Resource-based Industries and CO_2 Emissions Embedded in Value Chains: a regional analysis for selected countries in Latin America

Abstract:

This paper analyses the relative content of CO_2 emissions embedded in regional supply chains in four different countries from Latin America: Brazil, Chile, Colombia, and Mexico. We estimate both the trade in value-added (TiVA) and the CO_2 content embedded in interregional and foreign exports, mapping the relative intensity CO_2 emission level on value chains. We apply an inter-regional input-output model to determine the interplay between the CO_2 emission embedded on goods of resource-based industries and their linkages with the others economic industries, revealing a map of CO_2 emissions on trade in value-added trade from a subnational dimension. The main result reveals an interregional dependence, indicating for resource-based industries, usually intense in CO_2 emissions, a higher level of embedded CO_2 on value-added in each regional economy. This finding has considerable implications for the sustainable development goals of these subnational areas, as the spatial concentration of production leads with an unbalanced regional capacity for promoting reductions on CO_2 emissions along with value chains.

Keywords: CO_2 emissions. Global and domestic value chains. Trade in value-added. Trade in carbon-based emissions.

1. Introduction

Regional natural resources endowment significantly influences carbon-based emissions embedded in tradable goods and services (Rehman et al., 2021). The abundant natural resource in Latin American countries makes these production and trade pattern linked to the supply of raw materials, with a relatively low level of value-added for both domestic and global value chains (Alvarado et al., 2021; Deng et al., 2020; Tillaguango et al., 2021).

For instance, resource-intensive sectors are responsible for a significant share of CO2 emissions worldwide, giving resource-intensive countries a key role in global warming (Jahanger et al., 2022). In recent years, especially in commodities case, there has been increased dependence on exports of low processing raw materials, rising the implicit amount CO2 from pollution-intensive economic industries thought tradable goods in international market. (Brenes et al., 2016; Haddad & Araújo, 2021; Vianna & Mollick, 2021). Furthermore, considering the economic geography of countries, natural resources are mainly concentrated in peripherical low-income regions, while the main areas of intermediate consumption are in large business centres (Amaral & Roberto, n.d.; Aroca et al., 2018; Azzoni & Haddad, 2018a, 2018b; Guerrero et al., 2021; Kanemoto et al., 2016; Sanguinet et al., 2021; Z. Wang et al., 2020).

Empirical evidence has focused on estimating the global CO2 flows embedded in trade with less attention to the role of subnational value chains. (Q. Liu et al., 2019; B. Meng et al., 2017; F. Wang et al., 2020; H. Wang et al., 2019; H. Zheng et al., 2020; J. Zheng et al., 2019). In this regard, at the subnational level, regional inequalities have a relevant role in determine the input-output networks, inducing both direct and indirect generation of CO2 emissions. Consequently, these structural linkages could influence the development of sustainable alternatives for resource-based industries to reduce CO2 emissions. Moreover, input-output interdependencies among subnational regions are an essential analytical tool to provide evidences on how local economies are linked through value chains, incorporating directly and indirectly CO2 on the domestic and international trade (Atienza et al., 2021; Duan & Jiang, 2018a, 2018b; Hanaka et al., 2021; B. Meng et al., 2018; Piorski & Xavier, 2017).

The intensity of CO2 emission from resource-based industries are well discussed in the literature (Chen et al., 2019; Clarke-Sather et al., 2011; Li et al., 2019). However, the role of interregional linkages and cross-sector transfers of value-added and embedded CO2 in trade between resource industries and the rest of the regional and national industry structure has not been studied, even within the growing literature on global value chains (C. Liu & Zhao, 2021;

Mudambi & Puck, 2016; Yan et al., 2020; Zhang et al., 2017). In this regard, the first aim of this paper is to analyse the direct and indirect interplay between resource and non-resource industries, computing measures of interregional trade and the international exports from Brazil, Chile, Colombia, and Mexico. In a complex economic structure, sectors or regions are not isolated entities. Therefore, it is crucial to consider the cross-sectoral interdependence of the CO2 embedded on trade among industries (Haddad & Araújo, 2021). By employing a multisectoral interregional framework, it is possible to identify the spatial-defined patterns of the trade in value-added (TiVA) and CO2-based multiplier effects from intersectoral trade. In addition, it is possible to find the main mechanisms by which the final demand is spatially connected in a specific country (C. Liu & Zhao, 2021; L. Meng et al., 2011; Zhang et al., 2017). The second objective is to analyse the regional dimension of the location of resource-based industries and the potential of spread the implicit CO2 emissions through the regional supply chain, which can increase – and determine – the polluting profile of Latin American economies (Ahmed et al., 2020; Danish et al., 2019, 2020; Jiang et al., 2019; H. Wang et al., 2019).

Furthermore, the regional analysis of the selected value chains' CO2 linkages provides a clear portrait of the relative intensity of CO2 emissions in the subnational production networks for sustainable competitiveness in Latin America, well-known for resource-based dependency (Perobelli et al., 2015; Vale et al., 2017). In this regard, this paper advances on providing evidence on the role of interregional linkages in terms of CO2 emissions embedded in production and trade - direct and indirectly - into goods and services in the regional supply chain for selected Latin American countries, focusing on the geographic dimension of the resource-based value chains. Brazil, Mexico, Chile, and Colombia have in common a strong dependence of natural resources endowments in value integration chains (Danish et al., 2019, 2020; Xuemei et al., n.d.).

To estimate the relative intensity of intersectoral linkages of the resource-based industries' CO2 emissions embedded in trade are calculated the TiVA and the content of CO2 emissions for six selected value chains: (1) Agriculture; (2) Mining; (3) Low-medium-tech manufacturing; (4) High-tech manufacturing; (5) Business services; and (6) Other sectors. Therefore, we account for the direct and indirect effects of regional trade imbalances within an IO framework, tracking resource-based and non-resource spatial defined-value chains CO2 linkages. First, we calculate the TiVA and hence the CO2 emission content in the trade flows. Then, we use a multiscalar approach to compute the role of regional natural resources endowments integration in both domestic (between subnational regions) and global value chains (from the subnational areas to global markets), expanding the analytical input-output economic-environmental scope.

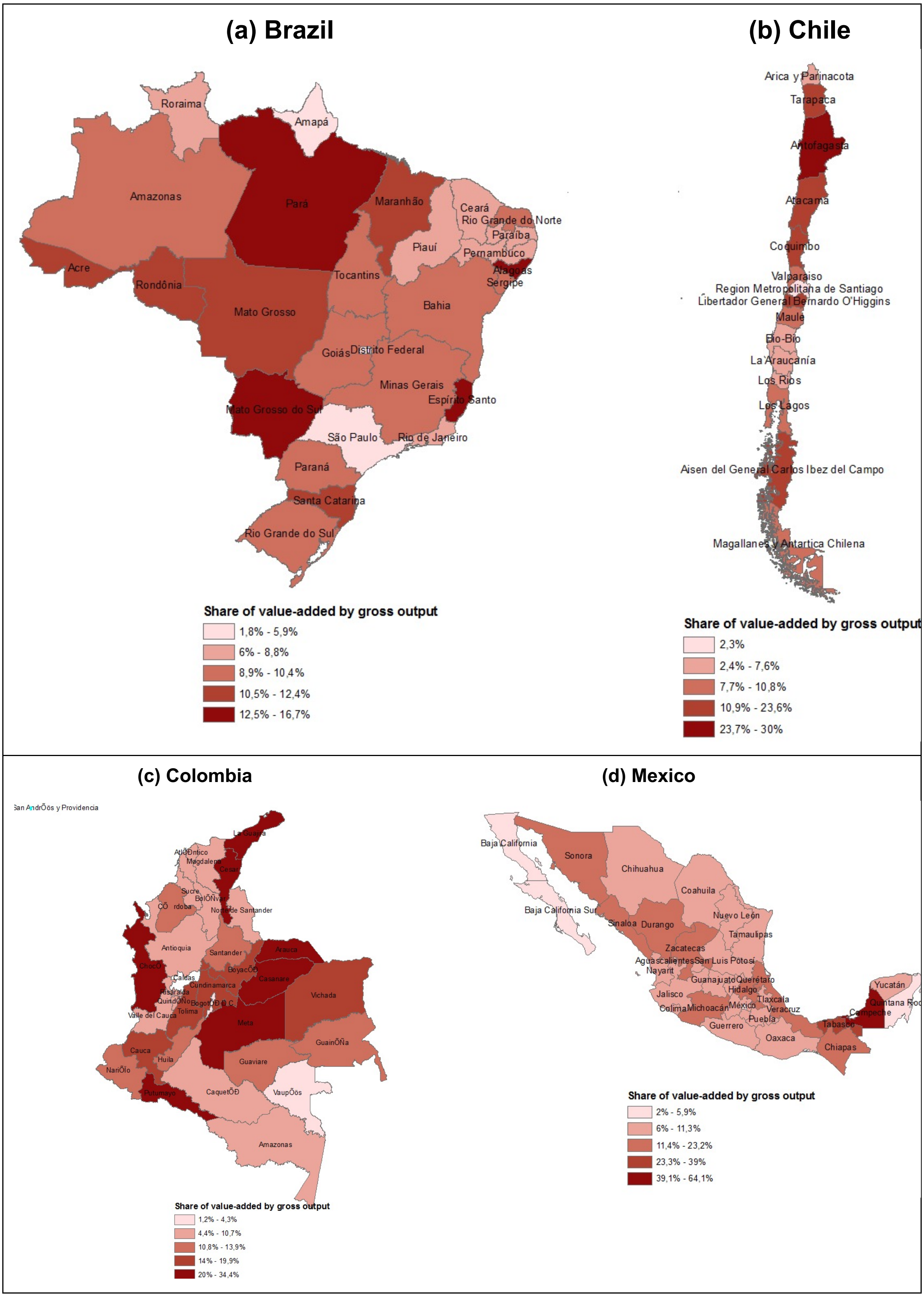
[41], [42]The paper is structured as follows: section 2 presents different dimensions of regional disparities in the four countries, considering their geography of natural resources and spatial economic structures. Section 3 discusses the main aspects of the adopted methodology. Section 4 presents the results of the empirical exercise, and Section 5 discusses the main findings of the document, including suggestions for public policy.

