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A relação entre participação, posicionamento e emissões ao longo das cadeias globais de valor para Argentina, Brasil e Chile: uma análise baseada em componentes principais*

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Resumo: Este estudo investiga a complexa interseção entre desenvolvimento econômico e sustentabilidade ambiental no contexto da fragmentação global da produção. O objetivo principal é analisar a relação entre participação, posicionamento e emissões ao longo das cadeias globais de valor para Argentina, Brasil e Chile. O estudo analisa o dilema da “Curva Tristeza” (*Crying Curve*): a participação nas Cadeias Globais de Valor (CGVs) concentra o valor nas extremidades da cadeia, ao mesmo tempo em que transfere a poluição para as nações em desenvolvimento, dificultando o cumprimento de seus compromissos ambientais. Este artigo integra três estruturas teóricas raramente discutidas em conjunto na literatura existente: a lógica do posicionamento funcional aplicada pela Curva Sorriso (Valor Acrescentado), a dimensão ambiental da Curva Tristeza (Intensidade das Emissões) e a Análise de Componentes Principais como ferramenta estatística para analisar a relação entre a participação nas CGVs, o posicionamento e as emissões. O estudo aborda, assim, as estruturas latentes ocultas nos dados e, em última análise, estabelece uma ligação entre a estrutura produtiva e as emissões ao longo das CGVs. A análise utiliza dados da OCDE para 67 países e 45 setores econômicos no período de 1995 a 2018. É complementada por Análise de Componentes Principais (ACP) para construir índices compostos de *upgrading*, identificar quais países e setores mais contribuem para as emissões globais e validar estatisticamente sua posição nas CGVs. Os resultados obtidos por meio da Análise de Componentes Principais (ACP) revelam um desacoplamento estatístico entre integração produtiva e impacto ambiental na Argentina, Brasil e no Chile. A Dimensão 1 (Integração Produtiva) e a Dimensão 3 (Intensidade Ambiental) apresentaram correlação próxima de zero, indicando que avançar para estágios de maior valor agregado não determina linearmente a pegada de carbono de um país. Além disso, o estudo identifica que, embora esses países compartilhem um perfil de integração de “média complexidade”, setores específicos intensivos em energia atuam como “refúgios de poluição” (*pollution havens*), sugerindo que os resultados ambientais dependem mais de políticas setoriais direcionadas, que modifiquem o padrão do posicionamento nas CGVs.

Palavras-chave: Participação e Posicionamento; Cadeias globais de valor; Análise Componentes Principais.

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The relationship between participation, positioning, and emissions along global value chains for Argentina, Brazil, and Chile: a principal component analysis

Abstract: This study investigates the complex intersection between economic development and environmental sustainability in the context of global production fragmentation. The primary objective is to analyze the relationship between participation, positioning, and emissions along global value chains for Argentina, Brazil, and Chile. The study analyzes the “Crying Curve” dilemma: whether participation in Global Value Chains (GVCs) concentrates value at the ends of the chain while transferring pollution to developing nations, making it more difficult for them to meet their environmental commitments. This article integrates three theoretical frameworks rarely discussed together in the existing literature: the logic of functional positioning applied by the Smile Curve (Value Added), the environmental dimension of the Crying Curve (Emission Intensity), and Principal Component Analysis as a statistical tool to analyze the relationship between GVC participation, positioning, and emissions. The study thus addresses the latent structures hidden in the data and ultimately establishes a link between productive structure and emissions along GVCs. The analysis uses OECD data for 67 countries and 45 economic sectors over the period from 1995 to 2018. It is complemented by Principal Component Analysis (PCA) to construct composite upgrading indices, identify which countries and sectors contribute most to global emissions, and statistically validate their position in GVCs. The results obtained through Principal Component Analysis (PCA) reveal a statistical decoupling between productive integration and environmental impact in Argentina, Brazil, and Chile. Dimension 1 (Productive Integration) and Dimension 3 (Environmental Intensity) show a near-zero correlation, indicating that advancing to higher value-added stages does not linearly determine a country’s carbon footprint. Furthermore, the study identifies that although these countries share a “medium-complexity” integration profile, specific energy-intensive sectors act as pollution havens, suggesting that environmental outcomes depend more on targeted sectoral policies that modify the pattern of positioning in GVCs.

Keywords: Participation and Positioning; Global Value Chains; Principal Component Analysis.

1 INTRODUCTION

Contemporary economic globalisation is characterised by the consolidation of Global Value Chain (GVCs), which are associated with gains in production efficiency, income redistribution, and a new hierarchy in the international division of labour (Baldwin, 2014; Gereffi; Fernández-Stark, 2016). At the same time, these chains are linked to the increase in global carbon dioxide (CO_2) emissions, resulting from the spatial displacement of pollution through international trade flows (Meng et al., 2023; Peters; Hertwich, 2007; Zhang et al., 2017).

There is a level of complexity within GCVs that hinders clear attribution of responsibility for emissions. Meng et al. (2023) propose a unified framework that enables the tracing of CO_2 emissions along the value chain at the sectoral, bilateral, and national levels. Beyond the quantification of emissions, this new framework allows for the redistribution of responsibility among producers,

consumers, exporters, importers, investors, and third-party countries, approaching the concept of "shared emissions" (Lenzen et al., 2007; Dietzenbacher et al., 2020).

