INTERNATIONAL TRADE AND GREENHOUSE GAS EMISSION PATTERNS BETWEEN BRAZIL AND THE ORIGINAL BRICS COUNTRIES[1]

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The objective of this study was to estimate the 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 EXIOBASE data, the emissions indicator reveals that China is the primary source of emissions embedded in Brazilian imports. At the same time, Russia records the highest emissions indicator among the destinations of Brazilian exports, indicating a greater emissions intensity relative to trade volume. The results show that China was the main destination for Brazilian exports, absorbing approximately 23.1 million tons of CO_2. It also accounted for the largest share of emissions embedded in Brazil's imports, with around 52.8 million tons of TCO_2, an outcome consistent with the trade volume between the two countries. The indicator analysis shows that, for exports, Russia (4.3%), India (1.4%), and South Africa (0.6%) present positive values, while China (-6.8%) has an emissions intensity lower than the average for Brazilian exports. In the case of imports, the pattern is reversed: only China presents a positive value (6.4%), indicating a higher emissions intensity than the average, while Russia (-2.6%), India (-0.2%), South Africa (-0.1%), and the rest of the world (-3.5%) record negative values. Emissions associated with exports were mainly concentrated in sectors such as food production and animal farming, whereas imports were dominated by intermediate and capital goods with high emissions intensity.

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

COMÉRCIO INTERNACIONAL E PADRÕES DE EMISSÃO DE GASES DE EFEITO ESTUFA ENTRE O BRASIL E OS PAÍSES ORIGINAIS DO BRICS

O objetivo deste artigo foi estimar as emissões de gases de efeito estufa (GEE) incorporadas no comércio entre o Brasil e os países originais do BRICS (China, Índia, Rússia e África do Sul) para o ano de 2022. Com base em dados da EXIOBASE, o indicador de emissões revela que a China é a principal fonte de emissões incorporadas nas importações brasileiras. Ao mesmo tempo, a Rússia

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apresenta o maior indicador de emissões entre os destinos das exportações brasileiras, indicando uma maior intensidade de emissões em relação ao volume comercial. Os resultados mostram que a China foi o principal destino das exportações brasileiras, absorvendo aproximadamente 23,1 milhões de toneladas de CO_2. Também representou a maior parcela das emissões incorporadas nas importações do Brasil, com cerca de 52,8 milhões de toneladas de TCO_2, resultado alinhado ao volume comercial entre os dois países. A análise dos indicadores evidencia que, nas exportações, Rússia (4,3%), Índia (1,4%) e África do Sul (0,6%) apresentam valores positivos, enquanto a China (-6,8%) possui intensidade de emissões inferior à média das exportações brasileiras. No caso das importações, o padrão se inverte: apenas a China apresenta valor positivo (6,4%), indicando maior intensidade de emissões que a média, ao passo que Rússia (-2,6%), Índia (-0,2%), África do Sul (-0,1%) e o restante do mundo (-3,5%) registram valores negativos. As emissões associadas às exportações concentraram-se principalmente em setores como produção de alimentos e pecuária, enquanto as importações foram dominadas por bens intermediários e de capital com alta intensidade de emissões.

Palavras-chave: análise insumo-produto; emissões de gases de efeito estufa; BRICS; comércio internacional; intensidade de emissões.

COMERCIO INTERNACIONAL Y PATRONES DE EMISIONES DE GASES DE EFECTO INVERNADERO ENTRE BRASIL Y LOS PAÍSES BRICS ORIGINALES

El objetivo de este estudio fue estimar las emisiones de gases de efecto invernadero (GEI) incorporadas en el comercio entre Brasil y los países originales del BRICS (China, India, Rusia y Sudáfrica) para el año 2022. Con base en datos de EXIOBASE, el indicador de emisiones revela que China es la principal fuente de emisiones incorporadas en las importaciones brasileñas. A su vez, Rusia presenta el mayor indicador entre los destinos de las exportaciones brasileñas, lo que indica una mayor intensidad de emisiones en relación con el volumen comercial. Los resultados muestran que China fue el principal destino de las exportaciones brasileñas, absorbiendo aproximadamente 23,1 millones de toneladas de CO_2, y también representó la mayor parte de las emisiones incorporadas en las importaciones de Brasil, con cerca de 52,8 millones de toneladas de TCO_2, resultado coherente con el volumen comercial entre ambos países. El análisis de los indicadores evidencia que, en las exportaciones, Rusia (4,3%), India (1,4%) y Sudáfrica (0,6%) presentan valores positivos, mientras que China (-6,8%) tiene una intensidad inferior al promedio de las exportaciones brasileñas. En las importaciones, el patrón se invierte: solo China presenta valor positivo (6,4%), indicando mayor intensidad que el promedio, mientras que Rusia (-2,6%), India (-0,2%), Sudáfrica (-0,1%) y el resto del mundo (-3,5%) registran valores negativos. Las emisiones asociadas a las exportaciones se concentraron principalmente en sectores como producción de alimentos y ganadería, mientras que las importaciones estuvieron dominadas por bienes intermedios y de capital con alta intensidad de emisiones y relevancia estratégica.