2. Geography of resource-based industries in selected Latin American countries

Using data from four interregional input-output (IRIO) tables, this section shows the main results from the economic geography of Brazil, Chile, Colombia, and Mexico, providing a general picture of the resource-based industries' location.

Overall, Latin America extends from a wide equatorial zone in the north to a narrow subarctic area in the South, with climatic conditions favouring economic development based on exploiting natural resources. Furthermore, Figure 1 shows the share of value-added of resource-based sectors in relation to the total gross product in each country. The geography of resources associated with climatic factors – such as average temperature and precipitation levels – favours the development of agricultural-related activities. The abundance of mineral reserves allows countries to supply local production chains and international partners. Moreover, the meat industry plays a relevant economic role in pasture zones, especially in Brazil. Even regions with extreme climatic conditions, such as the cold in southern Chile and the higher elevations of the Andes that limit agricultural production, allow for the harbouring of marketable native species, in addition to extensive areas for grazing, generating inputs for the clothing industry.

Figure 1. Value-added share of resource industries in total gross output



Source: Own elaboration 2022.

The relative importance of resource industries is regionally located in each country due to the spatial distribution of resources. In the Brazilian case, factors associated with the increase in the volume and price of international demand for raw materials since the 2000s, basically minerals, oil, coal, and the meat industry, prompted an increase in national specialization in these activities. The mining economy contributes significantly to the value-added of the states of Pará (North) and Espírito Santo (Southeast), while agribusiness accounts for a good part of the value-added in the Cerrado of Mato Grosso do Sul state (Midwest) in the vanguard of grain and meat exports and the exploration of sugar cane in Alagoas (Northeast).

The main resource-based economic driver in Chile is mining (Chart b). The country is considered the world's largest producer of copper (in addition to lithium and iodine). It has an important position in other agricultural products such as fruits and lithium carbonate. The primary mines are mainly located in the northern part of Chile, such as in Antofagasta, Tarapacá, and the Atacama. In the extreme south of the country, the region of Magallanes focuses mainly on domestic supply, and extractive activities have a significant economic role. Agriculture and forestry are also economically important, especially in the central-south axis, as in O'Higgins, Maule, and Aysen.

In Colombia, the resource-based economy is responsible for the largest share of the regional output, as shown in chart c. The coffee industry stands out, mainly in Antioquia, Valle del Cauca, and Cundinamarca. Moreover, Colombian agriculture, mining and floriculture have and important contribution for the total value-added generated at the subnational level. Activities related to livestock stand out in the Caribbean region, contributing to the meat industry and regional exports.

In Mexico, most states with high development and economic diversification are concentrated in the North, while the least developed ones are further south. There is an important contribution to the national GDP in agriculture industries in Jalisco, Michoacán, and Veracruz. In southern Mexico, the state of Campeche stands out for its high GDP per capita and the relative share of activities in the petrochemical and natural gas industry and fishing and agroindustry.

Input-output linkages have been considered a relevant element in explaining regional differences in countries' economic development. The leading economic centres of countries tend to be the main demanders of natural resources produced in less industrialized areas. In this sense, it becomes relevant to understand the potential of the linkages of resource sectors with the remaining local and global economies since the intensity in relative pollution generated by these sectors can impose considerable complications on sustainable regional development at the subnational level. In countries rich in natural resources endowments, extractive and agricultural industries often play a central economic role and have several links with other sectors of the economy. Such aspects challenge the sustainable development path in each country. Intersectoral strategies could enable more remarkable environmental preservation and carbon footprint reduction without undoing economic losses. The next section details the methodological procedures adopted to estimate the intersectoral and interregional contributions of resource industries to the rest of each national economy.

3. Methodology

We are interested in estimating the relative content of CO2-based pollution incorporated in the value chains, encompassing the input-output linkages between natural resource industries and all economic sectors. For this, we have considered two large sectoral groups: (1) resource-based and (2) non-resource-based industries. The classification used is shown in Table 1.

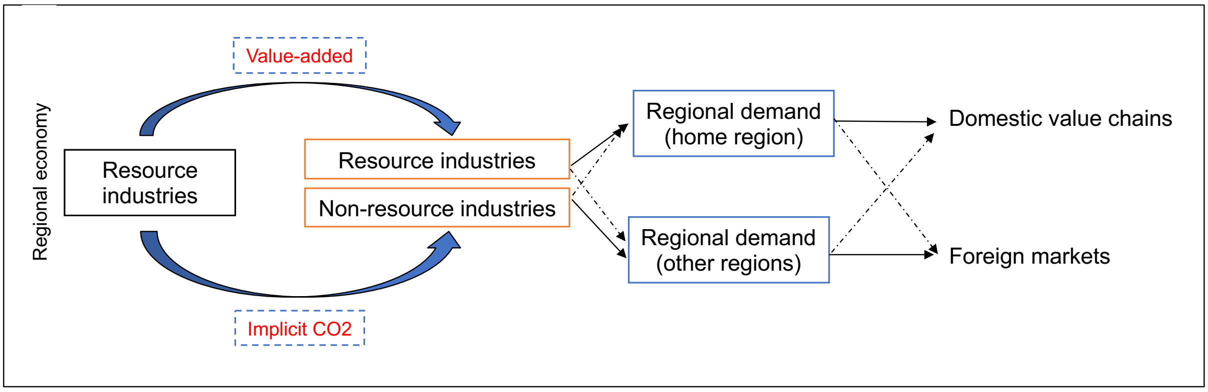
Table 1. Large selected industrial groups (value chains considered)

	Selected value chains	Natural resources industrial classification
1	Agri-food value chains	Resource-based
2	Mining value chains	Resource-based
3	Resource-based manufacturing value chains	Resource-based
4	Non-resource-based manufacturing value chains	Non-resource based
5	Business services value chains	Non-resource based
6	Other services value chains	Non-resource based

Source: Authors' elaboration 2022.

Our empirical exercise focuses on calculating both the regional value-added and the CO2 content in trade to identify the spatial configuration of domestic supply chains and their relative polluting intensity. Specifically, we have counted the direct and indirect content embedded in production for meeting the final demand from a subnational perspective (Figure 2).

Figure 2. Empirical strategy scheme



Source: Own elaboration 2022.

3.1 Estimation procedure

We first compute the VA content traded throughout value chains, based on extending the global value chain (GVC) approach to an interregional (subnational) input-output system (Chen et al., 2018; Haddad & Araújo, 2020; Haddad, Mengoub, & Vale, 2020; Los, Timmer, & De Vries, 2016). We adopt a demand-driven trade in value-added (TiVA) perspective (Meng, Fang, Guo, & Zhang, 2017; Timmer et al., 2019), entertaining the idea that the use of intermediate inputs can affect the production process other than the trade in final goods, leveraging the promotion of linkages throughout the supply value chain.

Formally, let us consider an interregional input-output model (IRIO) for each country with J industries groups (labelled as i, j), R subnational regions (r, s), and U final demand components to attend the interregional domestic (U^r, U^s) and foreign (U^{RoW}) consumption, as represented by Figure 3. The model is based on the main fundamentals of the general equilibrium of a social accounting matrix (SAM), recording the interrelationships of a regional economy, including intermediate uses and final demand. For our purposes, the IRIO structure offers the advantage of linking consumption and interregional trade patterns to the interindustry structure of intermediate demand at the subnational (interregional) level.

Figure 3. An interregional IO with R regions and J sectoral groups.

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Source: Authors' elaboration based on Hewings & Jan Oosterhaven (2015).

Within an IO framework, the intermediate consumption from an industry i to j, from a subnational region R to another region S, is represented by z_{ij}^{RS}; **A** is the technical coefficients' matrix equal to the ratio between z and the industrial output $\mathbf{x_j}$, $\mathbf{A} = \mathbf{Z}(\hat{\mathbf{x}})^{-1}$. Therefore, the aggregated regional gross output can be expressed as follows:

$$\mathbf{x} = \mathbf{Z} + \mathbf{Fi} = \mathbf{Ax} + \mathbf{F}\boldsymbol{i} \tag{1}$$

where **F** is the final demand, and $\boldsymbol{i}$ is a summation vector of ones. This relationship can be expressed as:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{F}\boldsymbol{i} = \mathbf{LF}\boldsymbol{i} \tag{2}$$

where $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ is the well-known Leontief matrix. The IRIO system allows us to analyse the specific regional and industrial interdependencies in terms of linkages and input-output value chains networks. In a formal way, one could estimate the gross output for two sectors (supposing label 1 refers to resource-based industries and label J ($J = 1, \dots, J$) as non-resource industries) for two regions (R and S) considering the relationship between the Leontief' matrix and the final demand **F**:

$$\begin{bmatrix} \mathbf{x_1^R} \\ \mathbf{x_j^R} \\ \mathbf{x_1^S} \\ \mathbf{x_j^S} \end{bmatrix} = \begin{bmatrix} \underbrace{\begin{matrix} \mathbf{L_{11}^{RR}} & \mathbf{L_{1j}^{RR}} & \mathbf{L_{11}^{RS}} & \mathbf{L_{1j}^{RS}} \\ \mathbf{L_{j1}^{RR}} & \mathbf{L_{jj}^{RR}} & \mathbf{L_{j1}^{RS}} & \mathbf{L_{jj}^{RS}} \\ \mathbf{L_{11}^{SR}} & \mathbf{L_{1j}^{SR}} & \mathbf{L_{j1}^{SR}} & \mathbf{L_{jj}^{SS}} \\ \mathbf{L_{j1}^{SR}} & \mathbf{L_{jj}^{SR}} & \mathbf{L_{jj}^{SS}} & \mathbf{L_{jj}^{SS}} \end{matrix}}_{\text{Interregional Leontief}} \end{bmatrix} \begin{bmatrix} \underbrace{\begin{matrix} \mathbf{f_1^{RR}} & \mathbf{f_1^{RS}} & \mathbf{f_1^{R,RoW}} \\ \mathbf{f_j^{RR}} & \mathbf{f_j^{RS}} & \mathbf{f_j^{R,RoW}} \\ \mathbf{f_1^{SR}} & \mathbf{f_1^{SS}} & \mathbf{f_1^{S,RoW}} \\ \mathbf{f_j^{SR}} & \mathbf{f_j^{SS}} & \underbrace{\mathbf{f_j^{S,RoW}}}_{\text{Exports}} \end{matrix}}_{\text{Final demand}} \end{bmatrix} \boldsymbol{i} \tag{3}$$

