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Three essays on structural change, international trade, and greenhouse gas emissions: An
input-output case study of Argentina

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Germán Augusto Zamorano

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RESUMO

Esta tese consiste em três ensaios sobre mudança estrutural, comércio internacional e sustentabilidade ambiental, baseando-se em perspectivas estruturalistas, neo-schumpeterianas e da economia ecológica. Enquanto as abordagens estruturalistas e neo-schumpeterianas destacam o papel das estruturas produtivas e da inovação tecnológica no desenvolvimento econômico, a economia ecológica ressalta a necessidade de alinhar essas mudanças com a sustentabilidade ambiental. Ao integrar esses referenciais, este estudo contribui para o debate sobre a transição verde em uma economia em desenvolvimento como a Argentina, por meio de um estudo de caso empírico baseado na metodologia insumo-produto. O primeiro ensaio explora a relação entre a brecha tecnológica da Argentina e seu impacto na sustentabilidade ambiental, com foco na estrutura produtiva e na especialização comercial do país. A análise se baseia em perspectivas neo-schumpeterianas, estruturalistas e evolucionárias para abordar os desafios impostos pelas mudanças climáticas. A Argentina, caracterizada por uma especialização em commodities intensivas em recursos naturais, enfrenta barreiras significativas para alcançar um crescimento sustentável devido à sua dependência de vantagens comparativas estáticas. Um estudo de caso qualitativo da Argentina ilustra as implicações ambientais de seus atuais padrões de exportação, estrutura produtiva e abundantes reservas de combustíveis fósseis. Os resultados contribuem para o debate mais amplo sobre desenvolvimento sustentável em economias emergentes, oferecendo insights sobre como as brechas tecnológicas influenciam os impactos ambientais e as perspectivas para uma transição verde. O segundo ensaio consiste em uma análise de decomposição estrutural a partir da metodologia insumo-produto para examinar os determinantes das emissões de gases de efeito estufa (GEE) da Argentina entre 2000 e 2016, em diferentes condições econômicas. Os resultados revelam que o fator mais influente na variação das emissões de GEE é a demanda final, que aumenta durante períodos de crescimento econômico e estagnação e diminui durante recessões. Paralelamente, o efeito da intensidade energética desempenha um papel fundamental, comparável ao da demanda final, mas com impacto inverso sobre as mudanças nas emissões nos períodos de recessão e crescimento. O efeito da intensidade de emissões contribui para o aumento das emissões em períodos de aceleração do crescimento e para sua redução em fases de crescimento e estagnação. Os resultados ressaltam que, juntamente com o efeito da intensidade energética, o nível da demanda final é o principal fator determinante das variações nas emissões de GEE. O estudo fornece evidências que apoiam a promoção da eficiência energética como um meio eficaz de alcançar reduções significativas nas emissões de

GEE, mesmo dentro de uma economia em crescimento. O terceiro ensaio utiliza um modelo insumo-produto multirregional para estimar as emissões de GEE, os recursos naturais e o valor agregado incorporado no comércio da Argentina com Brasil, China, Estados Unidos e União Europeia entre 2000 e 2016. Os resultados oferecem insights críticos sobre as dinâmicas do comércio entre o Norte Global e o Sul Global, bem como sobre o comércio entre países do Sul, ao explorar não apenas os ganhos e perdas econômicas, mas também os padrões de emissões entre os principais parceiros comerciais. Os resultados ressaltam a presença de um padrão de troca ecologicamente desigual entre a Argentina, por um lado, e os Estados Unidos e a União Europeia, por outro. Esses resultados são relevantes para a formulação de políticas voltadas para práticas comerciais mais sustentáveis entre os países do Norte e do Sul Global, promovendo um comércio mais equilibrado tanto do ponto de vista econômico quanto ambiental.

Palavras-chave: Mudança estrutural; comércio; sustentabilidade ambiental; Argentina; insumo-produto.

ABSTRACT

This thesis consists of three essays on structural change, international trade, and environmental sustainability, drawing from structuralist, neo-Schumpeterian, and ecological economics perspectives. While structuralist and neo-Schumpeterian approaches highlight the role of production structures and technological innovation in economic transformation, the ecological economics perspective underscores the necessity of aligning these changes with environmental sustainability. By integrating these frameworks, this study contributes to the debate on the green transition of a developing economy such as Argentina through an empirical case study based on an input-output framework. The first essay explores the relationship between Argentina's technological gap and its impact on environmental sustainability, focusing on the country's productive structure and trade specialization. The analysis draws from neo-Schumpeterian, structuralist, and evolutionary perspectives, to address the challenges posed by climate change. Argentina, characterized by a specialization in resource-based commodities, faces significant barriers to achieving sustainable growth due to its reliance on static comparative advantages. A qualitative case study of Argentina illustrates the environmental implications of its current export patterns, productive structure and abundant fossil fuel endowments. The findings contribute to the broader debate on sustainable development in emerging economies, offering insights into how technological gaps influence environmental outcomes and the prospects for a green transition. The second essay employs an input-output structural decomposition analysis to examine the drivers of Argentinian greenhouse gas (GHG) emissions from 2000 to 2016, under markedly different economic conditions. The findings reveal that the most influential factor affecting GHG emissions variation is the final demand, exhibiting an increase during economic growth and stagnation periods and a reduction during recessions. Concurrently, the energy intensity effect plays a pivotal role, comparable to final demand but exhibiting an inverse impact on emissions changes during economic downturns and growth phases. The emission intensity effect contributes to emissions growth during growth acceleration periods and emissions reduction during growth and stagnation. The outcomes underscore that, in conjunction with the energy intensity effect, the level of final demand is the primary driver of GHG emission variations. The study provides evidence supporting the promotion of enhanced energy efficiency as a highly effective means of achieving significant reductions in GHG emissions, even within a growing economy. The third essay employs a multi-regional input-output model to estimate GHG emissions, natural resources and value-added embodied in Argentina's trade with Brazil, China, the United States and European Union,

during 2000-2016. The results offer critical insights into Global North-South and South-South trade dynamics, as the study explores not only economic gains and losses but also emission patterns across key partners. Its findings underscore the presence of a pattern of ecologically unequal exchange between Argentina and the United States and European Union, and are relevant for shaping future policies aimed at more sustainable trade practices between Global North and Global South countries, promoting a more balanced trade from both economic and environmental perspectives.

Keywords: Structural change; trade; environmental sustainability; Argentina; input-output.

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LIST OF ABBREVIATIONS AND ACRONYMS

CBAM	Carbon Border Adjustment Mechanism
CO ₂	Carbon dioxide
ECLAC	Economic Commission for Latin America and the Caribbean
EET	Emissions embodied in trade
EKC	Environmental Kuznets Curve
ETS	European Union Emissions Trading System
EU	European Union
EUE	Ecologically Unequal Exchange
EVs	Electric Vehicles
GDP	Gross Domestic Product
GFC	Government Final Consumption
GFCF	Gross fixed capital formation
GHG	Greenhouse gas
GVC	Global Value Chains
GWO	Green Windows of Opportunity
HFC	Household Final Consumption
IDA	Index Decomposition Analysis
IPCC	Intergovernmental Panel on Climate Change
LDCs	Least Developed Countries
LMDI	Logarithmic Mean Divisia Index
LNG	Liquefied Natural Gas
MFA	Material Flow Accounting
MRIO	Multi-regional input-output
Mt CO ₂ e or Mt	Million tons of CO ₂ equivalent emissions
NC	Net embodied CO ₂ emissions exports
NDC	Nationally Determined Contribution
NPISH	Non-Profit Institutions Serving Households
NVA	Net value-added exports
PHH	Pollution haven hypothesis
PTB	Physical Trade Balance
PTT	Pollution terms of trade
RER	Real Exchange Rate

RoW	Rest of the World
SDA	Structural Decomposition Analysis
SAM	Social Accounting Matrix
SMEs	Small and medium-sized enterprises
STI	Science, Technology, and Innovation
UNCTAD	United Nations Conference on Trade and Development
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
VA	Value-added
VCRS	Symmetric Revealed Comparative Advantages
WTO	World Trade Organization

LIST OF VARIABLES

y^E : Growth rate consistent with the balance of payments equilibrium.

ε : Income elasticity of exports.

π : Income elasticity of imports.

y^C : Growth rate of the center countries.

y^S : Growth rate required to eradicate poverty.

y^A : Growth rate compatible with the environmental boundary.

A: Matrix of technical coefficients.

x: Sectoral output vector.

f: Final demand vector.

I: Identity matrix.

C: GHG emissions vector for each of the n sectors.

EN: Vector of energy consumption for each of the sectors.

$\frac{C}{EN}$: Vector of emission intensity. Relationship between emissions and energy consumption of each sector.

$\frac{EN}{x}$: Vector of energy intensity. Represents the amount of energy consumed to produce a unit of output value by each sector.

$\hat{c}$: diagonal matrix of dimension n x n representing emission intensity.

$\hat{e}$: diagonal matrix of dimension n x n representing energy intensity.

L: Leontief inverse matrix. Represents the structure of intermediate consumption by each sector.

f_d : Domestic final demand vector

f_f : Foreign final demand vector.

c_h : Household final consumption vector.

cg: Government final consumption

n: Non-profit institutions serving households.

k: Gross fixed capital formation.

s: Changes in inventories.

l: Scalar representing the level (total amount) of domestic final demand expenditure over all sectors

B: Matrix indicating the proportion of total expenditures by final-demand category that was spent on the product of each Argentinian sector.

d : Vector that indicates the distribution of the total amount of domestic final demand across the different final-demand categories.

δ^m : Emission intensity vector representing each country's GHG sectoral emissions per unit of output.

γ^M : Vector representing each country's sectoral value-added per unit of output.

EC^{AB} : GHG emissions embodied in exports from country A to country B.

EV^{AB} : Value-added embodied in exports from country A to country B.