Palabras clave: análisis de insumo-producto; emisiones de gases de efecto invernadero; BRICS; comercio internacional; intensidad de emisiones.

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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 the integration of 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.

The extent to which emissions embedded in trade affect different countries is highly asymmetrical, influenced by variations in trade patterns, productive structures, and technological development (Caro et al., 2015; Afionis et al., 2017). Research by Meng et al. (2018), Wu et al. (2020), and Liu, Lackner and Fan (2021) highlights the regional disparities in the economic and environmental consequences of international trade. Moreover, the literature underscores the relationship between pollution levels, economic growth, and institutional frameworks, demonstrating that lower-income regions tend to become "pollution havens," where environmentally harmful activities concentrate (Cole and Elliott, 2003; Duan, Ji and Yu, 2021). Conversely, as Nunes et al. (2023) argue, international trade can also foster opportunities for external financing of climate mitigation projects, including investments in renewable energy within developing economies.

In this context, 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 GDP and 21% of international trade, consolidating their role as key players in the world economy. This economic expansion, however, has been accompanied by rising GHG emissions, with all five nations ranking among the world's top 20 emitters (UNCTAD, 2023).

In preparation for, Brazil is set to host the United Nations Climate Change Conference (COP30) in 2025, when countries are required to submit new Nationally Determined Contributions (NDCs) with mitigation targets for 2035 to uphold the Paris Agreement's objective of limiting global warming to 1.5 °C. Achieving this pathway necessitates a reduction in global emissions by 42% by 2030 and 57% by 2035, culminating in net-zero emissions by 2050 (IPCC, 2024). The IPCC report (2024) stresses that ambitious targets alone are insufficient without concrete implementation measures; if emissions remain at current policy projections for 2030, meeting the Paris goals or even limiting warming to 2 °C will be unfeasible.

Given these challenges, the accelerating pace of climate change demands a coordinated global response aligned with the Paris Agreement and the

Sustainable Development Goals (SDGs). Nonetheless, unilateral measures adopted by developed economies, such as the European Union's Carbon Border Adjustment Mechanism (CBAM), pose additional obstacles for emerging economies. By imposing tariffs based on the carbon content of goods exported to the EU, the CBAM risks undermining the growth prospects of BRICS countries, thereby adding complexity to their economic and environmental strategies (Thorstensen et al., 2023).

Within this framework, the present study seeks to quantify the total GHG emissions embedded in Brazil's trade flows with the other four original BRICS countries. Given the bloc's economic significance and the member states' commitments to emission reductions, a detailed understanding of the volume and sectoral composition of these emissions is critical for informing public policies. This is particularly relevant in light of the recent BRICS expansion, which in 2023 welcomed five new members (Saudi Arabia, the United Arab Emirates, Egypt, Ethiopia, and Iran) and further strengthened in 2025 with Indonesia's accession, thereby broadening cooperation opportunities.

To achieve this aim, we employ an emissions decomposition analysis that maps 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 utilize data from the environmentally extended multiregional input-output model EXIOBASE (EE MRIO) to estimate emissions embedded in trade flows between Brazil (BRA), China (CHN), India (IND), Russia (RUS), South Africa (ZAF), and the rest of the world (ROW) for the year 2022. This approach enables a detailed sectoral examination of emissions trade relations, allowing for a precise analysis of the origin and destination of Brazil's emissions within the BRICS trade network.