Meng et al. (2023) present the positioning of activities at the extremes of the chain, namely: research and development (R&D) and marketing, as upstream and downstream respectively, which generate higher added value, while manufacturing stages, located at the centre of the chain, generate lower added value, thereby creating the Smile Curve. However, the study also introduces the Crying Curve, which has an inverted U-shape, where activities at the chain's extremes, research and development (R&D) and marketing, generate lower CO_2 emissions, while intermediate stages, such as manufacturing and assembly, exhibit higher levels of emissions.

Participation in GVCs, as well as positioning within them, has been widely analysed through the decomposition of value added in exports. Meng et al. (2023) highlight that the data show developing countries are significantly increasing their participation in GVCs, particularly in complex, energy-intensive domestic chains. The models provide a framework to quantify participation in GVCs, linking increased participation to the convergence of emissions across countries (Koopman et al., 2014; Cai et al., 2022), while sectoral emissions profiles indicate that industrial and manufacturing sectors lead the emissions transferred between countries through trade Meng et al. (2018), Koopman et al. (2014).

The environmental impact along GVCs can be estimated by combining value added and emissions, yielding different perspectives such as production, consumption, and trade (Meng et al., 2015a). Participation in GVCs may lead to the convergence of carbon emissions among nations, with studies showing a link between GCV participation and CO_2 growth (Cai et al., 2022).

According to OECD (2025), the total greenhouse gas emissions for Brazil, Argentina, and Chile, excluding land use, land-use change, and forestry (LULUCF). In 2022, Brazil stands out with 1.23 billion tonnes (1.23 Gt CO_2 -eq), followed by Argentina with 0.35 Gt, and Chile with 0.11 Gt. These results highlight a strong regional asymmetry, where Brazil concentrates the largest share of emissions among the three countries analysed. This difference suggests that structural factors, such as the size of the economy, the productive profile, and the level of integration into global value chains, may be associated with the observed environmental performance. When land use, land-use change, and forestry (LULUCF) are taken into account, Brazil remains far ahead of both Argentina and Chile, and continues to surpass China, India, and the United States.

Therefore, the main objective of this study is to analyse the relationship between participation, positioning, and greenhouse gas (GHG) emissions in Argentina, Brazil, and Chile (ABC Bloc), over the period 1995–2018. Considering this context, the present study seeks to answer the following question: how do countries' participation and positioning in GVCs relate to the sectoral and country emissions patterns of Argentina, Brazil, and Chile?

The study integrates three theoretical frameworks rarely discussed together in the existing literature: the logic of functional positioning applied by the Smile Curve (Value Added), the environmental dimension of the Sadness Curve (Emissions Intensity), and Principal Component Analysis as a statistical tool for analyzing the relationship between participation in GVCs, positioning, and emissions. The study thus addresses the latent structures hidden in the data and ultimately establishes a link between the productive structure and emissions along GVCs.

In addition to this introduction, the study is organized into four sections. The second section presents the literature review, providing a deeper contextualization of the topic. The third section describes the methodology employed, while the fourth section outlines the timeline and the next steps of the research.

2 LITERATURE REVIEW

2.1 The Importance of Industrial Upgrading for the Strategic Repositioning of Countries Along Global Value Chain

GVCs account for a significant share of global trade, GDP, and employment, as they connect firms, workers, and consumers worldwide. By examining this structure, we gain an understanding of how industries are organised and the dynamics of the various actors involved along the chain, tracing global production patterns and determining the roles played by developed and developing countries (Gereffi; Fernández-Stark, 2011; Gereffi; Fernández-Stark, 2016). This chain system represents a complex international production distribution in which tasks are allocated among firms globally or regionally, necessitating new indicators to measure countries' participation and positioning.

2.1.1 Participation and Positioning in Global Value Chain

Economic globalization is increasingly characterised by fragmented production processes for goods that are distributed internationally. As firms of all sizes seek to capitalise on factor cost differentials and the reduction of trade and investment barriers, international transactions of intermediate commodities have come to dominate global trade. Consequently, the heterogeneity in the origin of components is a hallmark of most commodities destined for final consumption. This internationalisation of the production process, however, presents a series of challenges and critical issues in definition and measurement, as conventional approaches for characterising trade flows and presenting trade statistics have proven inadequate for capturing the essential features of international production sharing.

According to Backer and Miroudot (2014), when considering GVCs, the first question that comes to mind is the extent to which countries are involved in vertically fragmented production. In other words,

it is about understanding how countries are integrated into different productive sectors and what their influence is within these chains.

Koopman et al. (2014) discuss participation in GVCs through the decomposition of gross exports. They illustrate how much of the exported value corresponds to domestic value added, foreign value added, and the portion subject to double counting - that is, the extent to which a country participates in GVCs and the degree to which its economy is involved in these exchanges.

Subsequently, this approach was criticised by Los et al. (2016), who proposed an alternative method based on "hypothetical extraction" for a clearer definition of value added in exports. Miroudot e Ye (2017) further refined the accounting framework, addressing other unresolved issues from Koopman, clarifying the nature of double counting, improving the calculation of foreign value added, and extending the framework to industry-level analyses.

Thus, the greater the incorporation of foreign value added in gross exports and the higher the value of inputs exported to third countries and used in their exports, the greater a country's participation in GVCs (Backer; Miroudot, 2014). Considering that a country or industry is an active part of GVCs, it is also necessary to examine its positioning.

The concept proposed by Antràs et al. (2012) positions countries or industries according to their distance from the extremes within GVCs. For example, being downstream indicates proximity to the end of the chain, such as an assembler or distributor, while upstream refers to the beginning of the chain, as in the case of suppliers of basic inputs. In this way, the metric assesses where a country or sector is located in the global production sequence.