For our empirical purposes, we are interested in estimating the subnational bilateral trade in both value-added and CO2 terms. For example, the value-added generated by a set of resource industries (let us call "sectoral group 1") and embedded in all industries final demand for both interregional and exports destinations can be expressed as follows:

$$\mathbf{va_1^R} = \hat{\mathbf{v}}_\mathbf{1}\mathbf{LF}\boldsymbol{i} \tag{4}$$

where $\hat{\mathbf{v}}_1$ is a diagonal vector of value-added coefficients for region *R* and the sectoral group 1, with zeros elsewhere ($\hat{\mathbf{v}}_1 = [[\mathbf{v}_1^R \quad \mathbf{0}]$). Equation 4 considers the total value-added for attending all final demand; that is, the sum of all industries computing both interregional (between subnational regions) and global demand (exports). Besides, following Haddad & Araujo (2020), Los et al. (2018), and Chen et al. (2017), we can measure the interdependence between the value-added and CO2 regional content of a specific sectoral group directly and indirectly embedded in the trade flows of another sectoral group. Our application also considers the trade flows for different geographical scales, accounting separately to trade for interregional and foreign destinations. We deal with that by treating both U^{RS} and $\mathrm{U}^{\mathrm{R,RoW}}$components separately from **F** matrix.

Thus, for an origin region R, the trade-based measure can be estimated considering the relevant components of each vector, i.e., value-added and both U components of the final demand. From region R, the value-added content generated by the sectoral group 1 (for example, the set of resource-based industries) that is direct and indirect embedded in the interregional final demand of sectoral group *j* can be expressed as follows:

$$\mathbf{va}_{\mathbf{1}j}^{\mathbf{RS}} = \hat{\mathbf{v}}_{\mathbf{1}}^{R}(\mathbf{I} - \mathbf{A})^{-1} \begin{bmatrix} \mathbf{0} \\ \underbrace{\mathbf{f}_j^{RS}}_{U^R} \end{bmatrix} \boldsymbol{i} \qquad (5)$$

For foreign destinations, we computed the domestic production embedded in exports final demand as suggested by Haddad et al. (2020). The value-added of industry 1 in region R that is embedded in exports of region 2 can be expressed according to:

$$\mathbf{va}_{\mathbf{1}j}^{\mathbf{R,RoW}} = \hat{\mathbf{v}}_{\mathbf{1}}^{R}(\mathbf{I} - \mathbf{A})^{-1} \begin{bmatrix} \mathbf{0} \\ \underbrace{\mathbf{f}_j^{\mathbf{R,RoW}}}_{U^{RoW}} \end{bmatrix} \boldsymbol{i} \qquad (7)$$

According to the same estimation procedure, we have counted the CO2 content embedded from one value chain group in another, replacing the value-added coefficients, $\hat{\mathbf{v}}$, by the CO2 industry-level intensity represented by $\hat{\boldsymbol{\varphi}}$, as it is given by:

$$\varphi_s = \frac{P_s}{x_s} \tag{1}$$

where $\boldsymbol{P}_s$ represents the total emissions and $\mathbf{x}$ the total output of each industry. Therefore, $\boldsymbol{\varphi}$ is the vector representing the direct emissions of each industry in the IRIO model. The total direct and indirect CO2 emissions are measured by multiplying the diagonalised vector $\widehat{\boldsymbol{\varphi}}$ by the Leontief inverse matrix. In this regard, from the sector 1 of region 1 to the final demand of an industry j located in the subnational region r, the amount of implicit emissions embedded in trade can be measured as:

$$\mathbf{co2_{1j}^{RS}} = \widehat{\boldsymbol{\varphi}}_{\mathbf{1}}^{R}(\mathbf{I}-\mathbf{A})^{-1}\begin{bmatrix}\mathbf{0}\\ \mathbf{f}_{j}^{RS}\end{bmatrix}\boldsymbol{i} \tag{6}$$

Similarly, the implicit emissions embedded in foreign trade exports can be measured as follows:

$$\mathbf{co2_{1j}^{R,row}} = \widehat{\boldsymbol{\varphi}}_{\mathbf{1}}^{R}(\mathbf{I}-\mathbf{A})^{-1}\begin{bmatrix}\mathbf{0}\\ \underbrace{\mathbf{f}_{j}^{row}}_{U^{RoW}}\end{bmatrix}\boldsymbol{i} \tag{7}$$

In this regard, we could map how much of the CO2 emissions generated by the resource industries are directly and indirectly incorporated into the trade of both resource and non-resource sectoral groups.

Finally, the last stage was estimating an index representing the relative polluting intensity among value chains. Herein, we are interested in estimating the trade-offs between embedded CO2 emissions from resource-based industries into seven selected value chains (computing for two large sectoral groups, i.e., resource-based and non-resources industries). Therefore, a relative intensity index was calculated, computing the CO2 emissions content in relation to the VA bilateral trade that flows at the subnational level, following Haddad et al. (2019; 2020). Specifically, the index was measured as the ratio of VA trade in relation to all VA traded inside each country divided by the ratio of CO2 trade in relation to all CO2 traded inside the whole economy. In other words, we first calculated two ratios and, thus, divided one by each other.

Formally, let us consider the relative importance of each interregional transfer of both VA and CO2 in each bilateral trade flow from a region R to another region S, as follows:

$$\mathbf{RPI^{RS}} = \frac{\mathbf{va^{R,s}} / \sum \mathbf{va}}{\mathbf{co2^{R,s}} / \sum \mathbf{co2}} \tag{8}$$

We calculated the average of each ratio for both trade sides (seller and buyer). In specific, let us consider the average of RPI for each region R, computing separately the seller side average (i.e. from R to another region S, computing the exports of VA in relation to CO2 exports). Further it is calculated the same average from the buyer side (i.e., from regions S to region R, computing the trade volumes of VA and CO2 imported). Formally, for a region R in a country with n subnational regions, the final index can be measured as follows:

$$\mathbf{RPI^{R}} = \frac{\sum \mathbf{RPI^{RS}} / \boldsymbol{n}}{\sum \mathbf{RPI^{SR}} / \boldsymbol{n}} \tag{8}$$

where n is the number of subnational regions in each country. In this regard, we have computed, in average, the interplay among VA and CO2 trade flows between all subnational regions inside each country as intensities values. Values greater than 1 indicate that bilateral trade is more intense in implicit CO2 emissions than traded VA, suggesting that the flow along the supply chain is intense in pollution. Values less than 1 indicate the opposite.

3.2 Data

We use four interregional input-output tables estimated by the NEREUS-USP, with the industrial and regional structure described as follows: (1) Brazil – 67 sectors, 27 regions, base year 2015, in BRL millions. (2) Chile – 12 sectors, 15 regions, base year 2014, in CLP thousands. (3) Mexico – 42 sectors, 33 regions, base year 2013, in MXN millions. (4) Colombia – 54 sectors, 33 regions, base year 2015, in COP billions. We harmonized the sectoral structure of each IO table with the sectors associated with the six defined value chains. The sectoral emissions data on the production side were obtained from the EORA national IO tables (Lenzen, 2013), which consider the EDGAR database estimates. To make it compatible, we used the harmonisation of Table A1 in the Annex. Although restrictive for the regional analysis, we assume that the sectoral coefficients are the same for all regions of each country. Table 2 shows the total emissions for each of the six value chains for each national economy included in this study. In general, we observe that the resource sectors (agri-food, mining, and resource-based manufacturing) contribute, on average, 33% of national emissions in Brazil (28%), Chile (47%), Colombia (33%), and Mexico (23%). These differences are explained by the relative importance of the sectors that make up each country's value chain.

Table 2. Total CO2 emissions (Gg) from EDGAR database

Selected VC	Brazil	(%)	Chile	(%)	Colombia	(%)	Mexico	(%)
Agri-food value chains	168,104	19%	2,807	4%	12,933	16%	33,658	7%
Mining value chains	7,658	1%	3,650	5%	5,459	7%	22,980	5%
Resource-based manufacturing value chains	67,044	8%	29,637	38%	8,116	10%	53,277	11%
Non-resource based manufacturing value chains	69,860	8%	14,569	18%	6,639	8%	66,967	14%
Business services value chains	239,836	28%	7,767	10%	15,746	19%	199,596	41%
Other services value chains	318,488	37%	20,385	26%	32,797	40%	115,906	24%
Total	870,991	100%	78,815	100%	81,689	100%	492,385	100%

Source: EORA National IO tables.

4. Empirical results

This section has three parts. First, we analyse the interplay between resource and non-resource-based industries, accounting for the CO2 and value-added embedded in production and trade between industries in each country. Second, we analyse the geography of the regional supply chain, identifying the main regional sources of VA and CO2 directly and indirectly embedded in trade flows. Finally, we explore the relative polluting network at the subnational level, mapping the regions and value chains with greater environmental responsibility in each country.