Furthermore, EXIOBASE offers the most recent (2022) and comprehensive database available among input-output models. While the full EXIOBASE database contains a highly detailed classification of around 200 sectors, for practical analytical purposes, it is commonly aggregated into approximately 50 sectors. Thus, providing a more granular sectoral breakdown compared to the 26 sectors available in the free version of Eora. It is important to note that the six new BRICS members were excluded from this analysis, as their accession occurred only after 2022.

Over the past two decades, trade relations between Brazil and the original BRICS countries have undergone significant structural transformations. China's emergence as Brazil's primary trading partner, alongside strengthened commodity trade ties with India and Russia, has been influenced by geopolitical shifts, including the consolidation of South-South alliances, and by international crises

that have reshaped trade flows, such as the 2008 global recession, the COVID-19 pandemic, and, more recently, the economic impacts of the Russia-Ukraine conflict (Pennaforte and Luigi, 2020; Mendonça et al., 2025). In this light, the year 2022 is particularly emblematic for analysis, marking both the gradual recovery of international trade post-pandemic and the intensification of debates concerning energy security, transitions to low-carbon economies, and global supply chain reconfigurations.

The structure of this study consists of five sections, including this introduction. The second section provides a review of related literature, followed by the third section detailing the methodology and database. The fourth section presents and discusses the results, divided into two parts: first, a descriptive analysis of trade relations between Brazil and the BRICS countries in 2022; second, the outcomes derived from the MRIO matrix estimation. The final section offers concluding remarks.

2 LITERATURE RELATED

Estimating emissions through a multiregional input-output (MRIO) matrix offers a robust methodology capable of capturing the complex and simultaneous interactions between 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 – a phenomenon whereby stringent environmental regulations in one country lead 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 transfer of emissions to countries with less stringent environmental regulations can undermine global efforts to mitigate climate change.

Su et al. (2021) explore spatial aggregation issues in MRIO analyses of regional emissions and intensities by linking regional and global datasets. Their empirical analysis of 30 Chinese regions and 43 countries for 2007 and 2012 examines four spatial aggregation schemes, revealing that aggregation affects sectoral outcomes more significantly than regional ones, with important implications for the accuracy of embedded emissions assessments in regional emission studies.

Building on these methodological advances, studies focusing on Brazil and China have applied the MRIO framework to examine the relationship between international trade within global value chains (GVCs) and greenhouse gas (GHG) emissions. Barcelos and Costa (2024) found that Chinese emissions are predominantly associated with energy generation and energy-intensive industries, reflecting the country's heavy reliance on fossil fuels to sustain industrial growth. In contrast, Brazilian territorial emissions mainly originate from the service sector and traditional industries, underscoring the need to improve energy efficiency in key sectors of the Brazilian economy. Similarly, Zhang et al. (2019) analyzed trade-related emissions between BRICS (original formation) and non-BRICS countries, identifying that most emissions embedded within the BRICS group were associated with intermediate goods rather than final demand. China emerged as the dominant player in traded emissions, acting as a key intermediary by facilitating the transfer of emissions embedded in Russian exports to other BRICS countries and driving significant inflows from major economies outside the bloc.

Complementing these findings, Boitier (2012) 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 better understand the drivers of carbon flows in international trade, Xu and Li (2012) developed a novel structural decomposition analysis (SDA) method based on the MRIO model that incorporates production emissions, revealing substantial increases in embedded emissions: EEE rose by 207% in China and 125% in India, while EEI surged by 330% and 338% for these countries, respectively, over the same period.

The main contribution of MRIO models lies in providing a comprehensive understanding of new patterns in international trade. Analyzing only gross export data can omit crucial information regarding countries' domestic production capacities (Wang, Wei, and Zhu, 2013). Nevertheless, some MRIO databases, such as EXIOBASE, Eora (Casella et al., 2019), and ICIO (OECD, 2023), are limited to accounting for flow emissions (i.e., emissions generated during production and trade flows) and do not incorporate stock emissions, which refer to accumulated emissions from land-use changes and deforestation. This omission is particularly relevant for countries like Brazil, where land-use change and deforestation accounted for 48% of total emissions in 2022 (Observatório do Clima, 2022). Despite this limitation, the MRIO model remains a highly appropriate tool, providing a solid methodological framework and sufficient data to support the analysis of GHG emissions generated and embedded in international trade relations – an essential contribution in the context of the current climate crisis.

