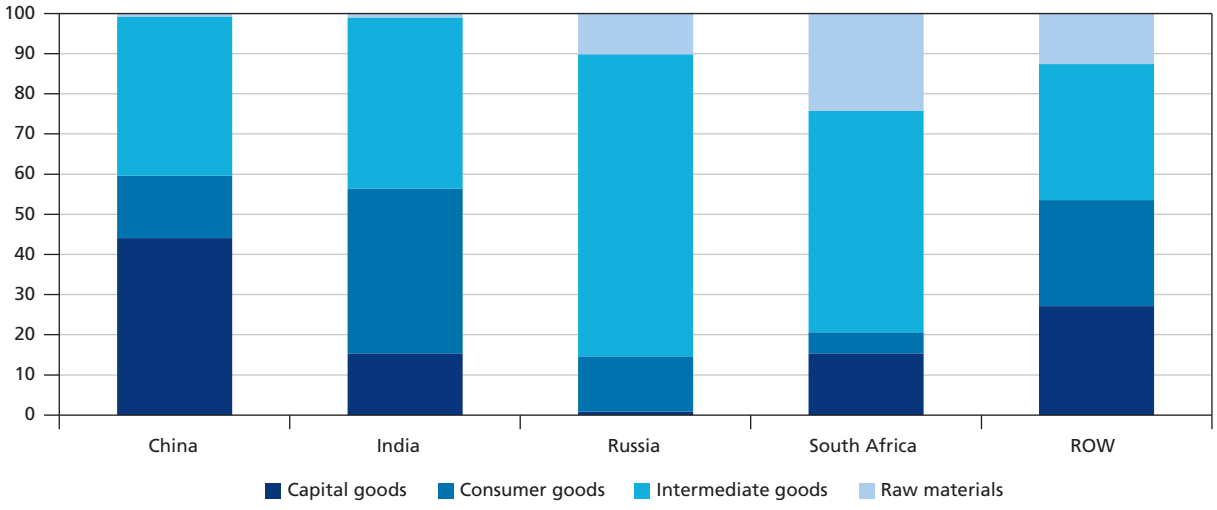


Source: WITS. Available at: https://wits.worldbank.org/referencedata.html.
Authors' elaboration.

FIGURE 2

Composition of total imports between Brazil and the BRICS members (2022)

(In %)



Source: WITS. Available at: https://wits.worldbank.org/referencedata.html.
Authors' elaboration.

The composition of Brazilian exports in 2022 reveals a striking characteristic: the persistent predominance of raw materials while capital goods remain a marginal share of total exports. This reinforces Brazil's structural reliance on primary commodity exports,

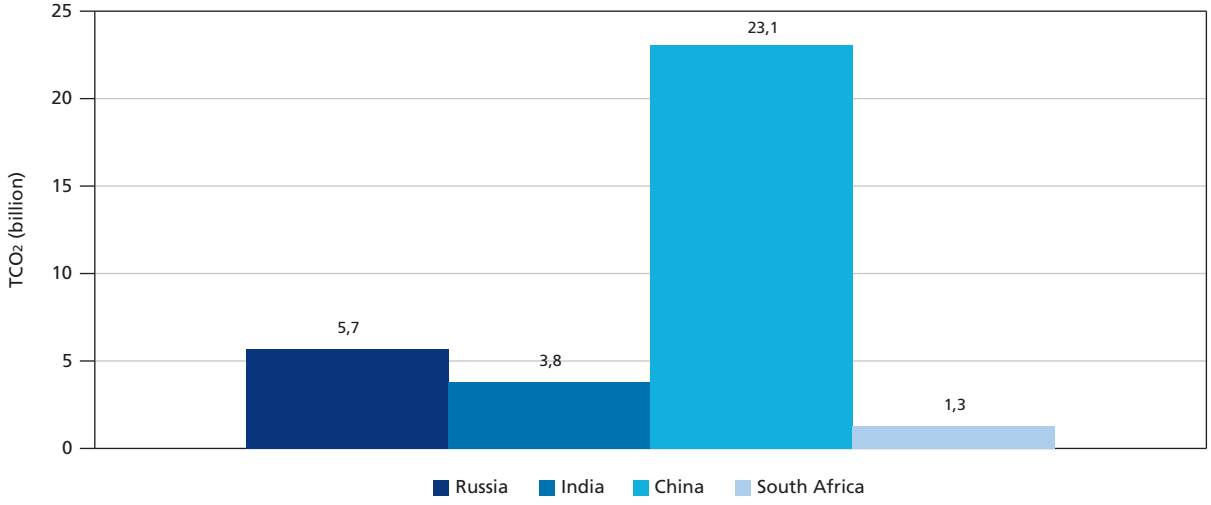
underscoring a pattern of specialization in low-value-added goods. In contrast, the import structure highlights the country's substantial dependence on external inputs for industrial production, with capital and intermediate goods making up a significant portion of total imports. Notably, imports of raw materials – especially from China – are relatively small, further emphasizing Brazil's role as a key supplier of primary products while maintaining high demand for industrial and technological inputs from abroad.