4.1 Interplay between resource and non-resource industries

Table 3 shows the TiVA from the the resource and non-resource industries to meet the final demand (for both inter-regional and exports destinations) for all countries analysed. It is interesting to note that the resource-based industries (usually primary sectors or directly linked to them) –present lower levels of VA. Nevertheless, these same industries are responsible for the highest shares of the CO2 embedded in the trade for each sector and country. For example, 23% of the VA trade for meet the final demand comes from the resource-based sectors in Colombia, while this share in Mexico and Chile are around 18% and 7% in Brazil. Given the upstream position in the production value chain, the manufacturing, and services business sectors have larger shares of VA – accounting for the non-resource industries.

Table 3. TiVA measures: From selected Value Chains to meet the final demand (domestic and foreign)

Value chains	Brazil	(%)	Chile	(%)	Colombia	(%)	Mexico	(%)
Agri-food	155	4.24%	490	11%	106	18%	9,865	2%
Mining	21	0.56%	160	4%	20	3%	49,335	11%
Resource-based manufacturing	84	2.30%	107	2%	11	2%	16,687	4%
Non-resource manufacturing	92	2.52%	1,387	32%	4	1%	69,211	16%
Business Services	1,085	29.63%	1,004	23%	252	42%	82,224	19%
Other value chains	2,224	60.76%	1,172	27%	210	35%	205,218	47%
Total	3,661	100.00%	4,319	100%	603	100%	432,540	100%

Note: (1) Brazil 2015 BRL millions. (2) Chile 2014 CLP thousands. (3) Colombia 2015 COP billions. (4) Mexico 2013 MXN millions.

Source: Own elaboration 2022.

Table 4 shows the relative content of VA and CO2 transferred from the resource-based industries to the interregional (domestic) and foreign exports' final demand in all industries for each country. In general, intersectoral transfers from resource-based activities account for 48% of the total domestic trade (interregional) in Brazil, 36% in Colombia, 47% in Mexico and only 7% in Chile. It is interesting to observe that the low contribution of VA from resource-based industries to intragroup final demand – i.e., from resource VA to resource industries final demand – highlights the agro-export and resource-dependent profile of the Chilean economy. At the same time, in countries such as Brazil and Mexico, the value-added of resource industries is outstanding, contributing significantly to the national (and regional) gross domestic product.

However, when we contrast this intra-sectoral relationship by accounting for the implicit content of CO2, the results point to the potential for domestic embedded of this greenhouse gas. More than half of the carbon incorporated in Brazil, Colombia, and Mexico is absorbed by their own economies (domestic demand). The exception is Chile, which embeds 31% of the CO2 emissions domestically and exports the rest internationally, confirming the country's level of trade openness compared to the rest of Latin America. The lower part of Table 4 shows intersectoral transfers from resource industries to meet the final demand of non-resource-based sectoral groups. Again, attention is drawn to the importance of domestic (subnational) value chains, which have much of the value-added generated by resource-based sectors. Intersectoral demand from manufacturing industries service sectors responds to the sectoral pattern of results.

Accounting for the TiVA from resource-based industries to attend the final demand of non-resource-based industries, it represents almost two-thirds of the total trade in Brazil and Colombia, while representing 46% and 44% for Chile and Mexico, respectively. This pattern indicates that the carbon footprint of inter-industry relations points to a considerable degree of responsibility on the domestic demand side. In other words, input-output relationships between sectors and subnational regions are essential drivers of CO2 emissions in resource sectors in source regions. The relative share of VA and CO2 in exports is smaller than the total embedded domestically consumed in all countries. Consequently, the spatial organisation of the regional supply chain is a relevant element to determine the origin and destination of CO2 emissions generated by the production and trade in each analysed country.

Table 4. Interplay in VA trade and CO2 emissions

	Brazil	**(%)**	**Chile**	**(%)**	**Colombia**	**(%)**	**México**	**(%)**
Resource to resource industries								
Domestic TiVA	168,921	48%	1,133	7%	22,371	36%	761,683	47%
VA exports	183,288	52%	15,452	93%	39,326	64%	868,041	53%
Total TiVA	352,209	100%	16,585	100%	61,697	100%	1,629,724	100%
Domestic CO2	62,781	55%	3,236	31%	7,047	56%	25,446	51%
CO2 exports	51,018	45%	7,222	69%	5,533	44%	24,245	49%
Total CO2	113,799	100%	10,458	100%	12,580	100%	49,691	100%
Resource to non-resource industries								
Domestic TiVA	12,702	73%	515	46%	1,885	79%	31,425	44%
VA exports	4,623	27%	595	54%	503	21%	40,289	56%
Total TiVA	17,324	100%	1,110	100%	2,388	100%	71,714	100%
Domestic CO2	3,061	72%	3,236	31%	314	75%	1,743	45%
CO2 exports	1,219	28%	7,222	69%	105	25%	2,128	55%
Total CO2	4,280	100%	10,458	100%	419	100%	3,871	100%

Note: (1) Brazil 2015 BRL millions. (2) Chile 2014 CLP thousands. (3) Colombia 2015 COP billions. (4) Mexico 2013 MXN millions. CO2 emissions in Gg.

Source: Own elaboration 2022.

While the empirical literature has focused on accounting CO2 embedded in international trade, our paper point out the importance of including the regional (or local) dimension of supply chains. The proposed estimation method defines the local value-added content embedded in interregional flows (domestic chains) and exports (destined to global chains). The analyses of vertical specialisation allow identifying market opportunities to add more value to production and increase sustainable regional trade competitiveness (Feenstra, 2004; Gereffi, 2019). The decomposition shows the value-added content of resource and non-resource-based industries embedded in interregional and international exports, describing the structure of selected value chains. The following section extends this technique to compute the CO2 embedded in trade of goods in value chains.

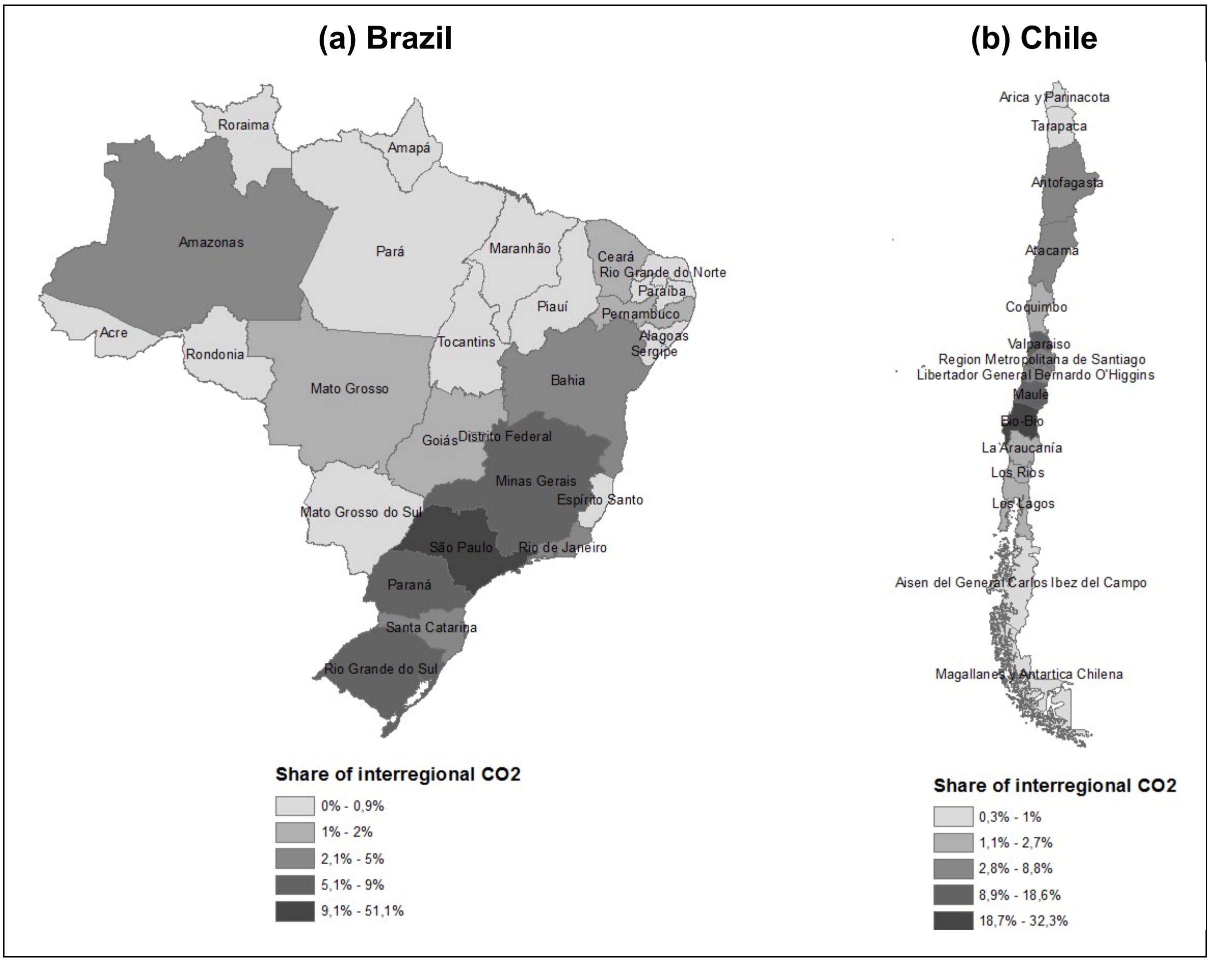
4.2 Spatial organisation of interregional VA and CO2 transfers