Despite the extensive body of research employing MRIO models to assess emissions embedded in international trade, significant gaps remain, particularly regarding a comprehensive integrated analysis of both greenhouse gas (GHG) emissions and value-added flows within BRICS economies. Previous studies have predominantly focused on estimating emissions flows at the global, national, or regional scales, as demonstrated by Miller and Blair (2009), Sato (2014), Zhang et al. (2017), and Su et al. (2021). These investigations have advanced the methodological framework and shed light on phenomena such as carbon leakage and spatial aggregation. Meanwhile, Barcelos and Costa (2024), Zhang et al. (2019), Boitier (2012), and Xu and Li (2012) have provided detailed insights into sectoral emissions and trade dynamics within the BRICS, emphasizing energy-intensive industries and interregional emission transfers.

However, few analyses have concentrated on the sectoral breakdown of emissions embedded specifically in intra-BRICS trade relations, coupled with an evaluation of their economic implications through value-added components. This study contributes to filling this gap by conducting a detailed sectoral analysis of GHG emissions incorporated in Brazil's trade flows with other BRICS countries, explicitly integrating the value-added dimension within the MRIO framework. By doing so, it offers a more nuanced picture of the environmental and economic interdependencies that characterize the BRICS trade network, which is essential for informing targeted policies on climate mitigation and sustainable economic development within the bloc.

3 METHODOLOGY AND DATABASE

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

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

In matrix terms,

$$X = AX + Y \tag{2}$$

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

$$X = AX + Y = A^D X + Y^D + A^F X + Y^F = A^D X + Y^D + E \tag{3}$$

where 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 multi-regional input-output 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 described below:

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

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

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

where 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 value-added estimation method (Johnson and Nogueira, 2012; Timmer et al., 2013):

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

where $\hat{V}$ 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:

1) 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.

2) 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 greenhouse gas (GHG) emissions. For this, we consider the following emissions coefficient (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:

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

Finally, we calculated the backward and forward linkage metrics for the $\hat{C}B\hat{Y}$ 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.

3.2 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 Rest of the World 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 greenhouse gas (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.

The choice of the EXIOBASE database is justified by its high level of sectoral disaggregation and the recent data update through 2022, which ensures greater proximity to the post-pandemic economic and production reality. Unlike other databases, such as Eora or ICIO, EXIOBASE integrates environmental satellite accounts in detail, allowing it to capture emissions associated not only with direct production but also with intermediate inputs along global value chains. However, it is recognized that this methodology does not include stock emissions, such as those from land-use changes and deforestation – a factor particularly relevant for Brazil, given the magnitude of these sources in its emissions matrix. Another limitation concerns regional aggregation: smaller countries or those with a low share of global trade are incorporated into "rest of the world" categories, which can smooth out significant heterogeneities in the emissions profile.

4 DISCUSSION OF RESULTS

4.1 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.

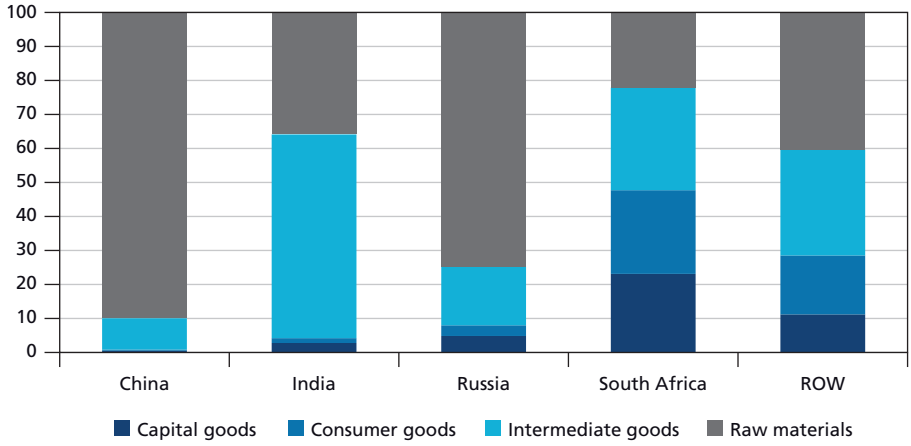
TABLE 1
Total exports and imports between Brazil and the BRICS members in 2022

BRICS and ROW	Total exported (US$ millions)	Total exported (%)	Total imported (US$ millions)	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: WITS (2024).
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%).[6]