5.2 Results obtained from the estimation of the MRIO matrix

Having presented the overall values, the focus now shifts to the emissions embedded in trade flows, captured by the ($\hat{C}B\hat{Y}$) matrix between Brazil and the BRICS countries, considering changes in global demand. Similar to the ($\hat{V}B\widehat{Y}$) matrix, the total forward emissions distribution was obtained by summing the rows, representing emissions associated with Brazil's productive structure and sold both in the domestic market and through exports to BRICS countries. Conversely, summing the columns provided the total backward emissions distribution, corresponding to emissions embedded in the consumption of goods and services, that is, Brazil's imports from its BRICS trading partners.

As illustrated in figure 3, the forward distribution of emissions embedded in Brazilian exports to the BRICS is predominantly directed to China, amounting to 23.1 billion tons of CO_2 (TCO_2), followed by Russia with 5.7 billion TCO_2, India with 3.8 billion TCO_2, and South Africa with 1.3 billion TCO_2. The remaining 81.3 billion TCO_2 was allocated to ROW.

FIGURE 3
Total Brazilian emissions forward linkages destined for BRICS countries (2022)

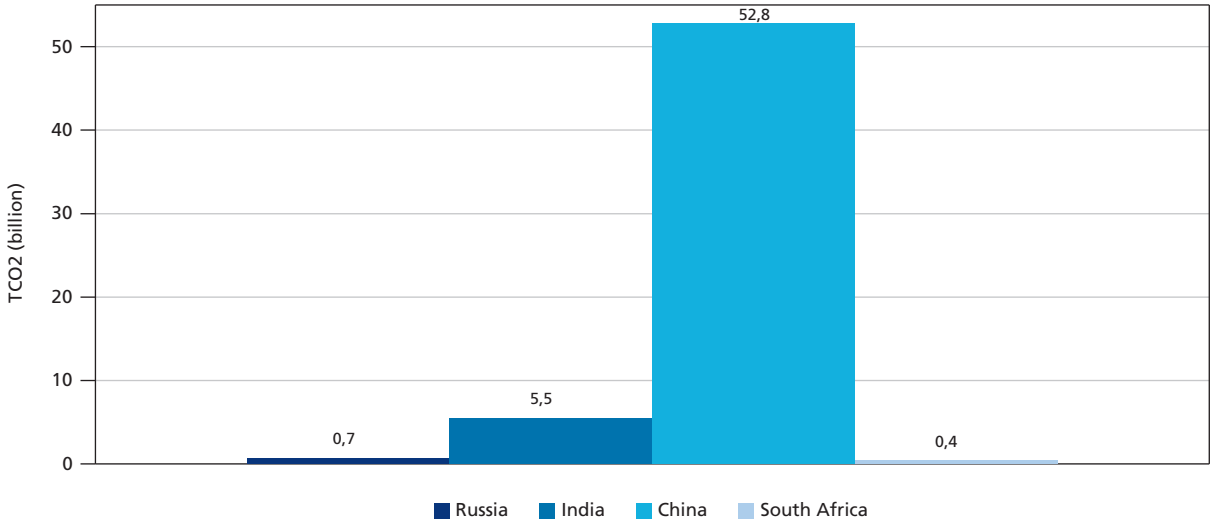


Source: Exiobase. Available at: https://zenodo.org/records/14614930.
Authors' elaboration.