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INTRODUCTION

This thesis is composed by three essays on structural change, international trade, and environmental sustainability, drawing from structuralist, neo-Schumpeterian, evolutionary and ecological economics perspectives. While the first three approaches emphasize the role of production structures and technological innovation in economic transformation, the ecological economics perspective highlights the need to align these changes with environmental sustainability. By integrating these frameworks, this thesis contributes to the debate on the green transition of a developing economy such as Argentina, through an extensive literature review and empirical qualitative and quantitative case studies, the latter based on input-output framework.

The reason for studying this country lies in its status as a case of an emerging economy that appears to be caught in the middle-income trap—a stage where growth decelerates after attaining middle-income status, and structural constraints hinder the transition to a high-income level. In the coming years, a significant proportion of GHG emissions will originate from developing economies, making this case study useful for deriving relevant lessons for other developing economies. Simultaneously, conducting local analyses is essential to account for specific local contexts.

An important gap is identified: neo-Schumpeterian, evolutionary, and structuralist approaches do not sufficiently address environmental sustainability while considering their complementarities. To bridge this gap, the first essay explores the relationship between Argentina's technological gap and its impact on environmental sustainability, focusing on the country's productive structure and trade specialization. The analysis integrates insights from neo-Schumpeterian, structuralist, and evolutionary perspectives, to address the challenges posed by climate change. Argentina, characterized by a specialization in resource-based commodities, faces significant barriers to achieving sustainable growth due to its reliance on static comparative advantages. A qualitative case study of Argentina illustrates the environmental implications of its current export patterns, productive structure and abundant fossil fuel endowments. The findings contribute to the broader debate on sustainable development in emerging economies, offering insights into how technological gaps influence environmental outcomes and the prospects for a green transition.

According to the Economic Commission for Latin America and the Caribbean (ECLAC), achieving environmentally sustainable growth requires significant advancements in technology and changes in production and consumption patterns. The structuralist perspective underscores the necessity of technological development to decouple economic growth from

environmental degradation. This view aligns with the neo-Schumpeterian framework, which focuses on technological gaps and their implications for growth and catch-up processes. Literature on technological gaps highlights that reducing these disparities is crucial for fostering structural change and enhancing trade competitiveness, particularly for developing economies.

The first essay is guided by following research question: How does the technological gap in Argentina affect environmental sustainability? The hypothesis posits that Argentina's technological lag impacts its productive structure and trade specialization—manifesting in a reliance on primary exports—which in turn exacerbates environmental challenges, particularly GHG emissions. The analysis combines an extensive literature review with a qualitative case study of Argentina.

The concept of the technological gap originates from the works of Posner (1961), Freeman et al. (1963), Hirsch (1965), and Vernon (1966). These scholars identified international technological differences as key determinants of trade specialization and economic development. Developing countries often attempt to bridge this gap by assimilating and adapting foreign technologies. However, many of them, including Argentina, remain trapped in a middle-income status, facing persistent challenges in developing the innovation capabilities necessary for transitioning to higher-value-added activities.

Structuralist perspectives argue that closing the technological gap and achieving environmentally sustainable development require fostering dynamic comparative advantages based on knowledge-intensive, low-carbon production processes. Similarly, neo-Schumpeterian approaches suggest that developing countries can enhance sustainability by shifting toward more complex, higher-value-added products with lower carbon footprints. UNCTAD (2023) outlines two pathways for integrating sustainability into global value chains: producing essential green economy goods, such as renewable energy technologies, and greening traditional manufacturing sectors. However, capitalizing on these opportunities depends on strong innovation capacity, digital infrastructure, and an integrated policy approach that aligns industrial, technological, and environmental objectives—elements that remain unevenly developed across many emerging economies. The cumulative nature of learning processes, highlighted by the evolutionary approach, leads to increasing returns, enabling some countries to achieve significant capability accumulation, while others face persistent constraints. This dynamic reinforces path dependence, leading to the reproduction of existing patterns of production and technological learning.

This essay underscores the convergence between structuralist, neo-Schumpeterian and evolutionary traditions in explaining Argentina's technological and environmental challenges.

By integrating insights from these schools of thought, it aims to contribute to the broader discussion on sustainable development, emphasizing the role of technological capabilities in shaping economic and environmental outcomes. Furthermore, the theoretical and qualitative case analysis presented offers several policy implications. In many cases, the policy recommendations of the theoretical approaches explored converge. However, when examining the green transition, the analysis uncovers points of synergy and mutual reinforcement that can be particularly useful in shaping policies aimed at driving this transition forward.

The second essay advances the study of decoupling economic growth from greenhouse gas emissions by analyzing the main drivers of emission changes in Argentina from 2000 to 2016. Given Argentina's diverse economic conditions during this period—ranging from one of its most severe crises to phases of rapid economic expansion—this essay provides valuable insights into the relationship between economic cycles and emissions in developing economies. The central research question guiding this essay is: What are the key determinants of GHG emissions in Argentina, and how can economic growth be decoupled from emissions in the context of a developing economy?

While essay 1 argues that Argentina's technological gap and commodity-based trade pattern not only lock the country into a middle-income trap and a carbon-intensive growth path but also constrain its green transition, it emphasizes that closing this gap through technological upgrading is essential for decoupling growth from rising emissions. Essay 2 empirically examines this proposition. Using a sector-level structural decomposition of GHG emissions for 2000–2016—spanning the nation's deepest crisis, subsequent rapid expansion, and later stagnation—it measures how the key elements flagged in essay 1 shape Argentina's carbon footprint: changes in the intermediate-input structure (a proxy for technological change), sectoral composition, export-led demand, and shifts in both energy and carbon intensity. By translating qualitative insights into context-specific, measurable effects, essay 2 not only reinforces the policy prescriptions advanced in essay 1 but also identifies the industries where targeted industrial and environmental measures could yield the largest emissions cuts.

The methodology employed in essay 2 consists of a structural decomposition analysis (SDA) of environmentally extended input-output matrices. This approach allows for a detailed examination of the key drivers of emissions, such as shifts in final demand, energy intensity, emission intensity and sectoral composition. This method is particularly valuable for analyzing Argentina's case, as it enables to determine how economic cycles have influenced emissions trends over time at a high disaggregated sectoral level.

A review of empirical studies on Argentina reveals a research gap: most input-output analyses focus on a single year, while retrospective time-series studies primarily employ econometric methods. Building on the existing literature, this essay contributes by applying a time-series analysis using an SDA through input-output approach—an unexplored methodology in the context of Argentina. Given the scarcity of research utilizing this framework for the country, this study fills a critical gap by providing an empirical analysis of Argentina's sectoral emissions profile under different economic cycles.

This essay's findings reveal several noteworthy insights. The main drivers of changes in GHG emissions, alongside energy intensity, were variations in final demand. The empirical results underscore the significant impact of final consumption on emissions, suggesting that demand-side policies—by influencing both the level and composition of final demand—could play a crucial role in emissions reduction. However, such policies may conflict with the social and economic imperatives of developing countries like Argentina, where economic growth is essential for wealth generation and income distribution.

Moreover, the results indicate an inverse relationship between the contributions of energy intensity and final demand to emission changes during periods of economic expansion and recession. The data suggest that rapid economic growth has been accompanied by gains in energy efficiency, challenging the assumption that growth necessarily leads to worsening energy performance. Conversely, the evidence indicates that during economic crises, energy efficiency tends to deteriorate.

It is important to highlight that this essay estimates emissions from a production-based accounting perspective, which involves summing all emissions produced within Argentina's borders. This methodology is the standard approach for compiling national greenhouse gas inventories. However, this approach does not account for the fact that countries with strict emission controls, regulations, or taxes may reduce their domestic environmental impact by shifting more polluting productive sectors to regions with laxer environmental regulations, and then importing the resulting products.

To account more accurately the carbon footprints embodied in international trade, essay 3 applies a consumption-based accounting framework using a multiregional input-output (MRIO) model with environmentally extended input-output matrices. Building on the growing body of literature at the intersection of trade, environmental impacts, and economic value distribution, we estimate environmental pressures—measured by GHG emissions and natural resources embodied in trade—and economic benefits—quantified by value-added—associated

with Argentina's trade with Brazil, China, the European Union, the United States, and the rest of the world, analyzing their evolution from 2000 to 2016.

Essay 2 focuses on the internal determinants of Argentina's emissions, yet many of those determinants are shaped by the country's position in world markets. Essay 3 extends the analysis outward, examining how Argentina's specialization in resource-based commodities—diagnosed as a symptom of its technological gap in essay 1—translates into an unequal exchange of both environmental burdens and economic benefits. By tracking the value added and greenhouse-gas emissions embodied in trade with Brazil, China, the European Union, and the United States, essay 3 reveals the sectors responsible for Argentina's growing emissions related to international trade and value-added generation. In doing so, it links the SDA results of essay 2 to a broader discussion of trade asymmetries and global environmental justice.

The relevance of studying Argentina lies in its position as a peripheral country specializing in natural resource-based exports, with strong commercial ties to both other peripheral economies (Brazil) and core economies (European Union and the United States), as well as China, which exhibits both core and peripheral characteristics.

This essay engages more profoundly with the Ecological Economics approach, specifically with the theory of Ecologically Unequal Exchange, focusing on the unequal distribution of environmental problems and economic benefits resulting from the structure of international trade and global power relations. This approach suggests that the most powerful and wealthy countries in the Global North have greater access to natural resources and waste absorption capacity from countries in the global south (Givens, Huang, and Jorgenson, 2019). This theory is built upon various critical development perspectives, including the theory of deteriorating terms of trade in developing countries, formulated by Prebisch (1950) and Singer (1975).

According to the theory of Ecologically Unequal Exchange, developed countries—also referred to as core countries or the Global North—leverage their economic, technological, and military power to obtain greater economic benefits while bearing fewer environmental burdens through unequal trade patterns with less developed countries—often called peripheral countries, developing countries, or the Global South. This framework highlights the existence of net resource transfers (energy and materials) from peripheral to core countries (Dorninger et al., 2021; Prell and Feng, 2016; Jorgenson and Clark, 2009), with resources from less developed regions being undervalued and compensated at lower rates compared to those from developed regions.