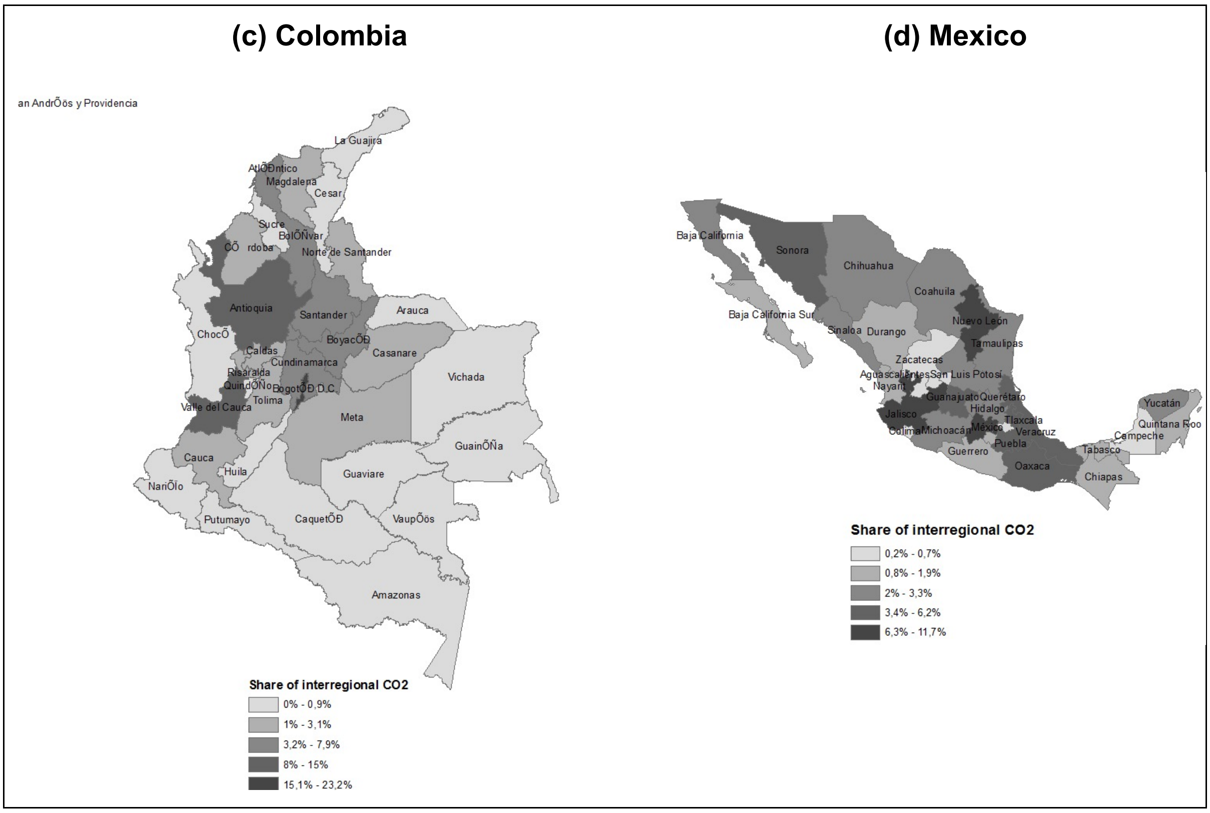
In the previous section, the contribution of VA and CO2 in subnational transfers suggests that domestic demand is responsible for most of the emissions generated by economic industries in the entire economic system. Furthermore, the economic importance of resource-based industries and the backward and forward chaining patterns suggest that it is crucial to understand the spatial organisation of domestic value chains to understand the environmental responsibility standards of CO2 emitted and embedded in value chains networks internally.

To provide a better picture of the interregional transfers of both VA and CO2, the Figure 3 shows the main subnational origins of the CO2 implicit content from the resource industries that is embedded in the final interregional demand of the non-resource-based sectors. It was possible to map the results obtained from estimating the implicit trade flows of CO2 in each region of origin to picture the geography of the main subnational origins. On analysing the shares of implicit CO2 shipments from each origin to all domestic destinations, it is observed that the total amount of CO2 emissions in interregional exports is proportional to the regional economic importance. This is due the intermediate demand for inputs tends to reflect the capacity to embed potentially pollution-intensive inputs. Annex also shows the CO2 content embedded in international exports originating in each subnational region.

The regions specialised in exploiting natural resources play an important role in internal environmental accounting. In Brazil, the State of São Paulo – the most prosperous – which has an economic diversification that ranges from the primary to the service business sectors – is the one that incorporates the largest share of emissions in the country. In Chile, the Biobío Region is an area whose main economic activities are forestry and fishing, secondary (food) agriculture, manufacturing and services, and the metal industries. This regional economic profile helps to understand the relative importance as a provider of intermediate inputs intense in CO2 transferred to other subnational areas. Traditionally, Antioquia has been Colombia's first export department, with its regional economy focused on mining, cattle ranching, agriculture, and forest products, mainly wood. These resource sectors account for a significative part of regional production and trade, distinguishing the region as intense in polluting activity. The capital Bogotá is the most prosperous and diversified region in the country. The linkages with the other regions dominate the demand for interregional intermediate inputs, revealed in the high relative percentage of emissions incorporated into domestic trade. In Mexico, the State of Nuevo Leon concentrates its activities in the petrochemical, food, and manufacturing industries, which shows the predominance of potentially CO2-intensive productive activities.

Figure 3. Share of CO2 content embedded in interregional trade (from regional source).





Source: Own elaboration 2022.

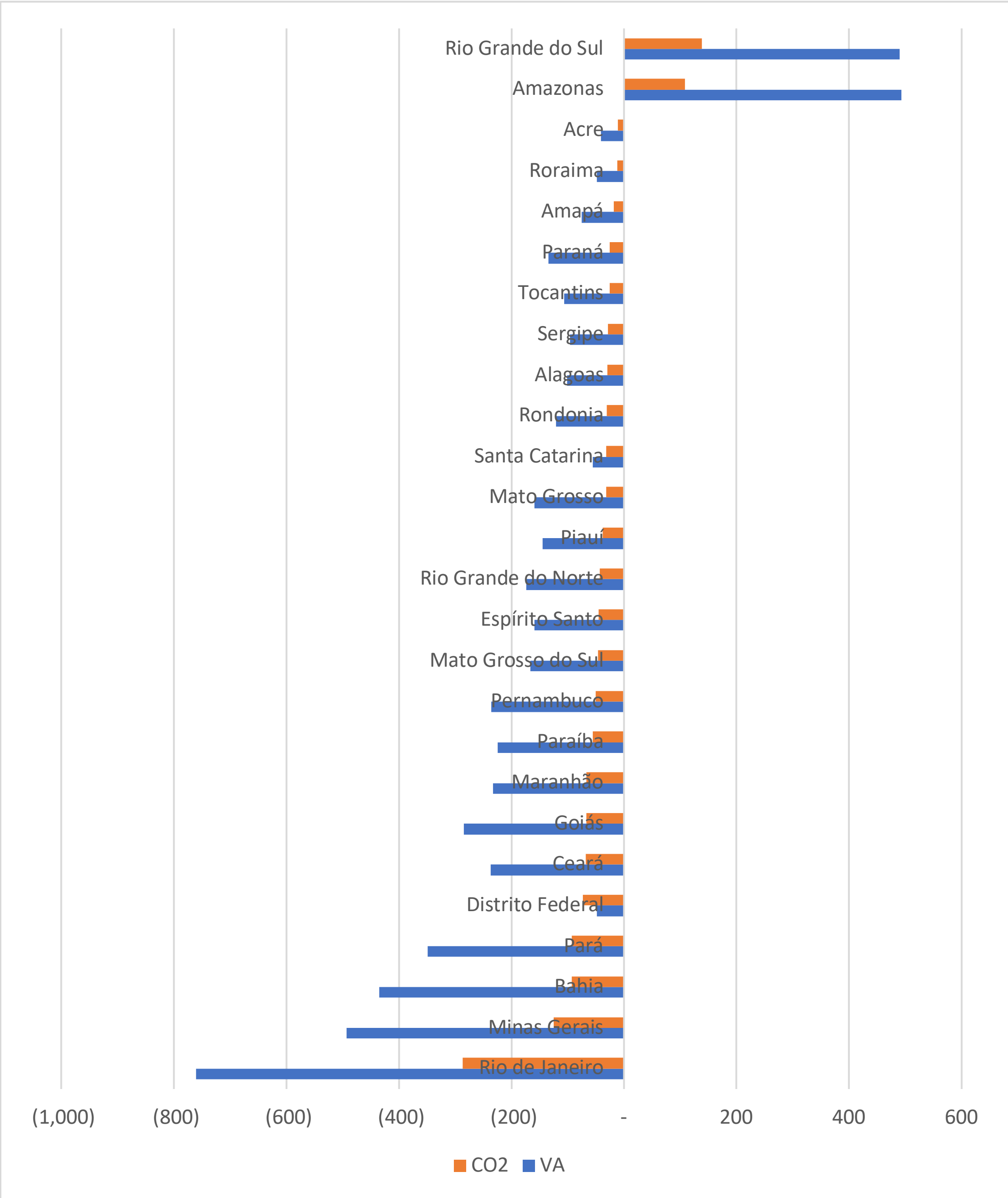
Figure 4 shows the regional net balances of interregional transfers of both VA and CO2. The measure is related to origin regions of the VA and the CO2 emissions of the resource-based industries embedded in the final demand of the non-resource-based industries. Values above one indicates that the regions are net exporters of VA and CO2, while values below one indicates that the regions are net importers. In general, the geographic distribution of positive and negative balances reveals a spatial pattern of transfers from intense regions in natural resources to more diversified and industrialised regions – usually the leading economic centres of each country. In particular, the spatial organisation of trade balances in resource sectors indicates the spatial location of natural resource-intensive export activities and the main economic business centres that demand intermediate inputs in each country.

The results reveal that the implicit transfers of CO2 are directly influenced by the geographic architecture of the domestic production chains. While input-output linkages networks between regions and sectors are decisive for the flows of goods and services required for production, they indirectly influence the carbon footprint at the subnational level. At the same time, the distribution of non-resource-based industries that incorporate VA and CO2 originated in resource-based peripheral regions reveal an unequal economic and regional pattern.