To analyse the positioning of countries and industries, it is important to consider the extent to which a country-industry pair sells its output to final consumers worldwide or supplies intermediate inputs to other producing sectors. A sector that sells more to final consumers (downstream) is closer to the end of the value chain, whereas a sector that sells little to final consumers is more likely to be at the beginning of the chain (upstream) (Mancini et al., 2024).

For most countries, some industries are positioned upstream, that is, in raw materials sectors, such as mining, basic metals, pulp and paper, wood, chemicals, and the utilities industry, including electricity, gas, and water supply. Downstream industries, which produce final goods or services, include food, hotels, restaurants, construction, public administration, health and social services, and education. In the middle of the chain are agriculture and transport services, such as air transport, which can represent intermediate inputs for other industries or domestic final consumption (Meng et al., 2020).

For individual firms, when identifying the production pattern, the logic of the Smile Curve is widely used to structure the position of industries within the chain. That is, inputs at the beginning and end of the chain generate higher added value, forming a curve where the centre is lower and the extremities attract greater investment. Rungi e Del Prete (2018) provides evidence that tasks at the initial and final stages of the supply chain generate higher value added.

Participation in GVCs, as well positioning within them, has been widely analysed through the decomposition of value added in exports. Meng et al. (2023) highlight that the data show developing countries are significantly increasing their participation in GVCs, particularly in complex, energy-intensive domestic chains. The models provide a framework to quantify GVCs participation, linking increased participation to the convergence of greenhouse gas (GHG) emissions across countries (Koopman et al., 2014; Cai et al., 2022).

2.2 Climbing the Value Chain with Lower Environmental Impact: The Challenge of Upgrading in the Era of Production Fragmentation

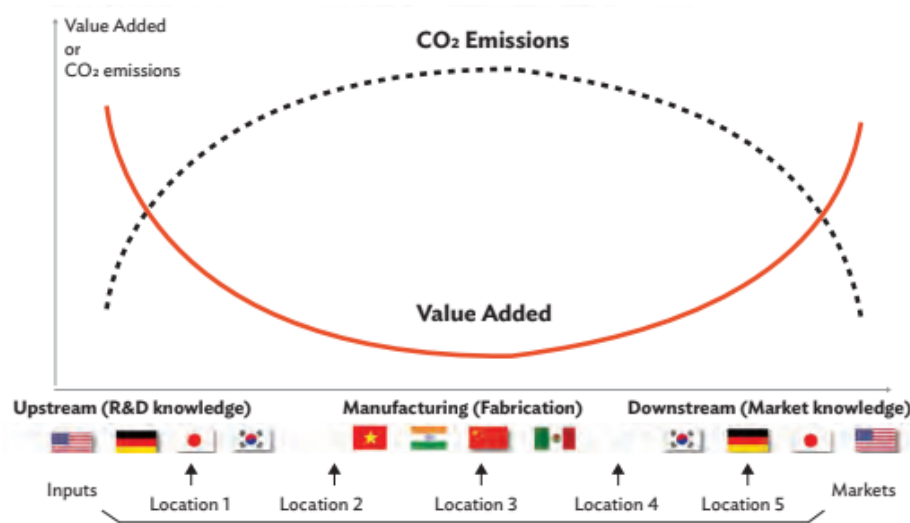
Global Value Chain (GVCs) contribute significantly to CO_2 emissions, with global direct emissions reaching approximately 40% through international trade (Wu et al., 2019). Although production activities contribute positively to countries' development and technological progress, the environmental consequences are negative in terms of pollution (Wang et al., 2020).

Li et al. (2023) note that improving a country's position in the value chain can enhance green economy performance, however, participation in the global value chain may have detrimental effects. However, according to Siewers et al. (2024), firms active in GVCs are more likely to adopt environmentally friendly technologies and practices, comply with regulations, and monitor emissions. The positioning of countries within GVCs promotes environmental quality in developed and emerging countries, as well as growth in developing and underdeveloped economies (Ali and Wang, 2023).

2.2.1 Smile Curve and Crying Curve Along Global Value Chain

The fragmentation of production and countries' integration into Global Value Chains (GVCs) generate distinct patterns of value capture and environmental impact. In order to understand these dynamics, the literature employs complementary graphical representations: the Smile Curve and the Sadness Curve. The former relates production stages to levels of value added, while the latter maps the concentration of CO_2 emissions along the same value chain. Figure 1 illustrates the trade-off between economic upgrading and carbon intensity in the international division.

Figure 1: Smile Curve of Value-Added vs Crying Curve of CO_2 Emissions along GVCs



Source: Meng et al. (2015b).

Since the beginning of the 21st century, economic globalization has significantly transformed the way countries divide labor internationally, resulting in the widespread expansion of the global value chain (GVCs). Participation in GVCs is important because it enables both developed and developing economies to leverage their comparative advantages and obtain value added, income, and employment opportunities (Gereffi; Fernández-Stark, 2016; Meng et al., 2020).

However, GVCs are also associated with massive greenhouse gas emissions and pollution in energy-intensive stages of production with Figure 1 (Meng et al., 2023).

For the People's Republic of China (PRC), accession to the World Trade Organization (WTO) in 2001 and its subsequent active participation in GVCs, particularly as the production hub of the so-called "Factory Asia", led to a sharp increase in CO_2 emissions (Meng et al., 2015b).