By comparing the gross and net flows of environmental burdens (measured by GHG emissions), natural resources (raw materials, water, and cropland area), and economic benefits (value-added) between Argentina and its trading partners, we provide evidence supporting the existence of ecologically unequal exchange between Global South and Global North countries.

These results are particularly relevant in the current context, which demands a global response to environmental challenges through enhanced cooperation, funding mechanisms for mitigation and adaptation, and regulatory standards.

Taken together, the three essays move from theory (essay 1), to empirics at the national level (essay 2), to international comparative evidence (essay 3). This sequence shows that Argentina's path-dependent specialization in carbon-intensive commodities is not only a domestic developmental challenge but also a representation of structural imbalances in the world economy. By combining structuralist, neo-Schumpeterian, evolutionary, and ecological-economics points of view, the thesis presents an interdisciplinary explanation of the challenges related to the green transition for middle-income, resource-based countries—and discloses policy levers, from guided industrial policy to trade negotiation, that could help to rebalance technological upgrading with environmental sustainability.

1 STRUCTURAL CHANGE, PRODUCTIVE DEVELOPMENT, AND TECHNOLOGICAL GAP: LIMITATIONS FOR THE GREEN TRANSITION OF THE ARGENTINE ECONOMY

1.1 Introduction

The escalating concentration of greenhouse gas (GHG) emissions observed in recent decades results in higher temperatures on Earth and in the oceans, contributing to climate change—a pressing environmental issue generated by productive activities—exacerbating the impacts of other environmental and social problems. Resource-based commodities sectors, rank among the primary sources of anthropogenic greenhouse gas emissions, according to the United Nations Conference on Trade and Development (UNCTAD, 2019).

In response to these deepening environmental pressures, the concept of a green transition has gained growing prominence in global policy and academic discourse. The green transition is interpreted as the structural transformation of economies, production systems, and societies onto environmentally sustainable models. It implies a transition away from fossil fuel-dependent energy systems and resource-led development paths towards low-carbon, resource-

efficient, and inclusive patterns of growth. This transition entails changes in energy production and consumption, industrial technologies, infrastructure, and patterns of investment and employment to reduce environmental degradation and climate change mitigation while enhancing economic and social development (OECD, 2019; Addison et al., 2024; IPCC, 2023).

According to Medeiros and Majerowicz (2025), the last decade has witnessed a significant resurgence in industrial policy among major global economies, particularly in the United States and European Union countries. This renewed focus is largely a response to the rapid ascent of China as a major economic and technological power, along with political concerns regarding national security, the green transition, and social inclusion. Unlike the industrial policies of previous eras, current strategies are comprehensive, encompassing multiple sectors and activities in a coordinated effort to bolster national competitiveness and address pressing global challenges, such as climate change. In this context, marked by environmental issues and geopolitical rivalries exacerbated by the pandemic and the war in Ukraine, these major economies have addressed the issue of environmental sustainability and competition with China's technological advancements by advancing towards the “twin transitions” (green and digital) through the implementation of Green Industrial Policies, such as the European Green Deal in 2019 and the Inflation Reduction Act in the United States in 2022. For Argentina and other Latin American countries, China's rise has reinforced traditional productive specialization based on the export of commodities (agricultural and minerals) and the import of manufactures. In this scenario, these countries, as well as other developing economies, need to critically evaluate their positioning in Global Value Chains (GVC), considering local realities marked by environmental degradation, deindustrialization, and increased poverty (Medeiros and Majerowicz, 2025).

While commodity production is one of the major contributors to climate change, it is also one of the sectors most affected by this phenomenon. Rising temperatures and increased occurrences of natural disasters disproportionately affect the agricultural sector, intensifying the urgency for diversification and modernization in countries specialized in these products (Intergovernmental Panel on Climate Change [IPCC], 2019).

According to the Economic Commission for Latin America and the Caribbean (ECLAC, or *CEPAL* in Spanish and Portuguese), one of the primary ways to maintain or increase environmentally sustainable growth rates is through technological progress and changes in production and consumption patterns. These changes should enable decoupling production from GHG emissions and resource consumption (ECLAC, 2020). Therefore, from the structuralist perspective, technological development assumes even greater relevance,

considering its role in achieving greater environmental sustainability while reconciling long-term economic growth with the transition to a global economy with lower GHG emissions intensity.

Notably, this line of thought converges in several aspects with the neo-Schumpeterian approach. Within this framework, the literature on technological gaps (Fagerberg and Verspagen, 2002; Meliciani, 2002; Fagerberg, 1987) seeks to comprehend how differences in technological levels impact growth rates and catch-up processes among developing and developed countries. It emphasizes that a reduction in the technological gap should occur simultaneously with changes in a country's productive and trade patterns.

These perspectives indicate that in countries where the technological gap persists or widens, a pattern of productive and trade specialization with low technological dynamism is observed. This competitiveness relies on static comparative advantages, which, in the case of developing countries, often revolve around the exploitation of natural resources and the intensive use of low-skilled labor (Fajnzylber, 1988). Simultaneously, it is noted that technologically lagging countries face a less dynamic international demand for their specialized products (natural resource-based commodities), increasing their vulnerability to recurrent balance of payment crises (Prebisch, 1950; CEPAL, 2020).

However, as noted by UNCTAD (2023), technology alone is insufficient to address environmental issues, but when innovation and scientific advancements align with the Sustainable Development Goals, they have the potential to steer global progress toward more sustainable and equitable practices.

In the current context of rapid technological transformations, countries have opportunities to move toward more inclusive and sustainable economies. However, the exploitation of new technological paradigms is contingent upon the processes of adopting and diffusing technical progress at production, social, organizational, and institutional levels. From this perspective, for a country to transition to a lower environmental footprint economy, improvements are necessary in terms of productive, scientific, and technological development.

In this regard, there is an environmental dimension related to the technological gap that has begun to be addressed in recent years from the structuralist tradition and the evolutionary and neo-Schumpeterian approaches. This work builds on this literature to identify the various channels through which the technological gap manifests at a specific level of GHG emissions for the case of Argentina, establishing a dialogue between these approaches. This objective seeks to contribute to the debate on sustainable development in Argentina and, more broadly, in developing countries.

The present essay is framed by the following research question: In what ways does the technological gap in Argentina affect environmental sustainability? Based on this question, the hypothesis is that the technological gap has specific effects on the productive structure and trade specialization (particularly a primarization of the export pattern), which, in turn, have particular impacts on the environment and, specifically, GHG emissions.

The methodology of this essay consists of an extensive literature review on neo-Schumpeterian literature (middle-income technology trap), structuralism, and evolutionary approaches, combined with a qualitative case study of Argentina. The relevance of studying this country lies in its status as a typical example of an emerging (or peripheral, or developing) economy trapped in a middle-income scenario. In the coming years, a significant proportion of GHG emissions will originate from developing economies, making this case study useful for deriving relevant lessons for other developing economies. Simultaneously, conducting local analyses is essential to account for specific local contexts.

In addition to this introduction, this essay comprises three additional sections. Section 2 conducts a literature review highlighting the significance of technological capabilities in explaining income disparities among different countries. Within these frameworks, the lack of capacity to introduce technological innovations is recognized as one of the primary constraints on the growth of several countries, especially those in Latin America with middle-income status, including Argentina. Subsequently, Section 3 delves into the connections between the productive structure and trade specialization resulting from the technological gap, closing with an analysis of the environmental dimension related to Argentina's productive structure and its commercial integration, analyzed through a qualitative case study. Section 4 extends the qualitative case study of Argentina, focusing specifically on the country's potential to become a global exporter of fossil energy resources and the associated risks and opportunities these pose for advancing a green transition. Finally, the conclusions and policy recommendations derived from this essay are presented.

1.2 Structural Change, Technological Gaps, and the Middle-Income Trap.

The ways in which structural change manifests itself are related to variations in the sectoral composition of economic activity, employment allocation, production, and factor utilization, as well as changes in the geographic location of economic activity, among other factors (Syrquin, 1988). In this context, structural change has been a key element in the design of development strategies focused on diversifying the productive matrix. These strategies are

based on building comparative advantages in sectors different from those in which countries were initially specialized.

This approach is grounded in the recognition that not all sectors possess the same capacity to promote productivity growth, stimulate the diffusion of technological progress to other sectors, tap into domestic and international demand, or generate employment productivity gains. Consequently, various heterodox schools of thought have developed taxonomies and classifications of productive sectors based on their technological intensity, which refers to the level of embodied technological content in a sector's products and processes. This is often linked to its research and development efforts, innovation capacity, and ability to absorb and disseminate technical progress (Castellacci, 2008; Lall, 2000; Pavitt, 1984). They adopt an approach that rejects the "neutrality" of sectoral specialization. According to these perspectives, economic development requires a transformation of the productive structure, achieved by reallocating productive factors from less productive sectors to those with higher productivity, where increasing returns prevail.

In this sense, development strategies have placed significant emphasis on industrialization as a driver of technological progress and long-term growth, based on the following characteristics:

i) Forward and backward linkages in the production chain are stronger in the industry than in other sectors of the economy (Hirschman, 1975).

ii) The industry is characterized by the presence of static and dynamic economies of scale, meaning that productivity in the industry increases with industrial production. This phenomenon is known in economic literature as the "Kaldor-Verdoorn law" (Kaldor, 1967).

iii) The manufacturing sector concentrates most technological development and has a greater capacity to generate technological spillovers, thereby facilitating the reallocation of labor and capital from less productive sectors to more productive ones, contributing to reducing structural heterogeneity (Prebisch, 1949).

iv) Industry helps alleviate the balance of payments constraint on long-term economic growth since the income elasticity of manufacturing is higher than the elasticity of primary products (Thirlwall, 1979).