Regarding emissions embedded in Brazilian production, figure 4 shows that China is the most significant source among the BRICS countries. In total, Brazil imported 52.8 billion TCO_2 from China, more than twice the amount it exported to the country. India ranked as the second-largest source, with approximately 5.5 billion TCO_2 imported. Russia and South Africa played a marginal role, contributing 0.7 billion TCO_2 and 0.4 billion TCO_2, respectively.

FIGURE 4

Total Brazilian emissions backward linkages destined for BRICS countries (2022)



Source: Exiobase. Available at: https://zenodo.org/records/14614930.
Authors' elaboration.

Table 2 presents the emissions export indicator between Brazil, the BRICS countries, and ROW. Among all countries and the ROW, Russia stands out with an emissions indicator of 4.3%, significantly higher than that of the other countries. India follows with a positive indicator of 1.4%, South Africa with 0.6%, and the ROW with 0.4%. In contrast, China displays a negative indicator of -6.8%, indicating that the emissions embedded in Brazilian exports to China are lower than the average emissions intensity of Brazil's total exports. In other words, China's consumption of Brazilian goods and services is relatively less emission-intensive compared to that of other trading partners.

TABLE 2
Emissions export indicator between Brazil, the BRICS countries and the ROW (2022)
(In %)

Countries	Forward linkages	Total export	Emissions indicator export
Russia	4.9	0.6	4.3
India	3.3	1.9	1.4
China	20.0	26.8	-6.8
South Africa	1.1	0.5	0.6
Rest of the world	70.6	70.2	0.4
Total	**100**	**100,0**	**–**

Source: Comex Stat. Available at: https://comexstat.mdic.gov.br/pt/geral; Exiobase. Available at: https://zenodo.org/records/14614930.
Authors' elaboration.

Concerning emissions embedded in imports, table 3 shows a reversal of this pattern. While the emissions import indicator is negative for almost all countries, China exhibits a positive value of 6.4%. This suggests that Brazil's consumption of Chinese goods is associated with a higher intensity of emissions than the average of Brazil's total imports. Once again, Russia is notable, showing a negative indicator of -2.6%, and the ROW records an even lower figure of -3.5%. India and South Africa also have negative values, although these are modest (-0.2% and -0.1%, respectively).

TABLE 3
Emissions import indicator between Brazil, the BRICS countries and the ROW (2022)
(In %)

Backward linkages	Total import	Emissions indicator import
0.4	3.0	-2.6
3.1	3.3	-0.2
29.6	23.2	6.4
0.2	0.3	-0.1
66.8	70.3	-3.5
100	100.0	–

Source: Comex Stat. Available at: https://comexstat.mdic.gov.br/pt/geral; Exiobase. Available at: https://zenodo.org/records/14614930.
Authors' elaboration.

It is important to note that, regarding Brazilian exports, the results may be influenced by limitations in MRIO databases in fully capturing emissions associated with deforestation and land-use change. Nevertheless, countries that import large volumes of raw materials from Brazil – such as Russia – still exhibit high emissions levels, reinforcing their carbon-intensive import profiles. In contrast, China, despite being a major importer of raw materials, presents a significantly negative emissions indicator.

With respect to emissions embedded in Brazilian imports, the results reflect the emission intensities of production processes in the exporting countries. Brazil imports a substantial share of capital goods from China, which are typically produced in sectors with high carbon intensity – particularly due to the fossil fuel-based energy sources used in Chinese manufacturing. The elevated emissions index associated with Chinese imports likely captures the carbon footprint embedded in these emissions-intensive global value chains. Conversely, Brazilian imports from Russia are concentrated in intermediate goods that may not be as emission-intensive. To further elucidate these trade patterns, the following section provides a disaggregated analysis of emissions by production sector.