China often specializes in low-value-added tasks, such as manufacturing and assembly, which are associated with high carbon emissions, whereas countries engaged in R&D and marketing capture more value added while bearing fewer emissions (Meng et al., 2015b; Baldwin, 2013).

Meng et al. (2023) present the positioning of activities at the extremes of the chain, namely research and development (R&D) and marketing, as upstream and downstream, respectively, generating higher added value and forming the Smile Curve. However, the study also introduces the Crying Curve, in which these same activities generate lower CO_2 emissions, while intermediate stages, such as manufacturing and assembly, are concentrated in emissions.

Rather than a deterministic relationship, the Crying Curve should be interpreted as a conditional pattern, contingent on energy intensity, regulatory frameworks, and technological adoption across sectors. Under this premise, the environmental cost along the global value chain can be estimated by

combining value added and emissions, yielding different perspectives such as production, consumption, and trade (Meng et al., 2015a).

Zhang et al. (2017) used a multi-regional input-output matrix to test the pollution haven hypothesis, highlighting the fragmentation of global production. It is observed that as countries engage in more trade of intermediate products within GVCs, they tend to bear higher emissions, whereas countries positioned more in R&D or marketing accumulate more value and less pollution.

The sectoral emissions profile indicates that industrial and manufacturing sectors lead the emissions transferred between countries through trade (Meng et al., 2015b; Koopman et al., 2014). At the global level, there is a strong interconnection among sectors such as energy, transport, chemical industry, and agriculture. However, the sectoral profile shows that primary and energy sectors have higher emissions intensity, while the services sector has a lower impact (Lenzen et al., 2007; Tukker et al., 2013). Mukut Sikder et al. (2022) point out that a 1% increase in industrialization leads to a 0.54% rise in CO₂ emissions.

Despite the high degree of global interconnection, recent evidence points to a process of deglobalization, in which economic agents are increasingly reducing their international linkages and relocating economic activity towards domestic economies, reshaping global supply chains. In this context, a gradual transition from global to more regionalized supply chains has been observed (Yucesan, 2025).

Given the impact evidenced by GVCs, particularly in the sectoral concentration of GHG emissions, it becomes necessary to understand how international governance instruments regulate and limit such impacts. In this context, the environmental commitments undertaken by Argentina, Brazil, and Chile, formalized in global agreements such as the Paris Agreement and the Madrid Protocol, establish the imperative of development trajectory that prioritizes decarbonization and environmental protection. However, the theoretical framework of Global Value Chains (GVCs), and specifically the concept of the Crying Curve, which highlights the concentration of the most polluting and lowest value-added, activities at the center of the production chain, typically in developing countries, poses a direct structural challenge to these objectives. Accordingly, this paper serves as an empirical bridge, employing Principal Component Analysis (PCA) to quantify and verify whether the Industrial Upgrading achieved by these countries is robust enough to generate simultaneous Environmental Upgrading, capable of reconciling economic growth with international sustainability obligations.

3 . METHODOLOGY

This study analyses how the participation and positioning of Argentina, Brazil, and Chile in Global Value Chain (GVCs) influence their sectoral greenhouse gas (GHG) emissions. To achieve this objective, the methodology combines environmental input-output analysis, the smile and crying curve

framework, and multivariate statistical techniques—specifically, Principal Component Analysis (PCA) and Cluster Analysis.

3.1 Definition of Key Variables

This study focuses on two key variables for analyzing development and integration into the value chain: industrial upgrading and environmental upgrading. The following sections detail the conceptualization and dimensions of each. The concept of "upgrading" has traditionally been applied to economic and functional improvements within global value chain (GVCs) (Humphrey; Schmitz, 2002; Gereffi, 2019), but it has more recently gained prominence in environmental dimensions as well (Bolwig et al., 2010; De Marchi et al., 2013).

Industrial upgrading is a central concept in the literature on Global Value Chain (GVCs) and economic development, referring to the process through which countries, firms, and sectors move toward activities with higher value added, greater productivity, and higher technological sophistication. As discussed by Costa (2025), industrial upgrading is a multidimensional phenomenon that cannot be captured by a single measure.

Industrial upgrading is not merely a technological process, it is also reflected in the extent to which economies or industries increase their participation in more productive, dynamic, and knowledge-intensive sectors. Costa (2025) argues that monitoring these variations makes it possible to assess the growth of sectors in terms of aggregate productivity, which constitutes a central element for characterizing trajectories of productive development.

In line with this literature, we employ indicators that capture sectoral behaviour over time - such as changes in value added, employment, and production linkages - to measure industrial upgrading. These indicators enable us to observe the industrial evolution of each country and sector, as well as their alignment with patterns of higher productivity and sophistication.

In this study, we also consider environmental upgrading within GCVs, a topic that has become increasingly central in debates on sustainable development and productive performance.

Krishnan et al. (2023) emphasize that upgrading only truly occurs when improvements in processes are accompanied by positive environmental outcomes; otherwise, environmental downgrading takes place. Accordingly, the process of environmental upgrading includes actions such as the adoption of more efficient technologies, improvements in production methods, environmental certifications and standards, agroecological practices, circular economy strategies, and eco-efficiency measures. Its measurable environmental outcomes include emission reductions, decreases in waste generation, lower use of input-intensive resources, and improvements in soil, water, or biodiversity quality.

In the following section, we discuss Principal Component Analysis, which will enable us to examine the industrial and environmental upgrading previously described.