In light of the above, the contraction of the industrial base can reduce opportunities for the development and accumulation of productive and technological capabilities, their spillover to other sectors, and contribute to external constraints on growth, thereby limiting long-term growth potential. This has led some scholars to associate premature deindustrialization in middle-income economies with the middle-income trap, as the underdevelopment of the

manufacturing sector can hinder the capacity to sustain the necessary productivity gains for catching up (Andreoni and Tregenna, 2020).

1.2.1 Technology gap, catch-up, and middle-income trap: the significance of technological capabilities

The concept of technological capabilities refers to the set of skills, knowledge, and institutional structures that enable firms and countries to absorb, adapt, and improve technologies over time (Lall, 1992; Bell and Pavitt, 1993). Such capabilities are critical in terms of diverging from low-productivity activities and pursuing innovation and economic upgrading.

According to Andreoni and Tregenna (2020), the term "middle-income trap" has been widely used in the literature on economic development to describe a situation where countries are unable to maintain sustained economic growth. This suggests a long-term equilibrium of income per capita stagnation, indicating a structural incapacity to reach the income levels of developed countries. Lee (2013), on the other hand, describes the middle-income trap as a situation where growth stagnates as countries become trapped between low-wage manufacturers and high-wage innovators. Their wages are too high to compete with low-wage countries, and their level of technological capabilities is too low to compete with advanced countries, highlighting the cases of Argentina and Brazil as examples of this situation.

In this context, the concept of the middle-income trap is related to income disparities between different regions of the world, which brings us to the concept of "catch-up". Fagerberg and Godinho (2006) define catch-up as a reduction in the productivity and income gap of a country compared to a leading country. Following a similar line of reasoning, Odagiri et al. (2010) describe catch-up as a process through which a late-developing country reduces its income gap and technological gap with a leading country. Thus, catch-up can be measured by the reduction in income gaps, productivity, and technological capabilities (Lee, 2013).

The concept of technological gap in the heterodox school of thought originates from the contributions of Posner (1961), Freeman et al. (1963), Hirsch (1965), and Vernon (1966). These scholars identified international technological differences as the primary determinant of trade flows and specialization patterns. These differences are related to various stages in the evolution of technology and an unequal distribution of innovative capabilities.

In the initial stage, technologically advanced countries have an innovative advantage that enables them to introduce new products, resulting in a significant share of the global market. Over time, technology progresses to a mature stage where products and processes

become more standardized, and international competitiveness is based on production cost advantages. Consequently, technology is transferred to less developed economies during this stage.

If, in the initial stage, innovative processes lead to income disparities among countries, the international diffusion of technological knowledge can serve as a source of convergence (Fagerberg, 1987, 1994). From this perspective, countries with lower income levels can benefit by replicating modern technologies that are available in more advanced countries (Gerschenkron, 1962).

However, it is essential to emphasize that the adoption and diffusion of these technologies are not automatic processes, but depend on various factors within the recipient country related to social capabilities and technological alignment, as outlined by Abramovitz (1986). Technological alignment refers to the fact that the knowledge available in more advanced countries may have limited relevance for less developed countries due to structural differences between them. Social capabilities are related to the fact that absorbing external knowledge requires capacities, both at the individual and collective levels, which are often lacking in less developed countries compared to the global economic and technological frontier. Significant efforts are therefore required to develop the necessary capabilities for catching up.

According to Verspagen (1991), the efforts required to absorb international knowledge flows can lead to a development trap. Countries that are further behind in terms of technological frontier will face greater difficulties in acquiring the resources necessary to invest in capability development, as well as in designing and implementing the policies needed to absorb and disseminate this knowledge. This explains why they have a higher probability of remaining at lower levels of development.

In this context, Pérez and Soete (1988) emphasize that increasing returns associated with productive and technological development create these self-reinforcing conditions for economic development. To produce new capital, prior capital is required; to absorb new knowledge, prior knowledge is necessary. Skills are necessary to acquire new skills, and a certain level of development is required to create the infrastructure and economies of agglomeration that make development possible. Thus, increasing returns associated with the learning process explain phenomena of significant capability accumulation on one hand and greater lag on the other. According to Cimoli and Rovira (2008), all these elements constitute forces contributing to "path dependence", generating an endogenous tendency to reproduce the dominant pattern of production and learning—that is, the prevailing configuration of technological capabilities, production structures, and knowledge accumulation trajectories that

shape how and where innovation occurs in the economy. This pattern tends to reinforce itself over time, making structural transformation and technological upgrading more difficult in economies that remain locked into low-productivity, resource-based activities.

Most developing countries have attempted to achieve catch-up by assimilating and adapting technologies from more advanced countries, following a strategy consistent with the product life cycle theory (Vernon, 1966). However, despite these countries' ability to grow and reach middle-income levels, in many cases (such as Argentina and other countries in Latin America), their economies have fallen into the middle-income trap. In this regard, overcoming the middle-income stage requires technological capabilities that enable a transition to higher value-added activities.

Andreoni and Tregenna (2020) extend this concept to a "technological" middle-income trap, resulting from three interdependent factors: i) limitations in terms of scale and technological competitiveness to penetrate increasingly concentrated global markets; ii) the challenges faced by domestic firms in integrating into GVC while generating linkages with the domestic production system; iii) the challenge of keeping up the pace with technological change and innovation.

In that same line of thinking, Lee (2013) acknowledges that technological innovation is increasingly recognized as one of the main constraints to the growth of several countries, especially those in Latin America with middle-income status. That's why he suggests that middle-income countries with certain technological capabilities take a leap-frog, leaving behind older technologies, avoiding large investments in outdated technological systems, and adopting and developing new technologies to gain a foothold in emerging markets, capitalizing on new techno-economic paradigms (Lee, 2005, 2013). Freeman and Soete (1997) and Perez and Soete (1988) point that emerging technological paradigms serve as windows of opportunities for less developed countries, as they are not locked into old technological systems and can seize new opportunities in emerging industries.

1.2.2 Technology gap, productive structure and commercial pattern.

According to the approaches discussed above, for a country to engage in the most dynamic international trade markets, it must possess a set of local capabilities that enable it to enter these markets successfully. In this regard, the participation of sectors with higher technological intensity and the ability to diffuse technological progress is a crucial determinant of trade specialization. At the same time, there are various ways in which a country's external integration contributes to modifying the sectoral composition of its productive structure.

As highlighted by Cimoli and Porcile (2015), there is a demand dimension linked to the processes of learning technological and productive capabilities that cannot be ignored. In this context, Cimoli et al. (2005) emphasize that one of the central elements of export activities is the generation of spillover effects throughout the economy, especially in technologically dynamic activities, which leads to technological and productive linkages with other domestic sectors.

From this perspective, international trade plays a key role in boosting aggregate demand for manufactured goods, reinforcing a virtuous cycle that drives broad-based productivity growth. The expansion of demand enhances productivity and employment through the diffusion of increasing returns within the industry, which in turn leads to greater production capacity and output. In line with Kaldorian theory, output growth triggers a self-reinforcing process of rising productivity and income, further stimulating increases in production capacity, output, and employment (Cimoli and Porcile, 2015).

Lema et al. (2020) emphasize that market catch-up refers to the ability of firms to expand their market share both domestically and internationally. Domestic market catch-up can be achieved through government policies that stimulate local demand, while global market catch-up requires meeting internationally competitive standards in terms of quality and price (Lee and Malerba, 2017). Market catch-up and technological catch-up can be mutually reinforcing: closer integration with larger and more sophisticated markets can provide valuable knowledge and experience that drive technological advancements (Schmitz, 2007), while enhanced technological capabilities can boost the competitiveness of national firms in both domestic and export markets (Lee and Malerba, 2017).

Porcile and Holland (2005) summarize the causal relationships between different variables suggested by Schumpeterian and Post-Keynesian growth models with external constraints based on the following stylized facts:

(i) International competitiveness depends on the technological gap and the ability to reduce it over time. A larger technological gap results in lower technological intensity in the products in which a country specializes in international trade.

(ii) International specialization driven by the technological gap leads to a lower potential for learning and long-term productivity growth, as sectors with lower technological intensity yield smaller gains in labor productivity compared to sectors with higher technological intensity.

(iii) There is a positive correlation between technological intensity and the dynamism of international demand. This means that technologically lagging countries not only have fewer

opportunities for learning and innovation but also face less dynamic demand for the products in which they specialize, increasing their vulnerability to recurrent balance of payments crises. This vulnerability reflects the lower income elasticity of demand for their exports compared to the income elasticity of their own demand for imports.

(iv) External borrowing can temporarily alleviate the external constraint but tends to re-emerge in the medium to long term, sometimes even more intensely. This occurs when interest and principal repayments exert more pressure on the balance of payments, resulting in cycles of growth followed by sharp external adjustments that contract economic growth and investment.

(v) The combination of these factors limits the effective growth of developing economies and their ability to capitalize on opportunities associated with technological paradigms, leading to a scenario of divergence where income and technology gaps between developed and developing countries persistently widen.

On one hand, activities intensive on technology generate positive externalities (technological spillovers) and various incentives for innovation and learning, driving capability accumulation in the long term. On the other hand, an economic structure heavily concentrated in low technological intensity activities will result in a limited process of learning and productivity growth. This can compromise innovation capabilities and, consequently, the potential to generate dynamic competitive advantages, enabling greater participation in more dynamic markets in terms of income elasticity of demand. Thus, a larger internal productivity gap reinforces the external gap, as sectors with low productivity face greater difficulties in adopting technologies, fostering learning processes, and ultimately innovating (ECLAC, 2010).

Furthermore, trade specialization can impact the productive structure through the Dutch disease phenomenon. This phenomenon involves currency appreciation resulting from trade specialization in natural resources, which stimulates the substitution of locally manufactured products with imports, further deepening the specialization in natural resources (Palma, 2005).