5.3 Results obtained from the estimation of the MRIO matrix for the main sectors

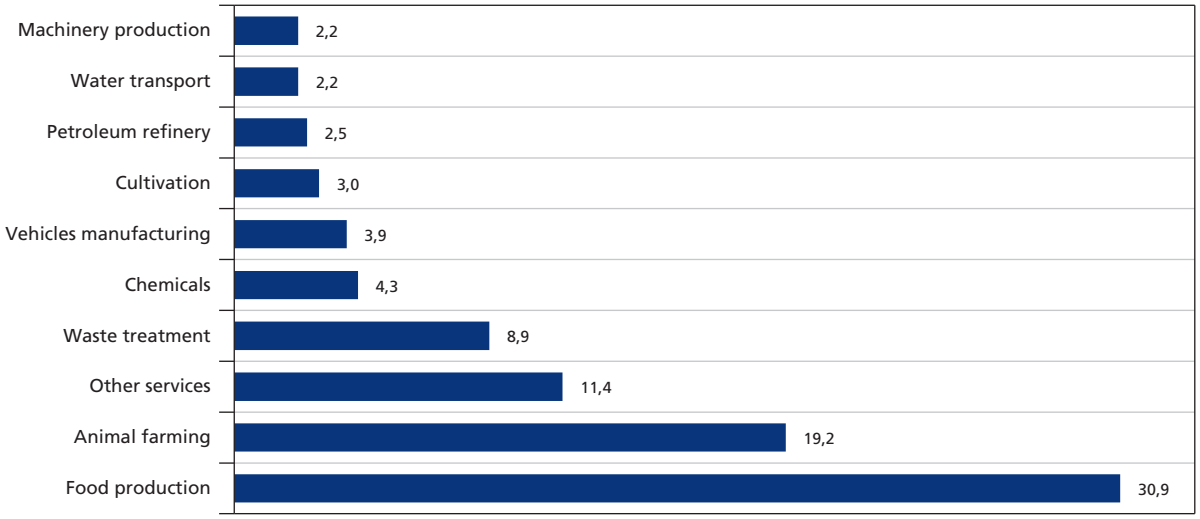
Figure 5 illustrates the sectoral distribution of total GHG emissions associated with forward linkages in 2022. The sector with the largest share of total emissions was Food Production, accounting for approximately 30.9% of total GHG emissions. This was followed by the Animal Farming sector with 19.2%, while Other Services, Waste Treatment, and Chemicals contributed 11.4%, 8.9%, and 4.3%, respectively. These results suggest that the main emitting sectors – those that supply both domestic consumption and export demand – are primarily linked to raw materials and intermediate goods.

Notably, *Food production* and *Animal farming* together were responsible for approximately 50% of total emissions. As highlighted in the previous section, this finding is even more significant considering the limitations of MRIO databases, which do not account for emissions resulting from deforestation and land-use change. This implies that actual emissions from these sectors could be higher than estimated.

It is important, however, to distinguish between emissions generated for domestic consumption and those embodied in exports. When focusing exclusively on emissions allocated to foreign markets, the ranking of the most emission-intensive sectors shifts. This is because the sectors with the highest overall emissions often allocate a

considerable portion of their output to the domestic market. For example, in the case of Food production, approximately 95.3% of its total emissions are linked to domestic consumption, thereby reducing its relative contribution to export-related emissions.