3.2 Principal Component Analysis (PCA)

The construction of the Industrial Upgrading and Environmental Upgrading indices will be carried out using Principal Component Analysis (PCA). This method makes it possible to extract the maximum variance from the original data in a lower-dimensional subspace, resulting in objective, uncorrelated indices that are representative of the latent structure of the set of variables. All variables were standardized before PCA to avoid scale-driven dominance and to ensure that the extracted components reflect correlation patterns rather than magnitude differences.

PCA solves the optimization problem of finding the best low-rank approximation of the matrix $X \in \mathbb{R}^{n \times p}$. The exact solution is obtained through the Singular Value Decomposition (SVD): $X = UDV'$. According to the Eckart–Young Theorem, we can minimize the reconstruction error by retaining only the first k principal components. The retained components are interpreted as latent dimensions capturing productive integration and environmental intensity, consistent with the multidimensional nature of upgrading.

This choice of method is justified because the objective is data reduction and index construction rather than modeling a latent causal structure with error terms. From this decomposition, two main outputs are essential for our economic interpretation:

- The loadings ($A = V_k$): These represent the weights of each variable (such as GVC participation or CO intensity) in the construction of the indices. They reveal which economic or environmental factors contribute most to the positioning of a country-sector pair.
- The scores ($F = U_k D_k$): These provide the coordinates of the observations in the new reduced space. They allow us to rank and group sectors based on their actual performance in industrial and environmental upgrading.

By reducing complexity, PCA enables the objective construction of composite variables that capture the most significant patterns of economic development and sustainability.

3.3 Empirical Analysis Framework

3.3.1 Construction of Indices

To operationalise the multidimensional concept of Upgrading, as discussed in the literature Humphrey and Schmitz (2002), Costa (2025), it is necessary to construct indices that aggregate economic, social, and environmental variables. Aligned with the theoretical framework, this study proposes the development of two composite indices (Industrial Upgrading and Environmental Upgrading) based on

a set of indicators detailed in Tables 1. The objective is to employ Principal Component Analysis (PCA) to objectively weight the contribution of each variable and capture the underlying dimension that defines the development and sustainability profile of each country or sector.

Table 1: Indicators

Indicators	Variable/Source	Definition
GVC participation indicators	<i>GVC_Pat_b</i> – OECD	Total backward participation: foreign value added embodied in exports
	<i>GVC_Pat_b_simple</i> – OECD	Direct component of backward participation
	<i>GVC_Pat_complex</i> – OECD	Indirect component of backward participation (through multiple stages)
Greenhouse gas emission	<i>GHG</i> – OCDE	Greenhouse gas emissions, tons, per capita

Source: Author's own elaboration based on RIGVC UIBE (2016)

The indicators employed by Costa (2025) provide a comprehensive basis for analysing the multidimensional nature of industrial upgrading, encompassing economic, social, and structural dimensions within the framework of the global value chain.

3.4 Database

This study adopts the multiregional environmental accounting approach, as proposed by Meng et al. (2023), which allows the simultaneous tracking of value added and emissions along the value chain. The core data for this tracking are extracted from the Organisation for Economic Co-operation and Development (OECD), which provides input-output tables and sectoral environmental accounts. This matrix serves as the basis for calculating participation and positioning indicators in global value chains (GVCs) and CO_2 emissions (GHG).

The variables presented in Table 1 will be structured for the following countries: Argentina, Brazil, Chile, and 64 other countries. Covering the period from 1995 to 2018, the period before the pandemic, for data analysis without the risk of noise. To ensure the robustness of the Principal Component Analysis (PCA), the number of retained components was determined based on three formal criteria: eigenvalues greater than unity (Kaiser Criterion), cumulative explained variance, and the economic interpretability of the dimensions. Furthermore, the stability of the PCA results was verified across the longitudinal dimension of the database, the unit of observation adopted in this research is the country–sector–year trio. The analysis covers the period from 1995 to 2018, totaling a historical series

that allows capturing structural changes in productive integration and environmental performance before the shocks caused by the COVID-19 pandemic.