Empirical research confirms that the Dutch-disease mechanism has long shaped Argentina's development path. Diamand (1972) showed that recurrent commodity booms raise export revenues yet chronically overvalue the real exchange rate, eroding tradable manufacturing competitiveness and slowing technological upgrading. Rapetti (2016) analyses three long-run growth channels through which the real exchange rate (RER) operates: (i) current-account dynamics, (ii) sectoral allocation of capital and (iii) interaction with external constraints. The second channel deals explicitly with Dutch-disease logic: a commodity boom

appreciates the RER, lowers the relative profitability of manufacturing and other tradable services, diverts investment toward resource-based or non-tradable activities and ultimately biases structural change away from high-technology sectors. Rapetti (2016) supports this mechanism with Latin-American evidence—citing Argentina and Brazil in particular—showing that prolonged real exchange rate appreciation coincides with a declining industrial share.

As mentioned, Brazil exhibits a parallel pattern, illustrating how an un-neutralised Dutch-disease dynamic, reinforced by a macroeconomic regime misaligned with industrial goals, set the stage for premature de-industrialisation. Trade- and capital-account liberalisation in the 1990s removed the mechanisms that had previously restrained real-exchange-rate appreciation, and the commodity boom of the 2000s intensified the pressure: rising rents from primary exports allowed those goods to remain profitable even under a persistently overvalued real (Bresser-Pereira, 2008). Chronic overvaluation, combined with structurally high real interest rates, eroded the profitability of medium- and high-tech manufacturing and limited investment in these activities (Oreiro et al., 2014). As capital and labour shifted toward resource-based sectors and imports displaced domestic manufactures, linkages and learning channels weakened. Extending the analysis, panel evidence assembled by Nassif et al. (2018) confirms that terms-of-trade shocks translated into real exchange rate appreciation, shifting resources toward primary exports, and accelerated de-industrialisation.

To the extent that this specialization pattern is linked to a higher exposure to recurrent balance of payments crises, it has a negative impact on long-term technological capacity-building processes. According to Cimoli and Porcile (2015), the capabilities embodied in individuals and firms are destroyed when companies exit the market, making it difficult to rebuild these capabilities later on, as new paradigms emerge and require more complex capabilities. Additionally, macroeconomic volatility promotes defensive behaviors by entrepreneurs, which shortens companies' planning horizons and hampers investment on research and development (Katz, 2015).

1.2.3 Critical reflections on Structuralist and Neo-Schumpeterian perspectives

Despite their fundamental contributions to understanding the structural constraints to development and the technological gaps faced by peripheral countries, both the structuralist and neo-Schumpeterian approaches present limitations when analyzing the specific challenges of a green transition.

On the one hand, traditional structuralism tends to emphasize external dependence, balance-of-payments constraints, and the need for productive transformation (Prebisch, 1950;

Ocampo, 2005), but it has historically paid little explicit attention to environmental issues. Although recent publications by ECLAC have incorporated the sustainability dimension and advanced proposals for an ecological transformation of the productive matrix (ECLAC, 2018, 2020, 2024), the structuralist perspective has remained largely anthropocentric and centered on accumulation, often failing to sufficiently problematize the biophysical limits to growth. In this sense, its notion of technological progress does not always distinguish between environmentally desirable or undesirable technologies, which may lead to the reproduction of extractive patterns under the rhetoric of “productive transformation.”

By contrast, the neo-Schumpeterian view—centered on innovation, learning, and capability building (Cimoli et al., 2009)—often assumes that technological progress automatically delivers higher ecological efficiency. Ecological economics research, however, questions this premise, showing that efficiency gains rarely lower overall environmental pressure once rebound effects and ongoing economic growth are factored in (Polimeni et al., 2015).

In this sense, both traditions often fail to fully incorporate the environmental implications of different technological pathways, assuming that technological upgrading will be inherently beneficial, falling short to critically assess whether new technologies are ecologically viable or desirable in the long run (Fischer-Kowalski and Haberl, 2007). As Lustosa (2002) notes from a historical perspective, environmental problems often give rise to solutions through the adoption or modification of technologies; however, such solutions may later become the source of new environmental issues. Drawing on an example from Kemp and Soete (1992), she recalls how in the late 19th century, London faced serious sanitary and environmental problems due to the widespread use of horses for transportation—each animal producing around 15 kilograms of manure per day. Gasoline-powered automobiles were first celebrated as a cleaner alternative to horse-drawn transport because they removed the streets’ waste. Over time, however, they generated new environmental problems—most notably urban air pollution and rising GHG emissions. This history reminds us that the ecological consequences of technological change are neither linear nor neutral, underscoring the need to evaluate innovation pathways critically and over the long term, rather than judging them only by short-term efficiency gains (Lustosa, 2002).

There is a deeper and typically overlooked dimension to the dynamics of technological change: its uncertainty itself. As Lustosa (2002) indicates, both the result and environmental impacts of new technologies cannot be anticipated, even as such innovations are initially designed to address specific problems. The solutions technology provides can have unexpected

consequences in the long term, as ecosystems evolve in complex and nonlinear ways. Uncertainty and ignorance here are structural components of the innovation process (Amazonas, 2001). New technologies emerge and spread under conditions of limited foresight, with research and development results being uncertain and even irreversible. Decisions made under uncertainty establish technological trajectories that are difficult—and sometimes costly—to alter. Even where innovation is successful, additional changes are commonly needed in order to adapt technologies within new socio-environmental contexts. The pathway of technological change is thus not only evolutionary but also discontinuous, subject to irregular development and high degrees of ecological and systemic uncertainty.

In spite of these limitations, both lines of thought are valuable and complementary to one another in examining the issues of a nation such as Argentina. The structuralist theory describes how the production and trade structure of the country—rooted in static comparative advantages and natural resource utilization—results in a pattern that has low technological dynamism. The neo-Schumpeterian theory thus offers the analytical instruments with which to investigate the contribution of technology gaps to the capacity to assimilate new green technologies, and how innovation is conditioned by intricate institutional, social, and organizational processes.

This essay theoretically and critically engages with both paradigms, acknowledging their tensions and partial incompatibilities. Structuralism provides insights regarding macroeconomic dynamics—like productive specialization, trade patterns, and external constraints—that condition the structural terms for the green transition. For its part, the neo-Schumpeterian strand offers explanation of micro and meso-level capability accumulation processes, innovation systems, and environmentally sustainable technology diffusion. The two approaches combined provide a complementary framework for analyzing the opportunities and challenges faced by countries like Argentina in achieving an equitable green transformation.

1.3 Technology gap and the environment: establishing dialogues between different approaches

In recent decades, the environmental dimension has been addressed within the framework of structuralism, particularly in the context of discussions about the development styles in Latin America and the Caribbean. This concept is one of the most relevant in the evolution of this tradition of thought. It starts with the recognition that the development style of countries in the region is based on a productive structure concentrated on static comparative

advantages derived from the relative abundance and exploitation of natural resources and unskilled labor force. In general terms, investments, innovation, and technological development have been oriented toward this structure, leading to the expansion of agricultural frontiers and the increased extraction of mining, forestry, and fisheries resources, which intensified pollutant emissions, resulting in negative externalities for the environment. Additionally, this productive structure has led the region to an unfavorable insertion into global value chains, outside of the most dynamic markets, increasing vulnerability to external shocks (ECLAC, 2014, p. 55).

From the structuralist standpoint, it is recognized that environmentally sustainable structural change should occur within the context of creating dynamic comparative advantages based on knowledge-intensive production and lower material and pollutant intensity. In this regard, there is a need to develop industrial, scientific, and technological capabilities while promoting innovation, thereby improving the systemic competitiveness of countries in the region (ECLAC, 2012, p. 87).

From a neo-Schumpeterian perspective, developing countries can advance more sustainable production by transitioning to more complex, higher-value-added products with lower carbon footprints. According to UNCTAD (2023), there are two primary pathways for enhancing the sustainability of their participation in GVCs: first, by producing goods essential for the green economy, such as solar photovoltaic panels and wind turbines; and second, by greening traditional manufacturing sectors like food, garments and textiles, leather and footwear, and furniture. Greening these traditional GVCs can be supported by adopting digital frontier technologies linked to smart manufacturing, often termed Industry 4.0. This transition requires integrated policies co-created across energy-environmental and industrial domains. The rapidly evolving technological landscape presents “green windows of opportunity” (GWO) for developing countries to introduce new or improved products and services with reduced carbon footprints. Capitalizing on these opportunities could enable them to narrow development gaps, alleviate poverty, combat climate change, and ultimately strengthen their position in GVCs while advancing toward a more sustainable future.

In relation to the nature of GWO, Lema et al. (2020) underline the importance of institutional changes for creating new opportunities for latecomer development in the green economy. They suggest that catch-up dynamics in green sectors are markedly different from those identified in the prior literature. They point that in sectors associated to mass production and information technology, new windows of opportunity tend to open up unexpectedly, because they depend mainly on exogenous technological or demand changes. However, their empirical evidence from diverse green sectors shows that GWO, opened by institutional

changes such as new policies and new legislation, related to domestically or global sustainability transformation agendas, are central to latecomer catch-up. The directed nature of the green techno-economic paradigm increases the predictability of GWOs and transfers more planning power to public actors.

However, seizing these opportunities requires latecomer countries to foster innovation capacity, digital capabilities, together with the required infrastructure and institutions, while overcoming financial obstacles. Additionally, success hinges significantly on preconditions and existing capabilities, leading to a path-dependent outcome. A country already equipped with the capacity to manufacture medium and high technology products is better positioned to exploit these green opportunities. Conversely, nations mainly specialized in primary products face more limited starting points. Hence, acquiring skills is crucial for the adoption, adaptation, and creation of technologies (UNCTAD, 2023).