FIGURE 5
Total share of Brazilian emissions embodied by forward linkages by main sectors (2022)
(In %)



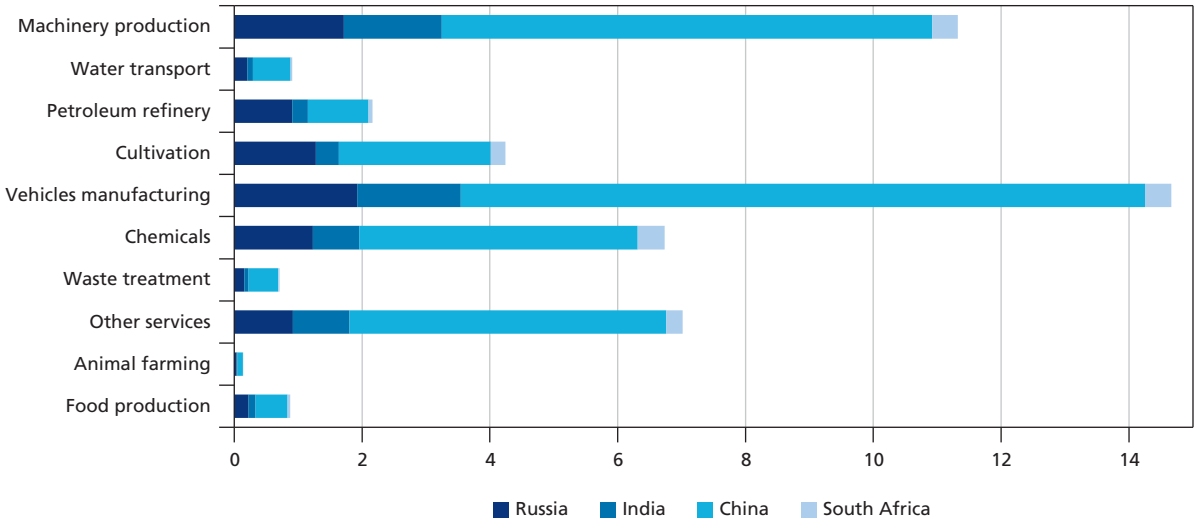
Source: Exiobase. Available at: https://zenodo.org/records/14614930.
Authors' elaboration.

A more detailed analysis by country, as shown in figure 6, reveals that emission exports to BRICS countries were predominantly concentrated in Vehicle Manufacturing and Machinery production, both part of the capital goods category. Although this sector is less carbon-intensive than chemicals, the production of electrical equipment and machinery still generates significant GHG emissions, particularly when the energy matrix relies on fossil fuels (Carneiro, 2012).

China and India also stand out in the other services sector, which encompasses a wide range of activities not directly linked to the production of tangible goods. This includes agriculture, mining, and other extractive industries, all of which are associated with high emission levels. Additionally, the chemical sector – classified under raw materials – holds substantial weight among the BRICS countries. This sector is characterized by elevated GHG emissions, both from production and from the supply of inputs to other industries. Consequently, forward linkages in these sectors contribute to a broad dispersion of emissions across production chains, affecting multiple economic segments dependent on these inputs (Carneiro, 2012).

Moreover, the Cultivation sector plays a significant role, particularly in Russia and China, as it falls within the raw materials category – one of the highest-emitting sectors in Brazil's production structure. This underscores the importance of agriculture-related emissions in Brazil's trade with its BRICS partners, reinforcing the country's reliance on emission-intensive primary production.

FIGURE 6
Total share of Brazilian issuances incorporated by forward linkages by main sectors and BRICS countries (2022)
(In %)



Source: Exiobase. Available at: https://zenodo.org/records/14614930.
Authors' elaboration.