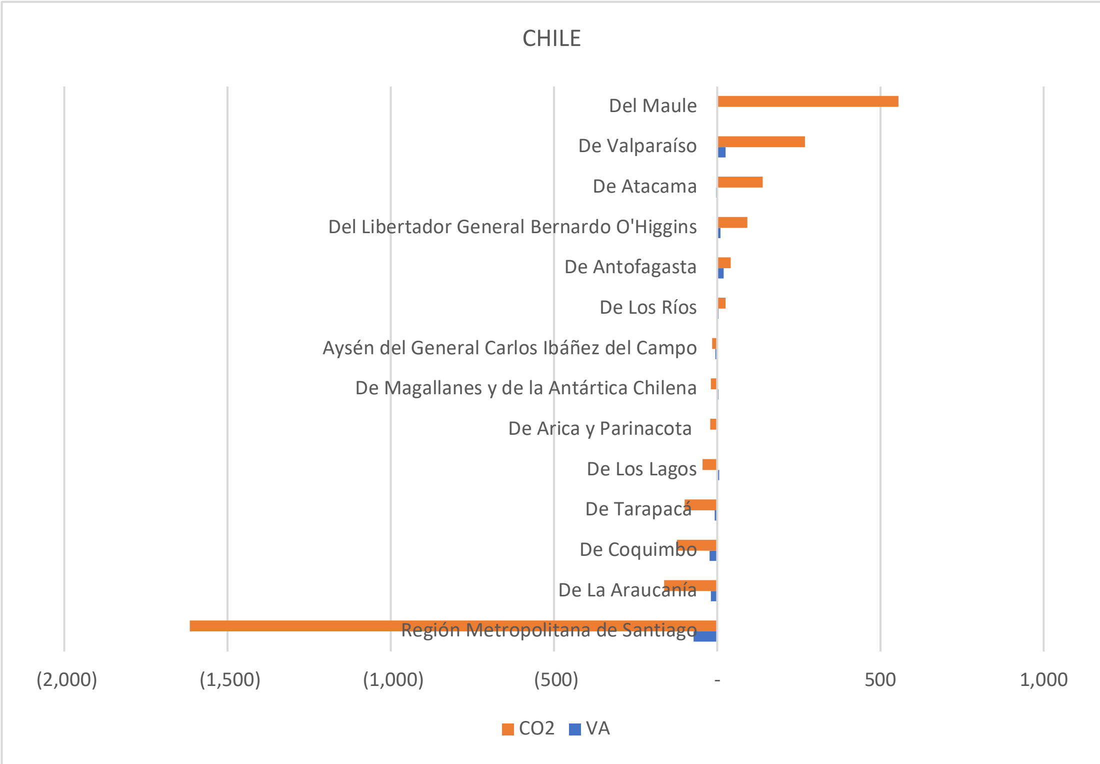
Resource-based industries tend to be in the subnational peripheries of each country, while the principal regional agglomerations seem to be more diversified, industrialised and with a greater supply of service sectors that incorporate VA and emissions from primary sectors. In Brazil, the states of São Paulo, Rio Grande do Sul and Amazonas (states with substantial relative participation in agribusiness and industrialised) are the leading net exporters of VA and CO2 embedded in goods, while Pará, Bahia, Minas Gerais and Rio de Janeiro are net importers. In the Chilean case, the results highlight the regions specialising in food production and mining for export - which also contributes considerably to meeting domestic demand - as net exporters of VA and CO2 that are absorbed by the demand of other regions. This is the case of the Del Biobio, Del Maule and Del Valparaíso regions, which stand out for the interregional shipments of high levels of VA and CO2 from the resource industries to meet the final demand the non-resource sectors. The economic core of this country, represented by the Metropolitan Region of Santiago, is a clear case of an intermediary importer of the VA and the emissions generated by the intense regions in the exploitation of natural resources, which are later commercialised internally and externally. A similar pattern occurs in Colombia, where the departments of Valle del Cauca, Atlántico, Antioquia and Bolívar, intense in the resource industry, are responsible for VA's central intermediate subnational transfers CO2 to other economic centres. The Bogotá region - the country's leading business centre - is a net importer of the pollution incorporated in the regions of origin of both VA and carbon.

Figure 4. Net balances of VA and CO2 in trade.

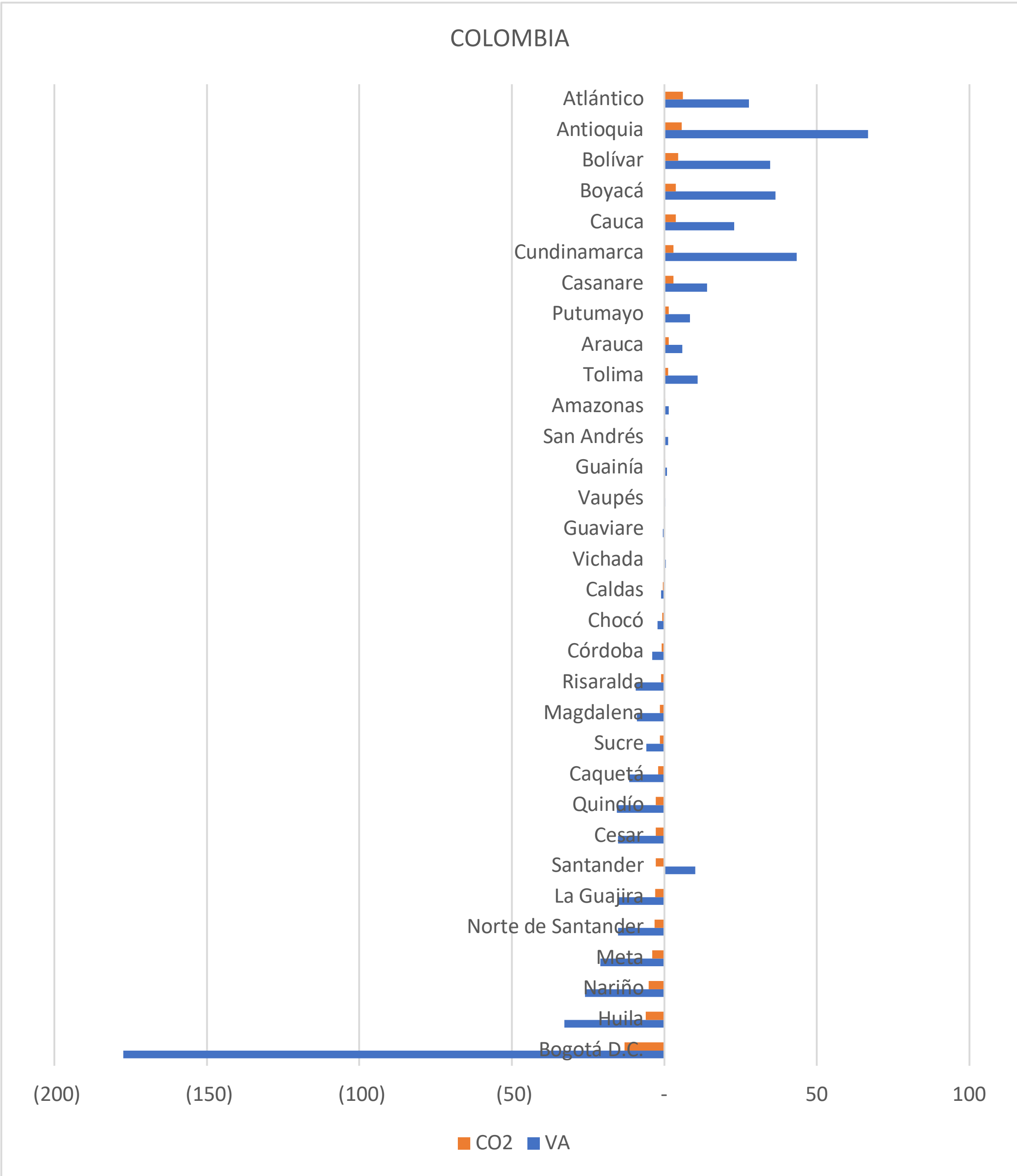
(a) Brazil


Rio Grande do Sul
Amazonas
Acre
Roraima
Amapá
Paraná
Tocantins
Sergipe
Alagoas
Rondonia
Santa Catarina
Mato Grosso
Piauí
Rio Grande do Norte
Espírito Santo
Mato Grosso do Sul
Pernambuco
Paraíba
Maranhão
Goiás
Ceará
Distrito Federal
Pará
Bahia
Minas Gerais
Rio de Janeiro
(1,000) (800) (600) (400) (200) - 200 400 600
CO2 VA