Developing economies face persistent challenges in achieving technological catch-up and upgrading, largely due to constraints imposed by unfavorable macroeconomic conditions. Carlota Pérez builds upon a tradition initiated by Herrera (1995), highlighting the limited effectiveness of Science, Technology, and Innovation (STI) policies when they are isolated from broader macroeconomic policies, including trade, monetary, fiscal, and competition policies. In the context of Latin America, these broader policies are often referred to as implicit STI policies (Cassiolato, Pagola and Lastres, 2009). Adverse macroeconomic conditions—like high inflation, significant external debt, and elevated interest rates—severely hinder long-term investments in both physical and intellectual capital, which are critical for industrial and technological development. These constraints highlight the need for a more integrated policy approach to overcome the barriers to technological and productive progress in developing countries.

Furthermore, within the structuralist tradition, developing economies are characterized by structural heterogeneity, which refers to the coexistence of highly productive activities near the international technological frontier alongside low-productivity sectors that lag significantly behind global standards. This structural heterogeneity reflects the challenges these economies face in adopting and diffusing advanced international technological practices across sectors and firms. Low-productivity sectors often struggle to innovate, adopt new technologies, and engage in effective learning processes, thereby deepening systemic competitiveness issues in Latin America. As a result, structural heterogeneity reinforces vicious cycles of poverty, slow growth, limited learning, and weak structural transformation (ECLAC, 2010, p. 92).

A convergence can be identified between the technological trap discussed in the evolutionary approach, driven by challenges in learning and technology diffusion, and the vicious cycles analyzed within the structuralist tradition. These cycles are tied to a heterogeneous productive structure, characterized by a heavy reliance on low-technology sectors and an international trade specialization focused on natural resources. This combination limits the capacity to generate and disseminate innovations and hinders participation in the most dynamic international markets. These factors contribute to weak economic performance that limits development and has adverse environmental consequences. Although neo-Schumpeterian literature has extensively explored technology gaps, it has placed less emphasis on sustainability. This section delves into how these dynamics, crucial in the context of technological catch-up, must be considered when designing development policies. While the literature on GWO touches on this intersection, certain structuralist perspectives provide valuable insights, deepening our understanding of the interplay between technology gaps and sustainable development.

1.3.1 Three gap model

In this sub-section, we will expand upon the concept of technological trap, examining how the determinants of this phenomenon interplay with the environment, specifically, constraining the transition to a lower environmental impact economy. To do this, we will use as a foundation the model of three gaps developed by ECLAC (2020). This model aids in establishing the causal relationships between the determinants of the technological trap in developing countries and the constraints these countries face in progressing toward a green transition of the economy, decoupling economic growth from GHG and predatory consumption of natural resources.

The three-gap model by ECLAC (2020) is highlighted, along with the model developed by Guarini and Porcile (2016), which, by introducing the environmental variable into the discussion of open economy models, address the links between environmental impact and the complex interactions that exist between international competitiveness and sustainability.

The three-gap model builds upon the conceptualization of the core-periphery framework from the tradition of structuralist economic thought. Under this approach, the international system consists of a heterogeneous group of countries that can be divided into two

groups: the core and the periphery. Each of these groups exhibits different technological capabilities, production capacities, and levels of per capita income.

On one hand, the core comprises countries with high per capita income levels and situated at the technological frontier. As a result, they achieve high international competitiveness in sectors characterized by advanced technology and dynamic demand, holding significant shares in these segments. These technological and production capabilities enable core countries to sustain innovative processes for creating new products, services, and production methods, leading to greater diversification in production and trade.

On the other hand, the opposite situation is observed in peripheral countries, which face technological lag. This technological gap creates a significant asymmetry between the capacities of firms in these two regions, limiting the ability of peripheral countries to compete in international markets (ECLAC, 2020). It's important to note that the characteristics of countries in this core-periphery framework are similar to those previously discussed in terms of developing and developed countries or less developed and advanced countries. Hence, these terms are used interchangeably.

The first gap addressed by the model is determined by the external constraint, which defines the growth rate consistent with the balance of payments equilibrium, also known as Thirlwall's Law:

$$y^E = \varepsilon/\pi y^C. \quad (1)$$

Where:

y^E is the growth rate consistent with the balance of payments equilibrium.

ε represents the income elasticity of exports.

π represents the income elasticity of imports.

y^C is the growth rate of the center countries.

This equation describes the maximum growth rate of the developing economy that is consistent with external balance. It depends on the ratio between the income elasticity of exports and the income elasticity of imports, as well as the growth rate of core countries.

In this context, according to balance of payments-constrained growth models, the convergence of per capita incomes between developing and developed countries is constrained by the external constraint, which depends on the income elasticities of exports and imports. These elasticities are determined by the productive structure and the pattern of trade

specialization of countries, which in turn depend on the technological and productive capabilities of these countries (Cimoli et al., 2010; Guarini and Porcile, 2016; ECLAC, 2020).

Countries with productive structures focused on low-technology-intensive activities tend to generate a high demand for imports when their growth rates accelerate, while their exports do not respond with the same intensity to increases in income in the rest of the world. The greater the technological and productive capabilities, the higher the ratio between the income elasticity of exports (ε) and imports (π) for developing countries, leading to a higher economic growth rate without increasing the trade deficit. When such a deficit does occur, an adjustment in the growth rate eventually is required to reestablish the balance of payments equilibrium. The higher the growth rate of developed countries (y^C), the more room developing countries have for increasing their exports, alleviating the external constraint.

According to ECLAC (2020), in peripheral countries, a certain gross domestic product (GDP) growth rate, combined with redistributive measures, is required to eradicate poverty and achieve a higher degree of equality in these countries. This rate is defined as y^S , and due to the high levels of inequality in less developed countries, with a large percentage of the workforce in informal conditions, this rate will necessarily be high, and necessary for creating formal employment at a rate high enough to absorb workers in an informality or underemployment situation, and financing universal social protection. Additionally, considering the specialization of developing economies based on natural resources and unskilled labor, the limit imposed by the external constraint is quickly reached, leading to a reduced rate y^E . For these reasons, the growth rate needed to achieve equality is higher than the rate compatible with the external constraint ($y^S > y^E$). This difference is referred to as the social gap.

The environmental problem, in this model, is simplified as a distribution of a certain total emissions capacity that the planet cannot exceed between two competing regions: the core and the periphery. The allocation of this emissions capacity among countries determines a carbon limit for each of them that they cannot exceed. As economic growth is directly related to GHG emissions, fixing a specific level of emissions will necessarily constitute an upper limit on the GDP growth rate, known as the growth rate compatible with the environmental boundary, y^A , in the case of developing countries.

The faster the growth in the core, the smaller the environmental space available for growth in the periphery, reducing y^A . The greater the technical progress in favor of the environment in both the core and the periphery that allows decoupling GDP from GHG emissions, the larger the environmental space available for the growth of both regions, by extending the carbon limits. Considering the urgency of the environmental situation, the limited

carbon threshold will determine that the growth rate compatible with the external constraint in peripheral countries is higher than that of the core-periphery environmental boundary, i.e., $y^E > y^A$. This difference is called the "environmental gap". The total gap between the rate required for equality and the rate compatible with the environmental boundary is referred to as the sustainability gap, as closing this gap ensures sustainable development in all three dimensions: economic, social, and environmental.

This model serves the purpose of succinctly expressing the relationships between the concepts developed throughout this essay. In this regard, the model reflects how the reduction of the technological gap or the exit from the technology trap can simultaneously contribute to overcoming the three gaps, allowing for the decoupling of economic growth from GHG emissions. This model will be further applied to analyze the Argentinian case in the following section.

1.3.2 Productive structure, trade specialization, and GHG emission pattern: characterizing the argentine case.

Argentina's productive structure is concentrated in activities with low technological content, and within these sectors, there is a predominance of specialization in less complex production areas. This type of productive specialization emerged from the structural changes of the 1990s, when less technologically dynamic activities gained prominence, and the industrial sector adopted a modernization strategy based on replacing local employment and capabilities with imported inputs, components and machinery. This discouraged the creation of endogenous production and technological capabilities, along with the dismantling of local linkages, fostering greater productive heterogeneity (Porta, 2015, p. 442).

Regarding the productivity gap, Katz and Bernat (2011) point out that in Argentina, during the first decade of the 2000s, the reduction of gaps with the best international practices was observed in sectors intensive in natural resources and industrial commodities, which were already close to the international frontier. Meanwhile, the largest gaps were observed in sectors intensive in employment and knowledge, whose productivity tends to deviate further from the best international practices. In this regard, Abeles et al. (2017) emphasize that there were no significant changes in the pattern of productive specialization during the post-convertibility period, which continued to focus on activities with low and medium-low technological intensity.

To analyze Argentina's external specialization, the Symmetric Revealed Comparative Advantages (VCRS) indicator developed by Laursen (2015) is used. VCRS values will range

from - 1 to 1, taking values between 0 and 1 in sectors where a country is more specialized, while sectors where the country has almost no specialization will have values between -1 and 0. The sectors are classified according to Lall's (2000) methodology, which distinguishes 5 groups based on their technological content: primary products, natural resource-based manufactures, low-tech manufactures, medium-tech manufactures, and high-tech manufactures. The following table shows the VCRS indicator values for Argentina for the period 1985-2018.

Table 1: VCRS, Argentina.

Period	1985	1995	2005	2015	2018	2023
Primary products	0,49	0,59	0,44	0,64	0,64	0,70
Natural resource-based manufactures	0,18	0,24	0,28	0,16	0,08	-0,21
Low-tech manufactures	-0,31	-0,16	-0,36	-0,60	-0,63	-0,80
Medium-tech manufactures	-0,57	-0,34	-0,23	-0,18	-0,26	-0,26
High-tech manufactures	-0,74	-0,82	-0,81	-0,75	-0,85	-0,96

Source: Own elaboration based on data extracted from COMTRADE

Based on Table 1, it can be stated that over the period covered, the Argentine economy exhibits a trade specialization based on the export of primary products and, to a lesser extent, natural resource-based manufactures. In the case of primary products, specialization significantly deepens from 2005 onwards, while specialization in natural resource-based manufactures shows a decreasing trend during the same period. For low, medium, and high-tech manufactures, there is a (de)specialization throughout the period, especially in the case of high-tech sectors.