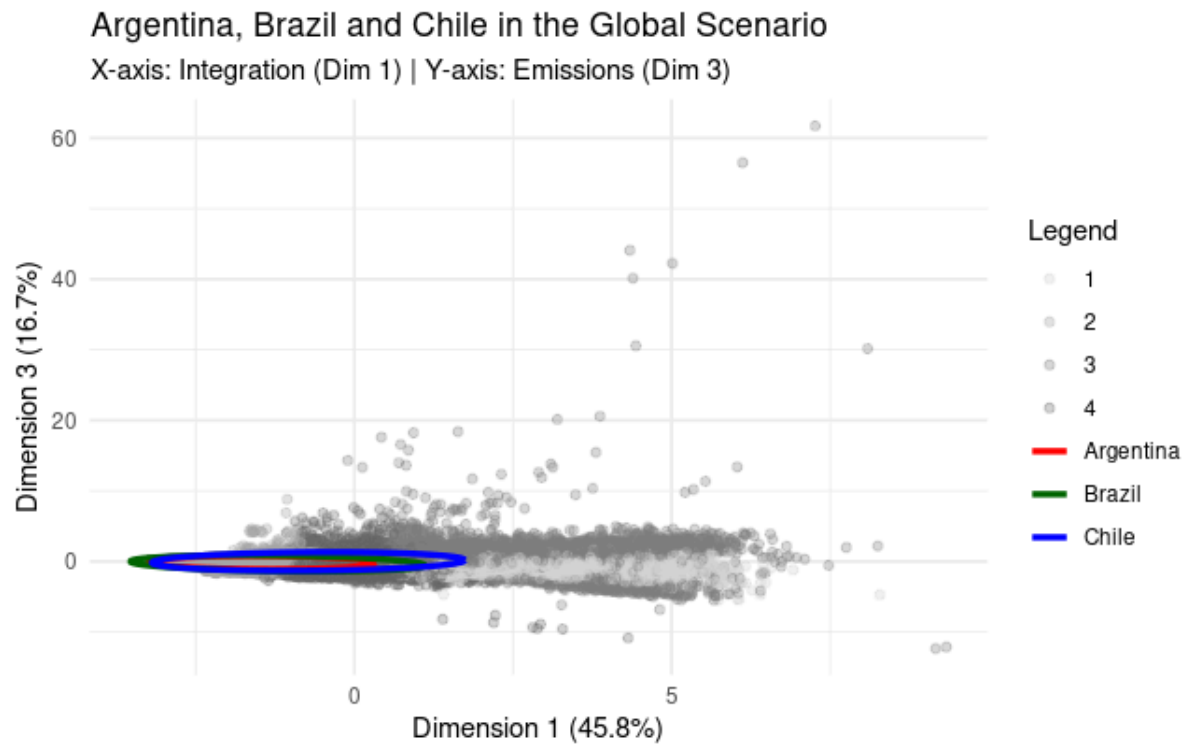
4 RESULTS

The PCA identified three main dimensions that capture the latent structure of the dataset. The first dimension (Dim 1) is interpreted as 'Productive Integration and Scale', as it shows strong positive loadings for Value Added and GVC participation variables. In contrast, the second dimension (Dim 2) specifically captures Environmental Intensity, being primarily associated with CO_2 emission.

A correlation analysis between the scores of Dim 1 and Dim 3 yielded a coefficient near zero, statistically confirming the orthogonality between productive integration and environmental impact in the ABC countries. This result indicates that economic positioning within Global Value Chains (GVCs) is not linearly associated with carbon emissions, suggesting the possibility of independent environmental trajectories.

Figure 2 positions the productive sectors of 67 countries within the multidimensional framework of Global Value Chains (GVCs) and the Environment. It can be observed that the confidence ellipses for the countries analyzed, Argentina, Brazil, and Chile, show substantial overlap. Economies with an intermediate level of participation and positioning are anchored in the Cluster according to the literature, remaining distant both from the centers of high technological sophistication (Cluster 1) and from the low-integration poles.

Figure 2: Global Overview

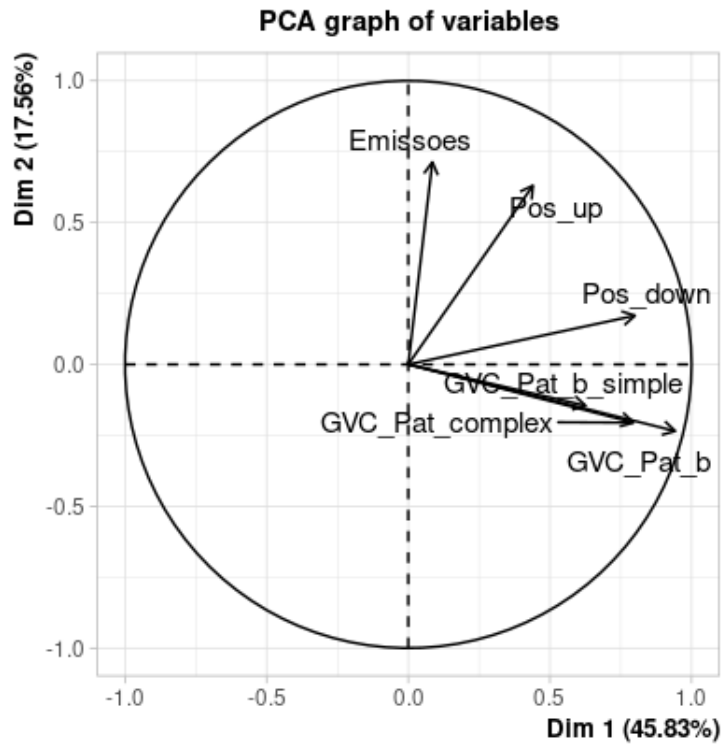


Source: Own elaboration

This concentration of the graph indicates that these countries operate predominantly in producer-driven chains, focused on intermediate manufacturing. The overlap of the confidence ellipses confirms that the ABC bloc shares similar structural challenges regarding external integration. Baldwin (2013) reminds us of the value-added trap, in which value capture is constrained by positioning in less technologically advanced segments of the chain. In contrast to Cluster 1 economies, which move toward the extremes of Dim 1 (higher sophistication), the ABC bloc remains in a zone of “medium complexity.”

The variables related to participation in the chains (GVC_Pat_b, GVC_Pat_complex) and downstream position (Pos_down) are strongly projected onto Dimension 1, which explains 45.8% of the total variance, as shown in Figure 3. In contrast, the Emissions variable is projected almost vertically onto Dimension 3 (or Dim 2 in secondary components), showing orthogonality (an angle close to 90°) relative to the economic variables. This empirical finding suggests a decoupling.