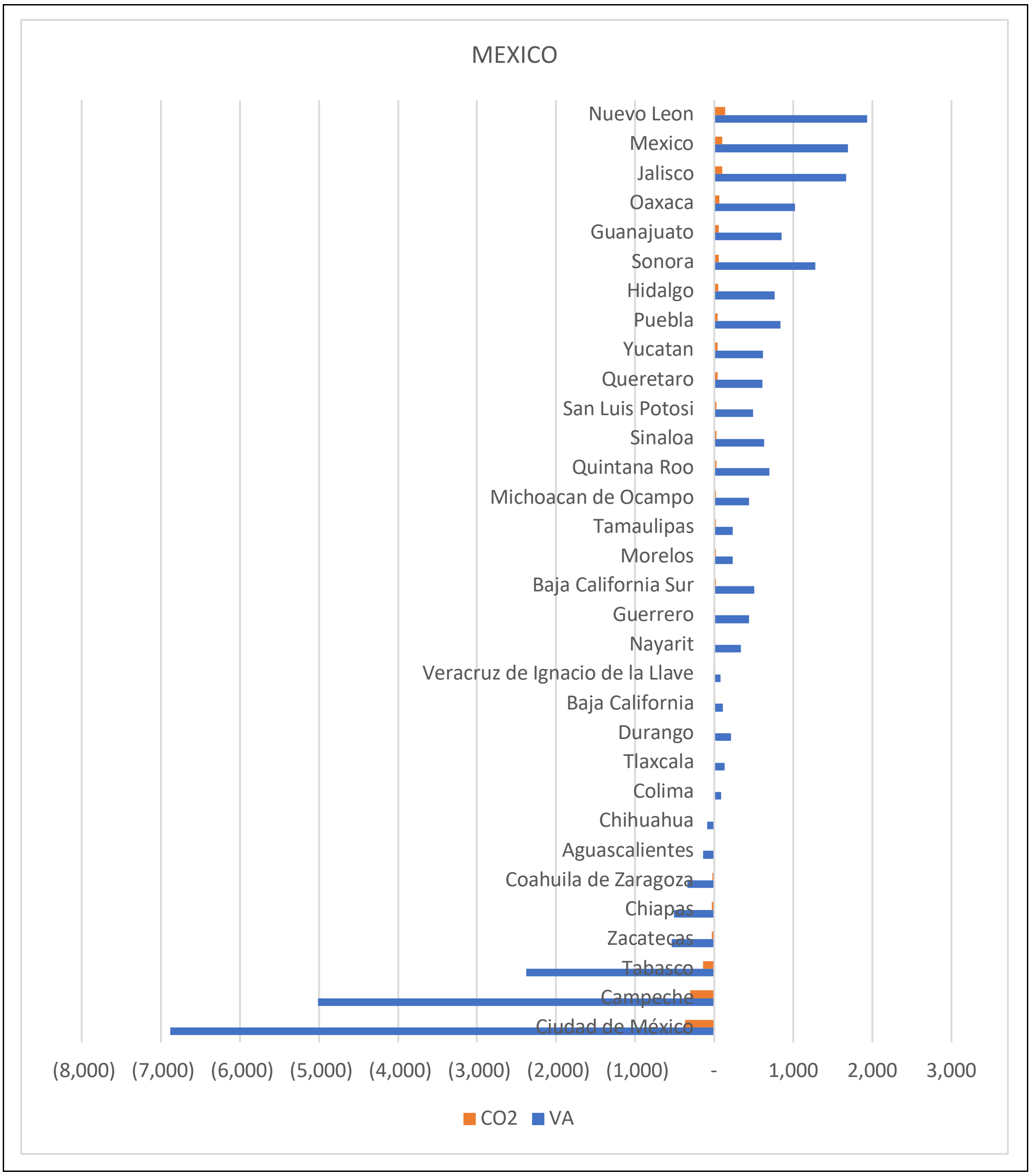
(b) Chile


CHILE
Del Maule
De Valparaíso
De Atacama
Del Libertador General Bernardo O'Higgins
De Antofagasta
De Los Ríos
Aysén del General Carlos Ibáñez del Campo
De Magallanes y de la Antártica Chilena
De Arica y Parinacota
De Los Lagos
De Tarapacá
De Coquimbo
De La Araucanía
Región Metropolitana de Santiago
(2,000)
(1,500)
(1,000)
(500)
-
500
1,000
CO2
VA

(c) Colombia


COLOMBIA
Atlántico
Antioquia
Bolívar
Boyacá
Cauca
Cundinamarca
Casanare
Putumayo
Arauca
Tolima
Amazonas
San Andrés
Guainía
Vaupés
Guaviare
Vichada
Caldas
Chocó
Córdoba
Risaralda
Magdalena
Sucre
Caquetá
Quindío
Cesar
Santander
La Guajira
Norte de Santander
Meta
Nariño
Huila
Bogotá D.C.
(200)
(150)
(100)
(50)
-
50
100
CO2
VA

(d) Mexico

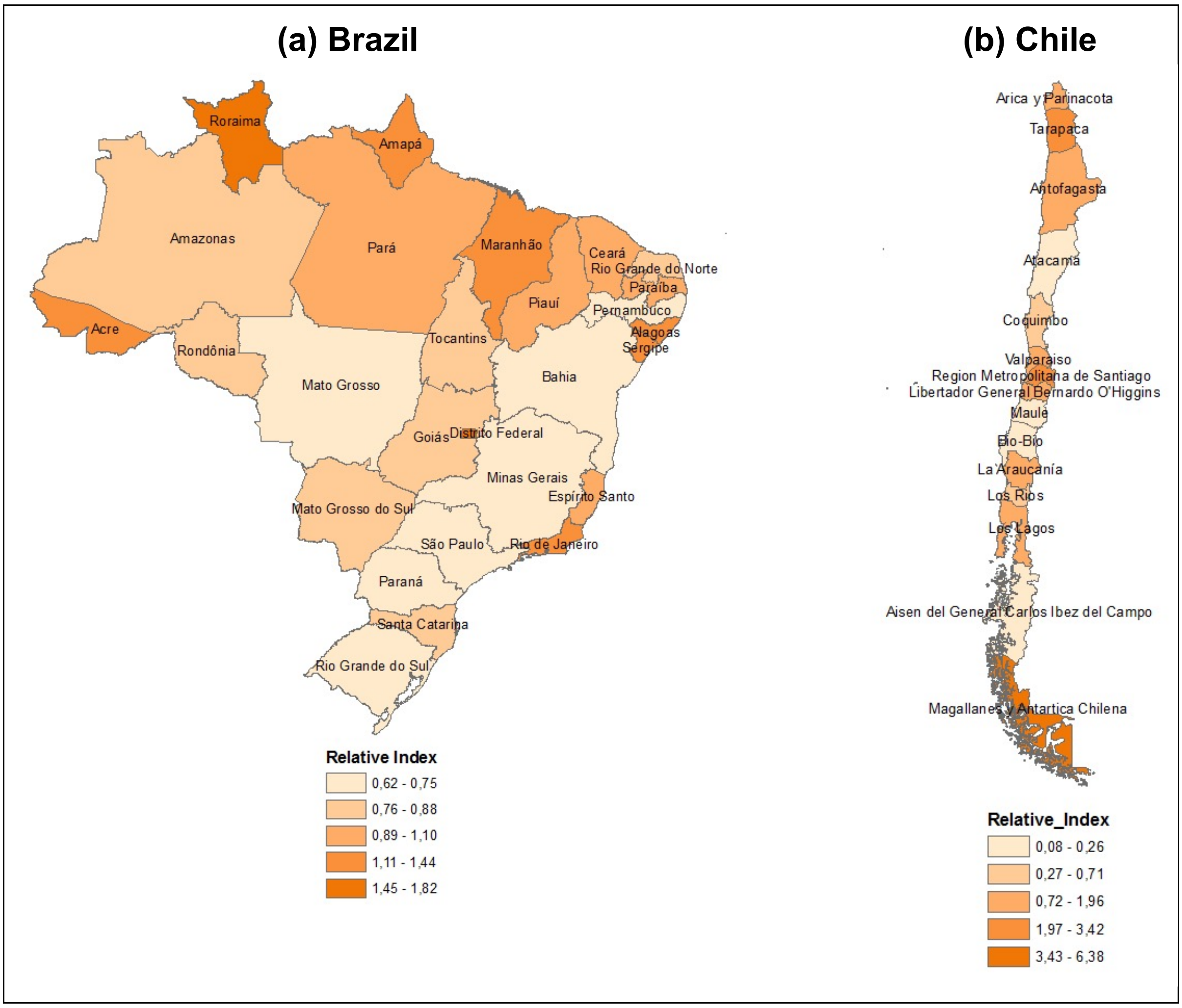


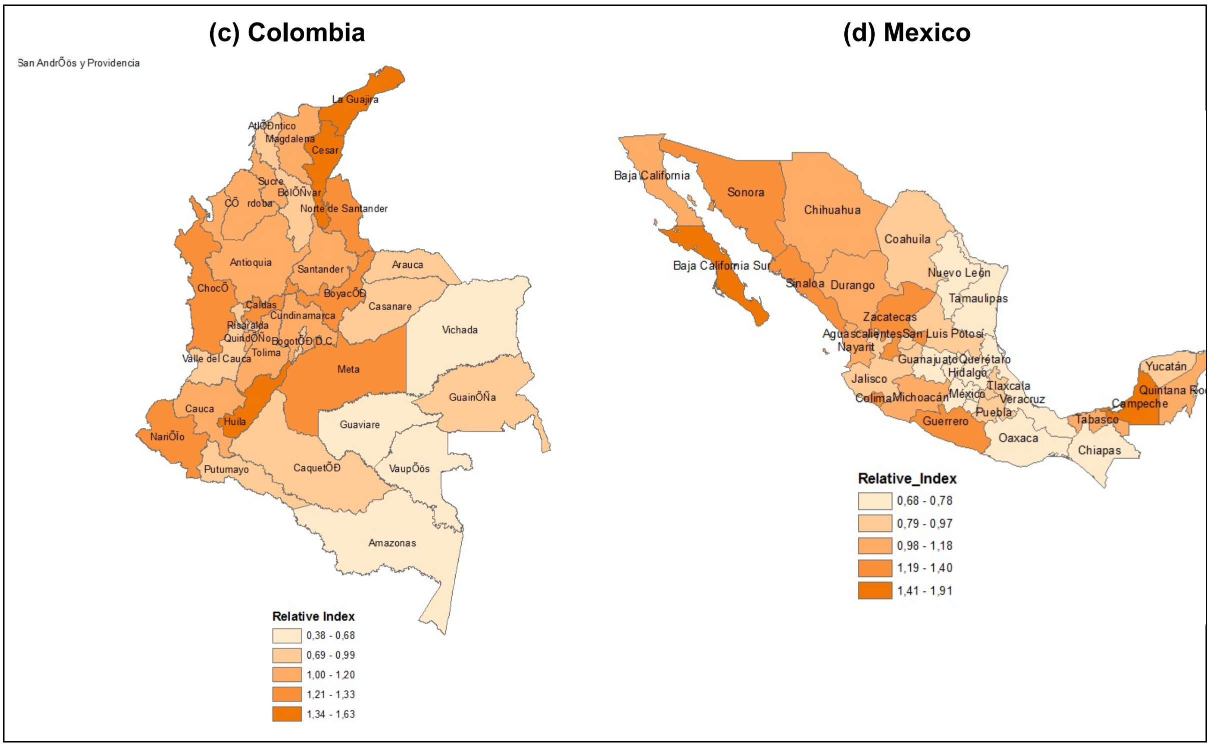
Source: Own elaboration 2022.