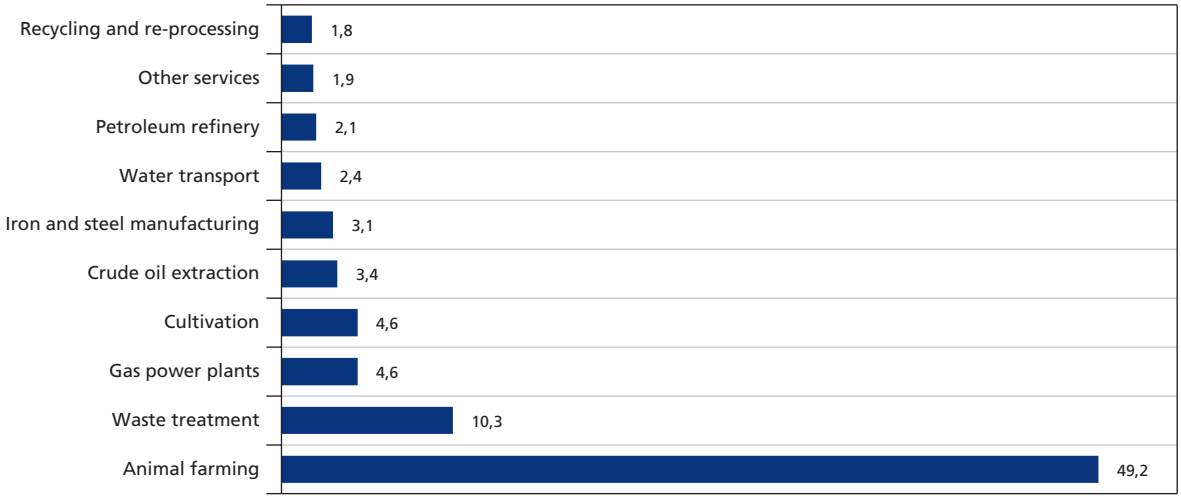
Turning now to backward linkages, figure 7 presents the sectoral distribution of total emissions for this category in 2022. When analyzing the emissions embedded in the Brazilian production process, the Animal farming sector once again stands out. Among the 50 sectors examined, it accounted for 49.2% of total GHG emissions, followed by waste treatment (10.3%), gas power plants (4.6%), and cultivation (4.6%).

These findings indicate that the largest share of imported emissions is concentrated in productive sectors linked to raw materials and capital goods. This pattern reflects Brazil's strong dependence on emission-intensive inputs, particularly from sectors associated with agriculture, energy production, and industrial processes.

FIGURE 7

Total share of Brazilian emissions embodied by backward linkages by main sectors (2022)

(In %)



Source: Exiobase. Available at: https://zenodo.org/records/14614930.
Authors' elaboration.

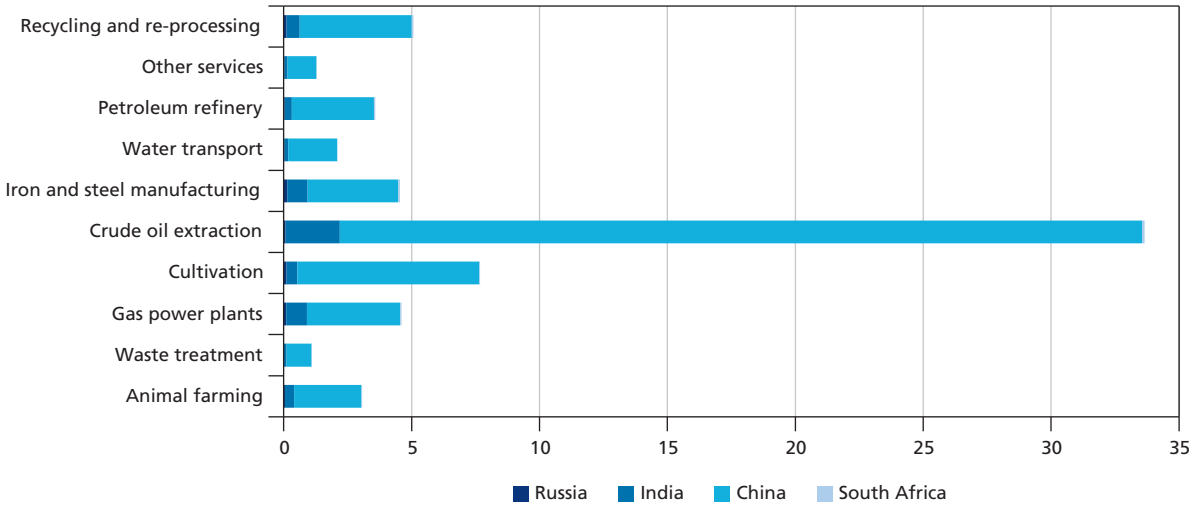
Figure 8 highlights China's dominant role in the total imports of key sectors in the Brazilian economy. In the Crude oil extraction sector, China accounts for 31.37% of embodied emissions. The country also stands out in the Cultivation sector, representing 7.11% of emissions. Additionally, China is a major exporter of petroleum derivatives, chemicals for fertilizers, plastics, and construction materials to Brazil, all of which are highly emissions-intensive (Losekann and Tavares, 2021; Oliveira, Ribeiro and Carvalho, 2020). Furthermore, Brazil imports capital goods such as drilling platforms, pipelines, and specialized machinery for oil extraction and transportation. In the cultivation sector, agricultural machinery and fertilizers are key imported goods.