FIGURE 1
Composition of total exports between Brazil and the BRICS members in 2022
(In %)

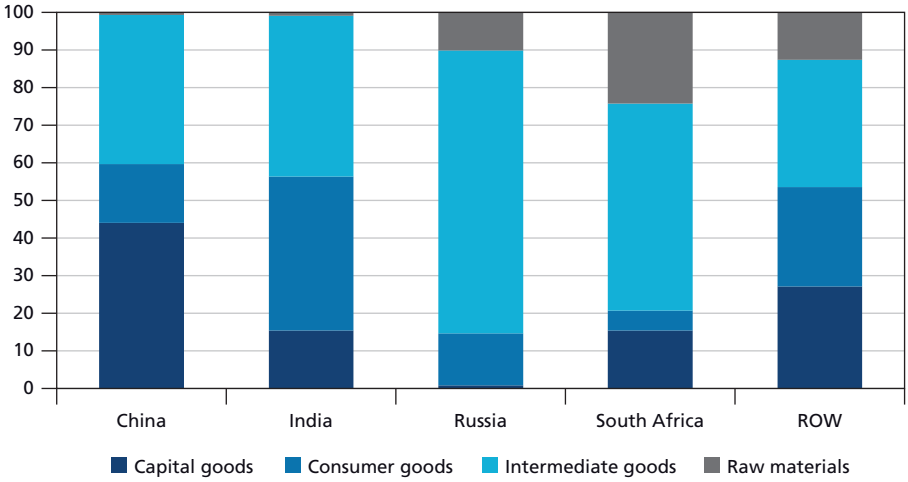


Source: WITS (2024).
Authors' elaboration.

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.

6. The product classification can be found in: https://wits.worldbank.org/referencedata.html.

FIGURE 2
Composition of total imports between Brazil and the BRICS members in 2022
(In %)



Source: WITS (2024).
Authors' elaboration.

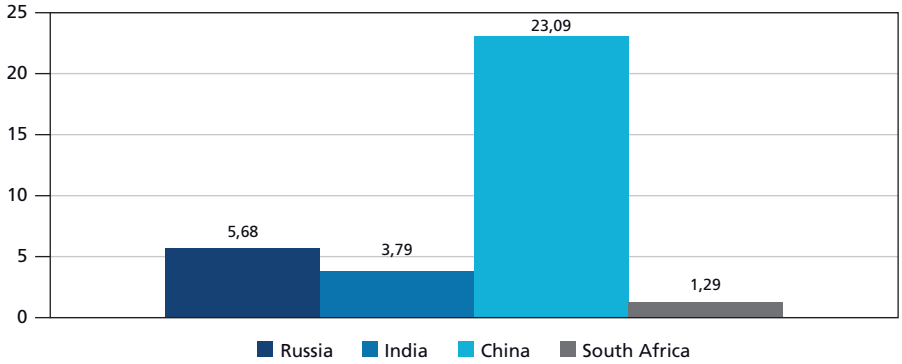
4.2 Results obtained from the estimation of the MRIO matrix.

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 $(\hat{V}\widehat{BY})$ 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 the rest of the world (ROW).

FIGURE 3

Total Brazilian emissions forward linkages destined for BRICS countries in 2022
(In TCO_2 billion)

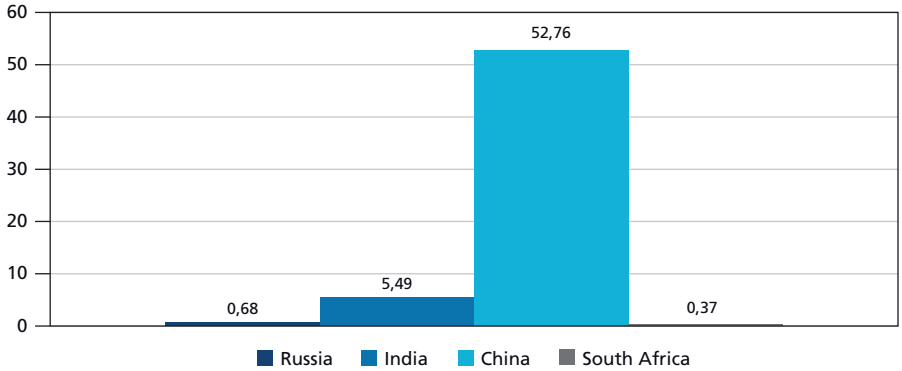


Source: EXIOBASE (2025).
Authors' elaboration.