4.3 Relative CO2 emission intensity value chain network at the subnational level

In this section, we analyse the results of the CO2-based pollution intensity index embedded in the value chains of each subnational region of Brazil, Chile, Colombia, and Mexico. The maps in Figure 5 show the results for each region: values greater than one indicate that the region is a relatively intense source of implicit CO2 emissions among interregional VA trade – from resource industries to non-resource sectors. Overall, the spatial distribution of CO2 emissions is relatively dependent on the location of regions intense in the exploitation of natural resources. The results indicate that the transfer of VA and CO2 emissions incorporated in interregional flows is relatively concentrated for each country's demand and supply sides. Peripheral regions, especially those specialising in agriculture and mining, emit CO2 at a greater intensity than their relative contribution from VA generated and transferred to other subnational areas. This implies greater environmental responsibility, with considerable distortions concerning the potential to generate VA locally. In other words, these regions transfer relatively carbon-intensive VA, increasing the carbon footprint absorbed within the country through domestic value chains.

Figure 5. Regional index of CO2-based polluting intensity (by regional source).





Source: Own elaboration 2022.

The spatial distribution of CO2 intensity concerning trade in VA implies that the interregional transmission of pollution-intensive intermediate inputs is regionally localised due to the production of resource-based industries. As a result, economic compensation does not always occur in the same proportion as the generation of local VA, which implies unequal opportunities for sustainable regional development. Nevertheless, the general trend revealed by the calculated index is that although the countries' total emissions assign a relevant role to domestic interregional final consumption. In this regard, the resource-dependent regions are an important driver for the implicit flows of CO2 within each country. This implies a need to consider the regional organisation of local value chains when building strategies that seek to make value and trade flow between internal areas more sustainable.

Small regional economies in Northern Brazil stand out for being sources of high levels of CO2 compared to VA generated and embedded in trade. As areas specialising in exporting natural resources, mainly mining, they present a profile of intense interregional transfers in pollution (CO2), with environmental responsibility on the supply side. At the same time, the importing states of this pollution content also have a relevant role, as they demand intense intermediate inputs in pollution. In this sense, the country's subnational economic structure is centred on the south-southeast axis, in which states demand intermediate inputs from peripheral zones.

In the Chilean case, the extreme southern regions are relatively small in terms of productive structure, implying higher implicit emissions in the interregional VA trade. The southern region of Magallanes y de la Antarctica Chilena stands out as the one that, in relative terms, incorporates more emissions in relation to the locally generated VA, transferring to the rest of the country content of intense trade in pollution. This region has comparative advantages in the mining sectors (especially oil, gas, and coal) and agriculture, which, given the geographical isolation area, allows the expansion of productive activity in these sectors. The high rate is explained by the supply side, in which the region transfers relatively CO2-intensive VA to other areas of the country. Next, the Metropolitan Region of Santiago stands out, which, in addition to specialising in the technology and services sectors, also stands out for its primary production. In relative terms, RMS transfers high levels of VA to the rest of the country, while the implicit CO2 content follows such a concentrated architecture of local production networks.

Local resource economies in Colombia present the most balanced results compared to other countries, as a large set of regions (departments) are not very intense in CO2 in relation to the VA generated and transferred internally. The highlights are the poor regions of La Guajira, Huilla and Cesar, with indices ranging from 1.45 to 1.69. These departments provide inputs based on resources absorbed by the intermediate demand of the other departments, with a relative level of implicit CO2. On the other hand, in the Mexican case, Campeche, Baja California Sur and Sonora are the most intense in CO2 embedded in interregional trade, highlighting as resource-based regions that contribute to the amount of carbon footprint that is generated and absorbed inside the country.

The maps in Figure 5 suggest that the contribution of all resource sector groups to interregional (subnational) flows of non-resource industries favour the generation of CO2 emissions in each of the four countries. A consequence of this increase in the importance of resource sectors for total carbon emissions is a masked responsibility of intersectoral demand for the generation of pollution in the poorest regions (intensive in natural resources). Although there is a geographic concentration of production in the most value-added sectors, the flows of intermediate inputs between subnational regions considerably increase the internal carbon footprint, which has consequences for the sustainable matrix of each country.

5. Final remarks and policy implications

Peripheral regional economies have faced several challenging issues, notably their over-reliance on resource-based sectors such as agriculture, mining, and key chained sectors. However, current trends in climate change, a specific look at the CO_2-based polluting intensity of economic activities, and other facts, such as natural disasters, have generated a discussion about the main challenges that can convert local economies into able spaces towards sustainable development. In this sense, focusing on the Latin American case, known for its specialised economic profile in primary-exporting sectors, this study highlighted the regional role of the intensity of CO_2 emissions originated by resource activities and transferred through subnational production networks.

As considering both VA and CO_2 trade measures, we provided evidence that the use of intermediate inputs can affect the production process other than the trade in final goods, leveraging the promotion of linkages throughout the domestic supply chain, including the polluting perspective. We accounted for the relationship between the value-added and CO_2 from resource and non-resource-based industries and the final demand, encompassing the interplay among the value-added and emissions from resource-based industries and the final demand sectoral setting (Chen et al., 2018; Los et al., 2016; Meng et al., 2017; Timmer, Miroudot, & De Vries, 2019). The main result suggests an interregional dependence that implies that resource sectors, generally intense in pollution, generate more CO_2 emissions in proportion to the value-added generated in each regional economy, which has considerable implications for the sustainable development goals of these subnational areas.

Inter-regional transfers of CO_2 emissions in trade have an essential role in trade, influencing the total regional CO_2 generation. The general results indicate some spatial patterns in terms of pollution intensity in trade. First, there is a space associated with primary-exporting regions with lower value-added shares in trade while being intense in pollution. These areas tend to benefit from the lower connectivity costs associated with their domestic trade and international export activities, providing primary inputs intense in implicit CO_2 generated and traded, which are then processed in other subnational regions or other global trading partners. Another profile is dominated by subnational regions strongly linked to domestic chains as important providers and demanders of goods and services in an articulated way. Second, intermediate regions, dependent on resources and industrial capacity, are less intense in implicit CO_2- based pollution, as they manage to generate more regional value-added. Third, in each country analysed, a dense productive area is connected to local and global markets, which has diversified industrial capacity in technological and human capital-intensive sectors that can internalise the value-added. In these same regions, however, despite having a more ecological and less polluting industrial profile, they are also economic areas that demand intense CO2 inputs produced in peripheral areas of each country, with a masked environmental responsibility. This locational pattern raises the discussion on how intersectoral linkages can be important drivers for generating emissions at the domestic level, especially in countries competitive in natural resource goods. Fundamentally, this third group includes the main diversified and globally connected regions, such as the dense agglomerations of São Paulo in Brazil, Santiago in Chile, Bogotá in Colombia, and Ciudad de Mexico in Mexico.

For policy purposes, the results make it possible to assess the dependence on natural resources for Latin American development. In recent years, there has been an increase in commodity trade, starting in 2003-2000, which considerably increased the share of natural resource goods in the export agenda of many countries in the Latin American (Ocampo, 2017). However, in addition to the fact that these sectors generate lower levels of value-added for subnational regions, they have the aggravating factor of being relatively intense in the generation of CO2, which can imply problems in meeting sustainable regional development goals. Although our results showed an internally heterogeneous pattern of dependence on natural resources, regions with less diversified economic bases faced more significant disruption with the collapse of commodity prices. Two potential problems for resource regions considering a possible new cycle of expansion of exports of natural resource goods can be appointed. First, resource regions may not internalise the benefits of investments in these sectors because, due to the architecture of the regional supply chain, the income generated can be absorbed by other regions and forward sectors in the value chain. Second, the level of environmental responsibility of regions specialising in emission-intensive resource-based sectors may limit sustainable and clean development alternatives. Thus, from a regional point of view, it is relevant to design effective strategies to change the intensity of emissions from resource sectors, promoting less polluting implicit trade levels and interregional and international IO linkages networks.

At the same time, it is crucial to consolidate policies to encourage and maintain an effective supply chain for less pollution-intensive inputs. For this, an essential condition is to create cleaner energy matrices, which allow green technologies that can reduce pollution intensity by commercialised value-added. Furthermore, in terms of local development, it is essential to create structures that allow local economies to generate greater levels of value-added to commercialised goods and services, facilitating the capture of value at the territorial level. Foster agglomeration economies regionally that allow increasing the value-added generated locally. The distortion of regional emission and emission intensity impacts the achievement of the emission reduction target and the emission reduction basis, as the targets are usually based on the emission of a given year. Therefore, governments must assign concrete targets according to local specificities, whether productive or linkages.

Finally, it is worth mentioning an essential limitation of the study, which considers equivalent sectoral coefficients, regardless of the region of origin of the emissions content. In this sense, given the regional differences in terms of climatic conditions or local economic structure, the assumption of coefficient equivalence is strong and may imply relatively different conclusions. Consequently, the latter approach can underestimate the content of CO2 emissions in certain regions. However, we consider that does not considerably change the main regional implications since the location of resource-based economic activity is fundamentally dependent on the geography of natural resources, which, in turn, is consistent with the sectoral and regional results of the economic variables of the input-output model (e.g., value-added and gross output). Therefore, the regional concentration of resource-based activities compared to the location of other activities, such as industry and the commercial sectors and services business industries, is consistent with the study's results and principal conclusions. Despite being conservative, the results indicate an intense level of pollution within the production networks in subnational areas dependent on natural resources. In any case, our empirical evidence suggests the importance of advancing in the formulation of regional statistics that allow approaching the issue of carbon-based emissions from a subnational and sectoral point of view. This suggestion is more important for Latin America since the domestic demand of each country reveals itself as one of the main areas of consumption of both generated VA and implicit emissions, with considerable consequences for the design and formulation of mitigation and control strategies for the polluting nature of production chains.

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