India also plays a relevant role, particularly in the crude oil extraction sector, accounting for 2.12% of Brazil's total emissions imports, followed by gas power plants (0.81%). The country is home to some of the world's largest oil refineries and exports refined petroleum products, chemicals, and fertilizers to Brazil. India also supplies turbines, generators, and industrial valves, which are essential for Brazil's gas-fired power plants (Losekann and Tavares, 2021; Oliveira, Ribeiro and Carvalho, 2020). Additionally, like China, India's mining sector is highly carbon-intensive, relying heavily on coal for electricity generation and industrial processes.

Russia appears in backward linkages as a relevant source of embodied emissions in the iron and steel manufacturing (0.14%) and cultivation (0.11%) sectors. As one of the world's largest steel producers, Russia exports steel bars, sheets, and semi-finished products to Brazil. In the Cultivation sector, fertilizers play a crucial role, as Russia is Brazil's main supplier. Fertilizer production can be GHG-intensive, particularly due to the reliance on natural gas for the synthesis of ammonia, a key input in nitrogen-based fertilizers (Losekann and Tavares, 2021; Oliveira, Ribeiro and Carvalho, 2020). However, the value of emissions transferred to Brazil in this sector was insignificant.

Finally, although South Africa's trade relationship with Brazil plays a minor role compared to the other three BRICS countries, its exports to Brazil are concentrated in the Chemical sector. South Africa supplies chemical products and fertilizers, contributing to embodied emissions due to its coal-intensive energy matrix (Brasil, 2022).

FIGURE 8
Total share of Brazilian issuances incorporated by backward linkages by main sectors and BRICS countries (2022)
(In %)



Source: Exiobase. Available at: https://zenodo.org/records/14614930.
Authors' elaboration.

6 FINAL CONSIDERATIONS

Given the high trade volume between Brazil and China, it is not surprising that China emerges as both the largest source of GHG emissions embodied in Brazilian imports and the main destination for emissions embedded in Brazilian exports. In 2022, China absorbed approximately 23.1 million tons of CO_2 from Brazilian exports, followed by

Russia (5.7 million), India (3.8 million), and South Africa (1.3 million tons of CO_2). On the import side, Brazilian purchases from China embodied 52.8 million tons of CO_2 – more than twice the emissions exported to that country – followed by India (5.5 million), Russia (0.68 million), and South Africa (0.37 million tons of CO_2).

However, when considering the emissions indicator – which measures the relative difference between trade volume and emissions – China displays a negative value for Brazilian exports. This suggests that, relative to trade volume, exports to China are less emission-intensive. Conversely, Brazilian imports from China show a positive emissions index, reflecting a higher carbon intensity, likely due to Brazil's strong dependence on Chinese capital and intermediate goods with energy-intensive production processes. Russia presents the inverse pattern: a positive index for Brazilian exports and a negative one for imports, indicating that Brazil exports more emissions to Russia than it imports. Although less expressive in magnitude, the emissions indices for India and South Africa follow a similar pattern to Russia's. In both cases, Brazil tends to export more emissions than it imports, suggesting that the composition of Brazilian exports to these partners is more carbon-intensive than the goods received in return.