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 in 2022
(In TCO_2 billion)



Source: EXIOBASE (2025).
Authors' elaboration.

Table 2 presents the emissions export indicator between Brazil, the BRICS countries, and the 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 World	70,6	70,2	0,4
Total	**100**	**100,0**	**-**

Source: Comex Stat (2025); EXIOBASE (2025).
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 (2025); EXIOBASE (2025).
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.

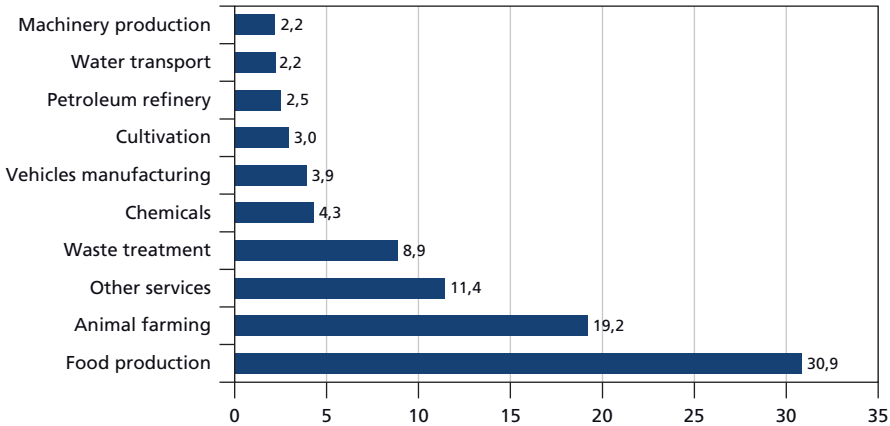
4.2 Results obtained from the estimation of the MRIO matrix for the main sectors

Figure 5 illustrates the sectoral distribution of total greenhouse gas (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 in 2022 by main sectors
(In %)



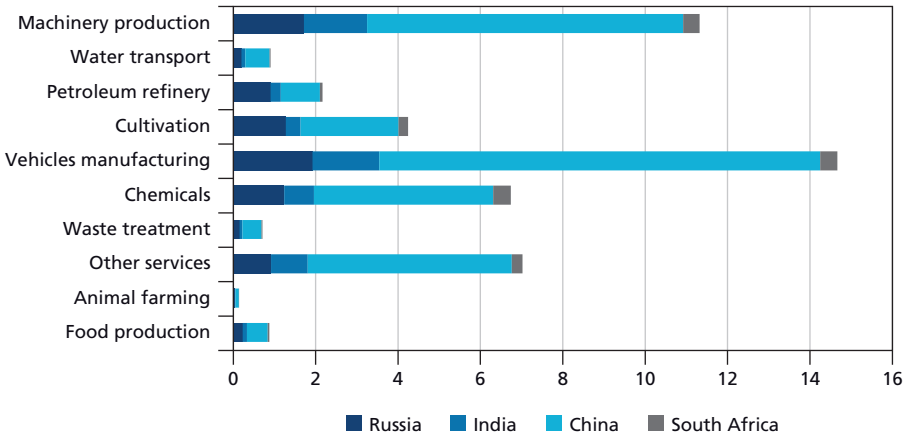
Source: EXIOBASE (2025).
Authors' elaboration.

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.

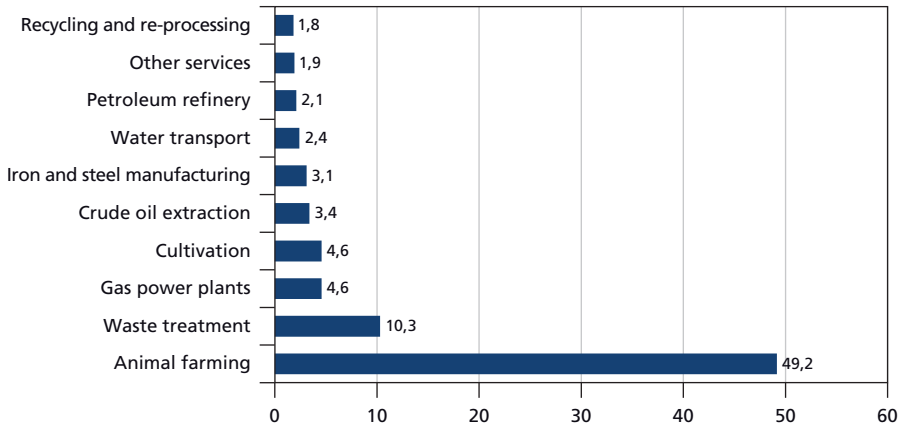
FIGURE 6
Total share of Brazilian issuances incorporated by forward linkages in 2022 by main sectors and BRICS countries
(In %)



Source: EXIOBASE (2025).
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%).