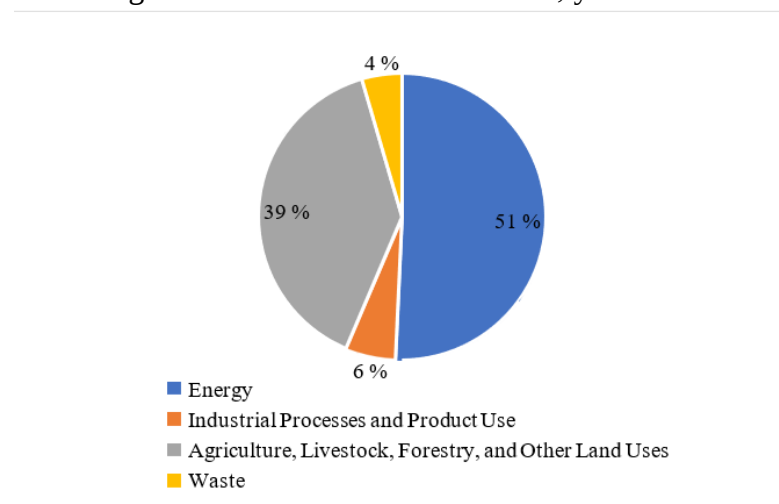
The revealed trend of specialization of Argentina, as per the VCRS analysis in Table 1, indicates a stable export structure that is highly dependent on primary commodities with minimal shift towards industries with higher value addition. In this sense, the increasing specialization of Argentina in primary goods, especially after 2005, demonstrates ongoing dependence on sectors of low technological intensity and limited potential for productivity improvements and technological spillover effects. This trend further underscores the difficulty encountered in ascending the global value chain, as shown by the persistent de-specialization recorded across low, medium, and high-tech manufacturing industries. This trend reflects the difficulty of developing the dynamic capabilities essential for long-run, innovation-led growth.

In accordance with the neo-schumpeterian perspective previously exposed, there is evidence of a large deficit in Argentina's technological and innovation capabilities. The persistent negative values of VCRS for medium- and high-tech manufacturing point to the

failure of the country to develop competitive advantages where knowledge accumulation and technological innovation are essential. This is consistent with the neoschumpeterian focus on the pivotal role played by innovation systems, learning mechanisms, and technological competences in configuring international competitiveness. The trend towards de-specialization observed in these sectors implies that there are serious difficulties for Argentina in building up dynamic capabilities to compete in knowledge-intensive industries that may constrain its participation in global value chains and the achievement of higher value-added production. This technology gap not only binds economic diversification but also intensifies the risk of being stuck in the "middle-income trap," where economies are unable to transition from resource-driven growth to innovation-driven development.

Regarding Argentina's GHG, according to the national inventory for the year 2018, they are distributed as follows among different sources.

Figure 1: Sources of CO₂ emissions, year 2018.



Source: Greenhouse Gas Inventory, Secretariat of Environment and Sustainable Development of the Argentine Republic.

Argentina had total emissions of 366 million tons of CO₂ equivalent emissions (MtCO₂e) in 2018. CO₂ equivalent emissions represent a standardized measure that captures the total global warming potential of all greenhouse gases emitted, not just carbon dioxide. This metric aggregates the impact of different gases, including methane (CH₄), nitrous oxide (N₂O), and fluorinated gases, by converting their individual warming effects into the equivalent amount of CO₂, based on their respective global warming potential over a specified time horizon, usually 100 years.

The energy sector is the largest contributor in terms of emissions, accounting for 51% of the total (186 Mt CO₂e), followed by Agriculture, Livestock, Forestry, and Other Land Uses

(143 MtCO_{2e} and 39%), Industrial Processes and Product Use, with a share of 6% (21 MtCO_{2e}), and Waste (16 MtCO_{2e} and 4%).

Within the energy sector, which refers to all activities within IPCC Category 1 guidelines encompassing GHG emissions from fuel combustion activities, 32% of emissions come from energy industries (including electricity generation, fuel production and petroleum refining), 27% from the transport sector, 17% from other sectors (residential, commercial, and agriculture), 18% from manufacturing and construction industries, and 6% from fugitive emissions in hydrocarbon production.

Among emissions originated from the transportation sector (50 MtCO_{2e}), it is noteworthy that the primary source of cargo transportation within the Argentine territory is focused on trucks, accounting for approximately 92% of the country's internal freight transport as of 2021. Rail transportation represents a small share of 4.5% of the total freight, followed by river transportation at 3.5%.

Regarding internal public transportation, according to data from the National Commission for Transportation Regulation, Ministry of Transportation, as of year 2021, the fleet of buses for urban and interurban passenger motor transport services amounted to a total of 22,133, nearly all of which were internal combustion vehicles. In this regard, as of the year 2023, Argentina has a total fleet of 95 electric buses in operation for public transportation, representing a marginal share of the national bus fleet. Similarly, the penetration of electric private vehicles in Argentina is very low, reaching 0.02% as of January 2021 of the total vehicle fleet, according to Iannuzzi and Scarpinelli (2021).

Furthermore, within the emissions from fuel combustion activities, in 2021, 57% corresponds to natural gas—which includes gas distributed through pipelines and used for pumping gas from the fields to consumption—, 20% to diesel, and 10% to the consumption of gasoline. On the other hand, the remaining 13% includes emissions from the combustion of fuel oil, blast furnace gas, liquefied gas, and other fuels with minor participation. In this sense, Argentina's energy matrix is strongly concentrated on fossil fuels, which together account for 84% of the primary energy supply (gas 52% and oil derivatives, 32%), while the rest of the energy sources exhibit marginal shares, according to data from the Ministry of Energy. In this regard, Argentina stands out as a fossil fuel-intensive economy, especially in natural gas.

The significant participation of natural gas, with a marginal contribution of diesel in electricity generation (3%) explains why electricity generation accounts for 11.1% of total emissions (40.61 MtCO_{2e}). This relatively low emission level is a result of the prominent role of natural gas in the electricity generation mix, as this is the fossil fuel that generates the lowest

level of GHG emissions, approximately 40% less than coal and 20% less than gasoline, as pointed by Eggleston (2006). Additionally, the minimal contribution of coal to the total primary energy supply (1%) is noteworthy, as it represents the source with the highest potential of GHG emissions.

The source explaining the second largest share of emissions is related to agriculture, livestock, forestry, and other land use, comprising 39% of total GHG emissions in 2018. This segment includes emissions from croplands, grasslands, and other types of land use. It also encompasses emissions from the management of livestock and manure, emissions from managed soils, and emissions from fertilizer applications. A total of 11.2% of GHG emissions in 2018 were attributed to land use changes. Furthermore, intensive livestock farming, in addition to exerting pressure on the expansion of the agricultural frontier, affects GHG emissions through enteric fermentation in cattle, which accounted for 15.2% of total emissions in 2018.

In conclusion, Argentina's GHG emissions are shaped by a complex interplay of factors. The country's substantial oil and gas reserves support its domestic energy needs, driven by population and economic growth, and the vast geographic distances that necessitate extensive fuel use for transportation. Additionally, the agricultural and livestock sectors, benefiting from favorable soils and climates, contribute to deforestation, further intensifying the country's GHG emissions.

1.3.3 The environmental impacts of the technological gap: transmission channels

On one hand, in economies like Argentina and other developing nations in Latin America, a productive structure marked by considerable structural heterogeneity, characterized by a substantial presence of low-productivity sectors and higher levels of informality, leads to production processes with a heightened potential for GHG emissions compared to more modern sectors. The adoption of green technologies—which include those designed to reduce GHG emissions and are linked to low-carbon electricity generation, low-emission transportation, energy-efficient construction and industrial practices, air pollution control, water and waste management, among other initiatives—requires incentives, financial resources, and skilled labor, elements often lacking in less productive enterprises.

A similar situation arises with the adoption of cutting-edge digital technologies associated with smart manufacturing, commonly known as "Industry 4.0"¹. Despite these

¹ These technologies include artificial intelligence (AI), the Internet of Things (IoT), blockchain, 3D printing, advanced materials, collaborative robotics, and cyber-physical systems, among others.

technologies not being primarily focused on environmental mitigation, their implementation can enhance logistics and energy efficiency and significantly contribute to reducing GHG emissions.

In this way, the same limitations in terms of technological and productive capabilities that lead these companies to widen the productivity gap separating them from the international frontier, constitute a barrier to the adoption of technologies aimed at increasing energy efficiency and reducing the environmental impact of production processes. This, in turn, results in a higher overall volume of GHG emissions.

However, as pointed by a firm level survey performed by Andreoni and Anzolin (2020), within the Argentine production matrix, it is also possible to find companies, activities, or sectors that stand out favorably due to their relatively modern production processes, high levels of productivity, innovation, learning, and quality parameters. These types of companies have significant competitive advantages, which enable them to have greater financial and technological resources to adopt green technologies. Moreover, their incentives to do so are higher because the environmental regulations in the foreign markets they serve, as well as their consumers, demand stricter compliance with environmental standards. However, in Argentina, only 3 per cent of firms were using digital technologies.

Nevertheless, these cases are often referred to as "islands of modernity" or "islands of excellence" because they have weak linkages with the rest of the production structure. Due to their limited integration with other sectors, the development of these activities relies more on imported inputs, and only a limited number of local suppliers are affected by a spillover of their higher environmental standards.

In line with this line of reasoning, a field study conducted by Fundación Centro de Investigaciones para la Transformación (CENIT) (2013) on a set of small and medium-sized enterprises in Argentina during the period 2013-2015 revealed that, while some companies do not engage in any environmental activities, others exhibit relatively sophisticated management based on innovations in less polluting products and processes, the incorporation of cleaner technologies, and certification of environmental management systems. According to this study, the companies with more advanced environmental management levels are those that have already adopted top maintenance and manufacturing practices, have certified their quality management systems, and engaged in technological innovation activities.