Sectoral analysis reveals that emissions associated with Brazilian exports are concentrated in raw materials sectors, particularly food production and animal farming. In contrast, Brazilian imports are characterized by emission-intensive intermediate and capital goods, such as machinery, equipment, and chemicals. Other relevant sectors include crude oil extraction, agriculture, and waste treatment, which also contribute significantly to emissions embedded throughout global value chains.

These findings highlight the pressing need for decarbonization strategies that address both export dynamics and the structural characteristics of the national production system. The continued centrality of primary sectors in Brazil's emissions profile underscores the importance of fostering sustainable production practices, investing in low-carbon technologies, and promoting industrial diversification. Furthermore, enhanced cooperation within the BRICS group could serve as a strategic platform for developing shared solutions, particularly in areas such as energy transition and emission reduction across supply chains.

Nonetheless, some limitations should be acknowledged. The MRIO methodology does not capture emissions from land-use change and deforestation, which are particularly relevant in the Brazilian context and may lead to an underestimation of the country's environmental footprint in trade. Moreover, the limited temporal coverage and disaggregation of international databases constrain the ability to assess recent shifts in global trade. Future research should incorporate more updated data and expand the analysis to include other major trading partners and regions – such as the United States, the European Union, Mercosur, and key Asian economies. Additionally, further

studies could benefit from applying structural decomposition analysis, as suggested by Barcelos and Costa (2024), to unpack the underlying drivers of trade-related emissions.

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APPENDIX A

TABLE A.1

Classification of 50 industries, factor of production and satellite account

Account	Description	Unit
Sector	Cultivation	M EUR
Sector	Animal farming	M EUR
Sector	Recycling and re-processing	M EUR
Sector	Forestry and logging	M EUR
Sector	Coal mining	M EUR
Sector	Crude oil extraction	M EUR
Sector	Natural gas extraction	M EUR
Sector	Natural gas liquefaction	M EUR
Sector	Uranium mining	M EUR
Sector	Non-ferrous metal ores mining	M EUR
Sector	Stone and minerals mining	M EUR
Sector	Food production	M EUR
Sector	Textiles manufacturing	M EUR
Sector	Wood production	M EUR
Sector	Paper and pulp production	M EUR
Sector	Coal refinery	M EUR
Sector	Petroleum refinery	M EUR
Sector	Nuclear fuel process	M EUR
Sector	Plastics production	M EUR
Sector	Chemicals	M EUR
Sector	Non-metallic minerals manufacturing	M EUR
Sector	Cement manufacturing	M EUR
Sector	Iron and steel manufacturing	M EUR
Sector	Non-ferrous metals manufacturing	M EUR
Sector	Metals manufacturing	M EUR
Sector	Machinery production	M EUR
Sector	Electronics and electrical manufacturing	M EUR

(Continues)

(Continued)

Account	Description	Unit
Sector	Vehicles manufacturing	M EUR
Sector	Other manufacturing	M EUR
Sector	Coal power plants	M EUR
Sector	Gas power plants	M EUR
Sector	Nuclear power plants	M EUR
Sector	Hydroelectric power plants	M EUR
Sector	Wind farms	M EUR
Sector	Oil power plants	M EUR
Sector	Biomass and waste power plants	M EUR
Sector	Solar power plants	M EUR
Sector	Other renewables power plants	M EUR
Sector	Electricity grid	M EUR
Sector	Gas refinery	M EUR
Sector	Gas distribution network	M EUR
Sector	Steam and hot water supply	M EUR
Sector	Other services	M EUR
Sector	Construction	M EUR
Sector	Railway transport	M EUR
Sector	Road transport	M EUR
Sector	Pipeline transport	M EUR
Sector	Water transport	M EUR
Sector	Air transport	M EUR
Sector	c	M EUR
Factor of production	Value-added	M EUR
Satellite account	CO2	Kg
Satellite account	CH4	Kg
Satellite account	N2O	Kg

Source: Exiobase. Available at: https://zenodo.org/records/14614930.

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