FIGURE 7
Total share of Brazilian emissions embodied by backward linkages in 2022 by main sectors
(In %)

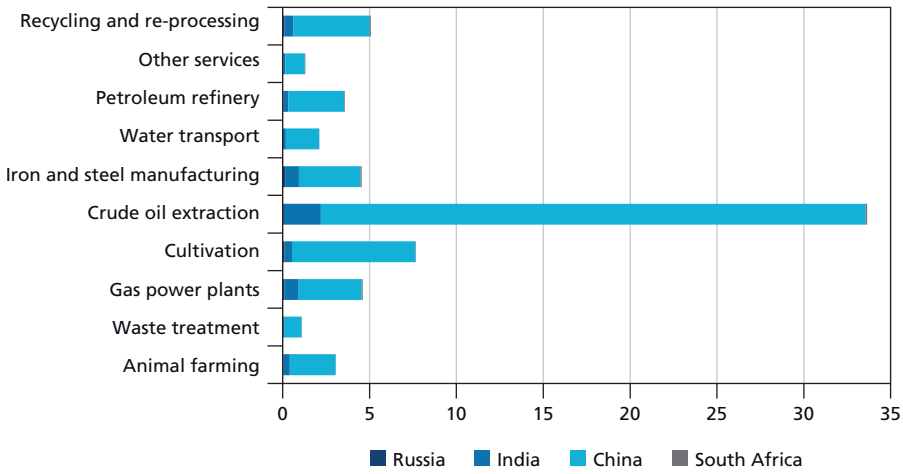


Source: EXIOBASE (2025).
Authors' elaboration.

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 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 et al., 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.

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



Source: EXIOBASE (2025).
Authors' elaboration.

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 et al., 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 et al., 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 (Brazil, 2021).

When compared to historical data, the 2022 results indicate a deepening of trends already observed over the last decade. China's share as both a destination and source of emissions incorporated into Brazilian trade remained high, but with a significant difference: while in the early 2010s, Brazilian exports to China were more intensive in relative emissions, a reduction in this indicator is observed, possibly associated with the greater share of agricultural products with a lower carbon footprint in the export mix. In contrast, imports from China maintain high emissions intensity, reflecting the strong dependence on energy-intensive industrial sectors. These patterns suggest that, while diversifying the export mix can reduce emissions intensity, dependence on high-carbon industrial imports tends to offset net decarbonization gains in bilateral trade.

5 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 were 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.

Finally, the findings of this study reinforce the need for policies that integrate foreign trade and climate mitigation. In the Brazilian case, this implies fostering value addition and the adoption of low-carbon technologies in strategic export sectors, reducing dependence on high-emission primary commodities. At the same time, it is essential to encourage technological cooperation agreements within the BRICS, aiming at the transfer and joint development of cleaner production processes, especially in the capital and intermediate goods segments. As a research agenda, we recommend exploring the role of regional value chains in the diffusion of green technologies and assessing the impact of BRICS expansion on emissions flows and value added. This includes the possibility of incorporating the seven new BRICS members that joined the bloc from 2022 onwards (Saudi Arabia, Egypt, Ethiopia, Iran, the United Arab Emirates, and Indonesia in 2023), alongside the founding members (Brazil, Russia, India, China, and South Africa). Future studies could also incorporate the land-use emissions dimension, allowing for more accurate estimates of the true environmental impact of Brazilian trade.

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APPENDIX A

TABLE A.1
Classification of 50 industries, factor of production and satellite account (EXIOBASE MRIO)

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
Sector	Vehicles manufacturing	M EUR
Sector	Other manufacturing	M EUR

(Continues)

(Continued)

Account	Description	Unit
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	CO_2	Kg
Satellite account	CH_4	Kg
Satellite account	N_2O	Kg