Figure 3: Variables

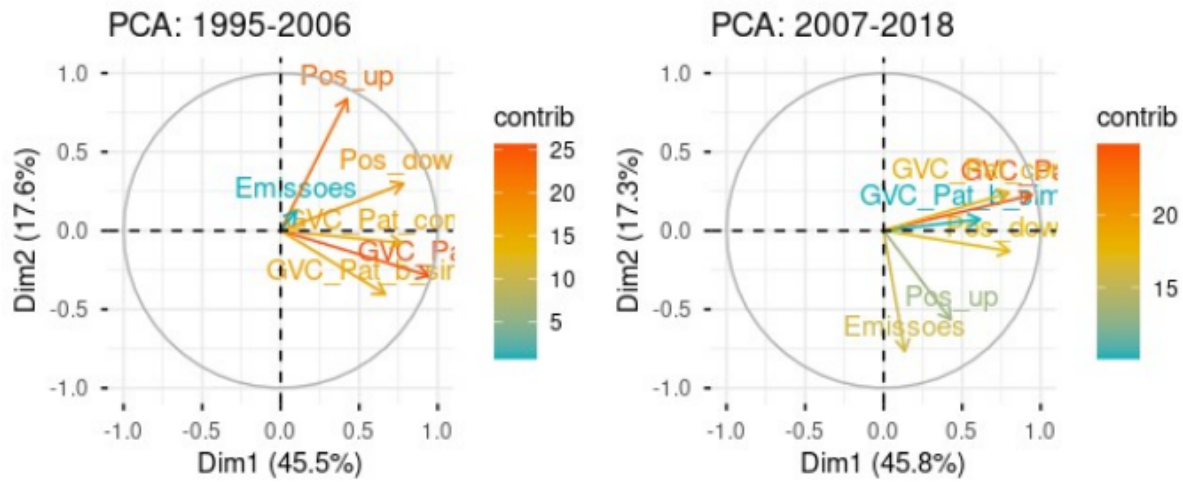


Source: Own elaboration

The comparison between the subperiods 1995–2006 and 2007–2018 reveals remarkable stability in the data, as shown in Figure 4, with the first dimension preserving nearly the same proportion of explained variance (45.5% and 45.8%, respectively). Variables related to productive integration and participation in global value chains maintain consistent projections on the first component, confirming that the patterns of economic integration of the ABC bloc constitute persistent structural characteristics over the decades.

Moreover, the preservation of the orthogonality of the emissions vector relative to the axis of economic integration in both periods provides robust empirical evidence of decoupling. The results point to an empirical decoupling between industrial positioning and environmental impact. This is evidenced by the near-zero correlation between the scores of the first and third principal components, suggesting that environmental upgrading can occur independently of a sector's integration level into global value chains.

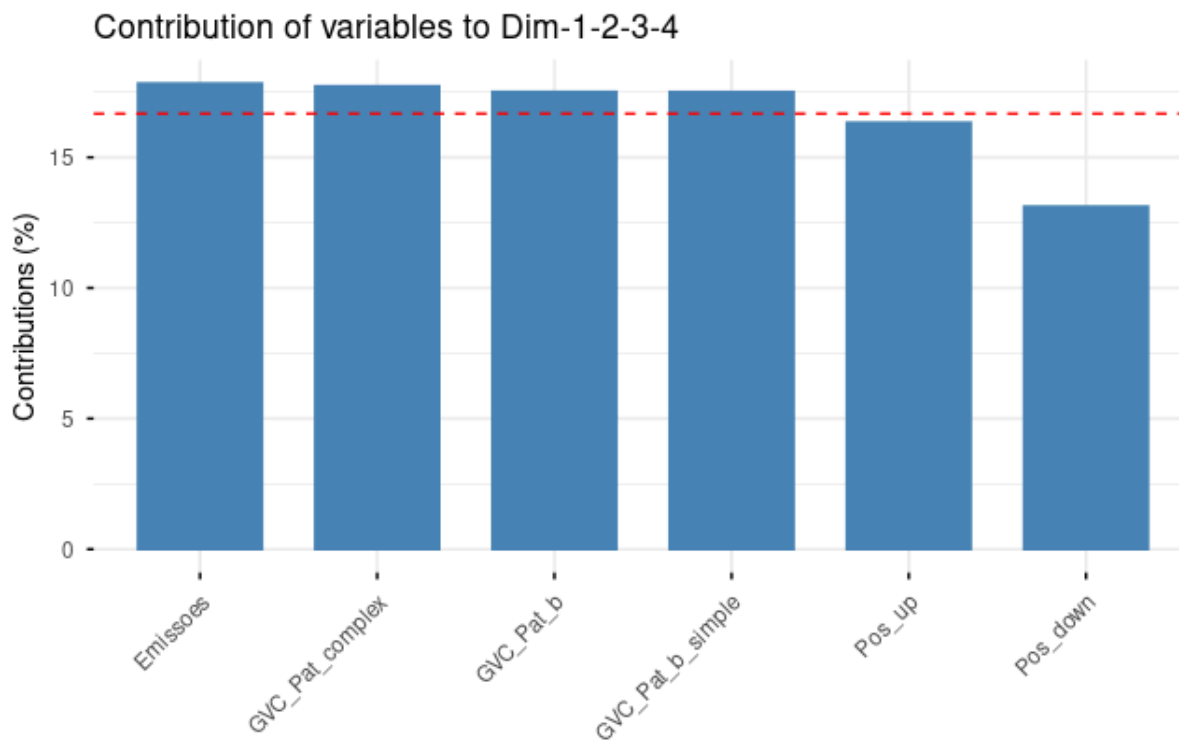
Figura 4: PCA for both sub-periods



Source: Own elaboration

In Figure 5, although the sectors of Cluster 2 are at the base of the Y-axis (low emissions), some sectors that scale vertically along Dimension 3. These represent the activities that confirm the Crying Curve: manufacturing or energy-intensive sectors that, when integrated into GVCs, become pollution hubs. The Emissions variable exhibits the highest CO_2 and the largest total percentage contribution to the model structure. This reinforces Krishnan et al. (2023) premise that upgrading is only effective if accompanied by positive environmental outcomes.

Figura 5: Contribution of variables



Source: Own elaboration

The points that appear as positive outliers along Dimension 3 (high-emission sectors) provide empirical evidence for the Pollution Haven Hypothesis. As suggested by Zhang et al. (2017) in their review, production fragmentation can shift pollution-intensive stages to developing countries. In the figure, these are the sectors that “escape” from the base of the ellipse, representing a risk to the sustainability of the ABC bloc.

In sum, the results obtained through Principal Component Analysis (PCA) allow us to conclude that the integration of Argentina, Brazil, and Chile into Global Value Chains (GVCs) occurs in a manner dissociated from sectoral environmental performance. The observed orthogonality between Dimension 1 (Productive Integration) and Dimension 3 (Carbon Intensity) provides empirical evidence of a decoupling scenario, challenging the deterministic view of the “Crying Curve” proposed by Meng et al. (2023). It is important to note that the orthogonality between emissions and GVC-related variables indicates the absence of a dominant linear association in the data structure, rather than the absence of any causal linkage. This demonstrates that the carbon footprint is not a direct, aggregate outcome of a country’s position in the value chain.

Furthermore, these findings suggest that pollution haven dynamics operate at the sectoral level rather than as a country-wide outcome of GVC integration. Although the convergence of the ABC bloc towards Cluster 2 confirms its insertion into medium-complexity links, as discussed by Gereffi e Fernández-Stark (2016), the independence of the environmental factor suggests that Environmental Upgrading, advocated by Krishnan et al. (2023), is a feasible and autonomous trajectory. Therefore,

advancement toward higher value-added stages (the Smile Curve) within the ABC bloc does not necessarily impose an inevitable environmental burden, provided it is supported by decarbonization policies that go beyond the mere logic of international productive fragmentation.

5 CONCLUSION

This paper investigated the complex relationship between Industrial Upgrading and Environmental Upgrading for Argentina, Brazil, and Chile (ABC Bloc) over the period from 1995 to 2018. Through Principal Component Analysis (PCA), it was possible to map how integration into Global Value Chains (GVCs) translates into environmental impacts, empirically testing the “Crying Curve” dilemma (Meng et al., 2023).

The results show that there is a statistical decoupling between economic performance and the carbon footprint in the ABC bloc. The orthogonality between Dimension 1 (Integration) and Dimension 3 (Emissions) indicates that the trajectory of productive sophistication does not linearly dictate the pollution footprint. This heterogeneity reinforces that climate policy cannot be delegated to trade or industrial upgrading strategies alone, requiring autonomous sectoral decarbonization policies that account for the distinct emission-production relationships within each industry. Consequently, future research could explore sector-specific PCA to better guide these targeted interventions, particularly by segmenting the analysis into extractive industries, energy-intensive manufacturing, and high-tech sectors. As it suggests that the ABC bloc can advance in value capture, as proposed by Gereffi and Fernández-Stark (2016), without necessarily exacerbating its environmental degradation.

The clustering in Cluster 2 confirms that these countries share a medium-complexity productive identity. However, the presence of outlier sectors with high emissions reinforces the validity of the Pollution Haven Hypothesis (Zhang et al., 2017) in specific niches, signalling the risk of a "dirty" specialization in intermediate manufacturing stages.

Given the independence between the dimensions, it can be concluded that Environmental Upgrading (Krishnan et al., 2023) is not an automatic by-product of economic growth, but rather the result of deliberate climate policies. For Argentina, Brazil, and Chile, the central recommendation is to strengthen governance mechanisms that promote sectoral decarbonization, regardless of the level of trade openness or productive integration.

From a public policy perspective, the evidence suggests that environmental upgrading is a feasible and autonomous trajectory that cannot be delegated to trade or industrial strategies alone. For Argentina, Brazil, and Chile, the central recommendation is to strengthen governance mechanisms that promote sectoral decarbonization independently of the level of trade openness. Since pollution haven dynamics operate at the sectoral level, policymakers should implement targeted interventions for energy-intensive manufacturing and extractive industries, identified as high-emission outliers, to

ensure that economic advancement along the 'Smile Curve' does not impose an inevitable environmental burden.

Although the study provides a robust perspective based on OECD data, the analysis primarily focused on territorial emissions derived from industrial production and energy combustion. It is suggested that future research explores consumption-based emissions (carbon footprint embodied in trade) to assess the potential occurrence of carbon leakage. Additionally, the inclusion of eco-efficient technological innovation variables (Çoban et al., 2025) and emissions from land use and deforestation is recommended. The latter is particularly crucial for the ABC bloc, as the dynamics of emissions in these economies are strongly influenced by the agricultural sector and land-use change, factors that could reveal new nuances regarding the observed decoupling between integration in Global Value Chains and the overall environmental impact.

This study has limitations that open avenues for future research. The analysis focused primarily on territorial emissions from industrial production and energy combustion, without accounting for consumption-based emissions or carbon leakage. Furthermore, the exclusion of specific variables related to eco-efficient technological innovation and emissions from land-use change (LULUCF) limits the scope of the findings. Given that the ABC bloc's environmental profile is significantly influenced by the agricultural sector and deforestation, integrating these factors in future sector-specific PCA models would provide a more comprehensive understanding of the relationship between global integration and sustainable development.

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