Based on these field studies, the obstacles faced by these companies in conducting environmental management activities are primarily related to the high costs of technologies and financing, lack of awareness of available technological alternatives, internal capability

constraints for addressing environmental issues, lack of knowledge about regulations, and a lack of public support, among other factors.

In the same vein, Allan et al. (2014), in a review of the literature examining the global diffusion of green technologies, find that, in addition to the availability of financial resources, the barriers faced by companies worldwide in adopting these technologies are linked to a lack of necessary knowledge to assess the costs and returns associated with them. They emphasize that while the benefits of adopting a technology may be similar among different users, there is a high variability in the costs of adoption, which include resources allocated to learning its use, adapting it to production processes, and integrating it into a company's practices. These costs can significantly differ among potential users of the technology.

Thus, the number of users and, especially, their interaction, constitute a critical factor in reducing uncertainty and costs related to the adoption of green technologies, leading to network effects. In this regard, there is a negative relationship observed between Argentina's structural heterogeneity and the diffusion of green technologies, as their adoption is limited to an exclusive group of companies operating at the international technological frontier. However, these companies are somewhat "isolated" from the rest of the production landscape, where firms exhibit various levels of productivity and technical capabilities and face substantial barriers to incorporating such technologies.

Likewise, network effects are relevant to the diffusion of renewable energies, as they depend on specific underlying infrastructure and compete with fossil fuel-based technologies for which there is already widespread infrastructure (Allan et al., 2014; UNCTAD, 2009; OCDE, 2019; Lütkenhorst et al., 2014; Unruh, 2000). The concept of "carbon lock-in" describes the tendency of specific carbon-intensive technological systems to endure over an extended period, essentially barring the adoption of lower-carbon alternatives. This persistence is a result of various interrelated technical, economic, and institutional factors. While these technologies might be costly to establish initially, their ongoing operation tends to be relatively inexpensive. Additionally, they gradually establish a framework of political, market, and social elements that create high barriers to transitioning away from or "unlocking" them. Among the main sources of carbon lock-in, coal-fired power plants are the first one, followed by gas power plants and internal combustion engine passenger vehicles (Erickson et al., 2015).

In this regard, Argentina's energy matrix exhibits a case of "carbon lock-in" in fossil fuel-based technological systems, as evidenced by their significant share of the total energy supply, accounting for 85%, at the expense of the diffusion of greener technologies, such as

renewable sources, comprising only 8% of the energy mix. The same happens with the transport system, heavily concentrated on internal combustion engine trucks and passenger vehicles.

The widespread adoption of renewable energy sources and electric vehicles requires costly modifications to current electricity grids and vehicle fleets, apart from the political economy challenges, which are beyond the scope of this essay. Despite significant price drops since 2009 until 2019, with solar photovoltaic electricity costs declining by 89% and wind by 70%, the market prices of renewable energy sources have generally remained higher than those of fossil fuels (Roser, 2020).

To replace fossil energy sources and internal combustion vehicles, Argentina should phase out their use, incurring financial costs as these assets may not have been fully amortized. Unlike developed economies, Argentina, like other developing nations, has more limited economic resources, influencing the extent of its energy choices. Consequently, economic incentives for energy transitions in developing economies tend to outweigh long-term climate change considerations (Moore, 2018).

Besides, adopting the use of renewable energy technologies is a move toward decarbonization but can also reinforce prevailing technological dependencies if such technologies—wind power equipment, photovoltaic panels, batteries, and control systems, among others—are foreign imports from industrialized nations. This can contribute to the external constraints of economies like that of Argentina since it raises foreign exchange demand and contributes to trade deficits. In addition, from an energy security perspective, reliance on imported components and technologies may expose developing countries to supply chain risks and geopolitical shocks, and raise issues of the long-term resilience and sovereignty of their energy systems. A sustainable energy transition, therefore, has to place special emphasis, in addition, on the development of local technological capacities and productive linkages.

1.4 Decarbonization pathways

Argentina submitted its second Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC), pledging an absolute and unconditional target of not exceeding net emissions of 349 MtCO_{2e} by 2030. This target reflects a 5% reduction in absolute GHG emissions over the span of approximately a decade, compared to the 366 million tons of MtCO_{2e} emissions recorded in 2018. However, it is important to highlight that the year of this national greenhouse gas inventory, 2018, was a year of recession, with a 2.6% contraction in GDP, according to the World Bank. Moreover, in the event of a return to a growth trajectory in the following decade, achieving this target would necessitate significant efforts to decouple future economic growth from GHG emissions.

The National Climate Change Adaptation and Mitigation Plan, developed by the Ministry of Environment and Sustainable Development, emphasizes various strategies for a comprehensive low-carbon transition. The plan places significant emphasis on advancing energy transition, fostering the development of national technological capabilities for renewable energy value chains, and promoting energy efficiency in industries, buildings, and residential equipment. Moreover, the plan focuses on sustainable mobility, aiming to reduce GHG emissions generated by transportation activities. This involves enhancing the railway services for the transportation of passengers and loads, the renewal of the motor vehicle fleet (public transportation, particular and trucks), among others.

Additionally, the plan incorporates measures under the strategic framework of Energy Transition, focusing on reducing GHG emissions through management practices, the replacement of inefficient and more polluting equipment, and the utilization of innovative technologies. This involves the execution of infrastructure projects to fortify and expand energy transmission and distribution networks, leading to improved energy access and enhanced national energy matrix diversification. The plan also includes initiatives within the scope of Productive Transition, aiming to develop specific national value chains, to impulse the transition to the so called “Industry 4.0”, drive innovation in production processes, and foster productive resilience in vulnerable sectors, thereby contributing to both climate change adaptation and the reduction of GHG emissions.

In this sense, it is important to acknowledge Argentina’s relatively small share in global emissions —about 1% at year 2019 (World Bank). In this context, adaptation measures acquire strategic relevance. Given the country’s high exposure to climate-related risks—such as droughts, floods, and ecosystem degradation—building resilience across productive sectors becomes as crucial as pursuing mitigation. Although international frameworks tend to emphasize mitigation commitments, a balanced climate policy agenda for Argentina must place stronger emphasis on adaptation, particularly in vulnerable rural, urban, and coastal areas.

Moreover, this plan highlights the importance of the sustainable administration of food systems and forests, comprising initiatives such as reforestation, prevention of wildfires in indigenous woodlands, and the encouragement of sustainable production techniques, which include agroecology and restorative livestock farming, along with the demarcation of forest areas. To execute this adaptation and mitigation plan, as indicated by the Ministry of Environment and Sustainable Development, an investment of at least USD 296,594 million would be required to implement a portion of these strategic measures (this estimate does not encompass all of the actions necessary to execute the plan in its entirety), and would originate

from local sources (both public and private) and international financial organizations for development. This amount equates to almost half of the Argentine GDP, which, according to the World Bank, amounted to around US\$630 billion (current US\$) in 2022.

Thus, even with access to a substantial portion of international credit for the green transition, Argentina would need to generate and invest a significant amount of local (both public and private) resources to finance this plan. It should be noted that by 2020, climate financing in Latin America and the Caribbean amounted to a total of \$22,7 billion (current US\$), according to the estimates by Samaniego and Schneider (2023). These funds encompass those from national, regional, and multilateral development banks, as well as resources mobilized by bi- and multilateral climate funds, green bonds, and other local resources.

In this context, to secure the financing required for these mitigation and adaptation plans, a substantial increase in resources is necessary. This demands a progressive process of structural change that transforms the production structure towards a specialization with higher technological intensity, fostering greater value addition in GVC. This transformation should foster poverty reduction and greater inclusivity, simultaneously generating the necessary resources to sustain economic growth without incurring balance of payments crises, thus freeing up resources to finance this green transition. If the productive structure remains largely unchanged, maintaining its current specialization in international trade centered around agricultural commodities and raw materials, the GDP's growth potential will continue to be restricted by external constraints, limiting fiscal resource generation for meeting both social needs through public policies aimed at greater social inclusion and for funding decarbonization-oriented policies (Lallana et al., 2021).

As mentioned in the preceding subsection, Argentina possesses substantial reserves of unconventional oil and gas, accounting for the significant share of these fossil fuels in the energy matrix and GHG emission patterns. Furthermore, the energy sector has the potential to emerge as a prominent player in the oil and gas international market in the near future, serving as an export source that can pave the way for Argentina to embark on a path of sustained economic growth and generate resources to finance a potential green transition. The three-gap model proposed by ECLAC (2020) represents a valuable analytical tool for comprehending the interrelation among all these elements.

To achieve this, it will be necessary to assess the potential of unconventional gas and oil in the current and near-future global energy matrix. This evaluation should involve a comprehensive exploration of concepts linked to carbon lock-in and green industrial policies. Furthermore, understanding the intricate interplay between these concepts can provide valuable

insights into the pathways for transitioning towards more sustainable energy systems and unlocking the potential of renewable energy sources. It is imperative to examine the implications of carbon lock-in and how it can be mitigated through the implementation of green industrial policies that encourage the adoption of cleaner energy alternatives. This assessment should also consider the various economic, social, and environmental dimensions, thus facilitating a more holistic approach to sustainable development and energy transition.

1.4.1 Argentina's Prospects as a Global Energy Player: challenges and opportunities

From Table 2, we can see that global primary energy consumption matrix exhibits a significant share of fossil fuels, maintaining an unchanged proportion of the total global primary energy consumption from 1995 to 2019, at around 78% (oil, gas, and coal combined). Notably, gas increased its share in total energy consumption in both developed and emerging countries in the last decades, passing from 20% and 18% in 1995, respectively, to 26% and 20% in 2019, showing an annual cumulative growth rate of 1,5% and 3,6%, in absolute terms.

Table 2: World primary energy consumption (exajoules)

Source/Year	1995	2005	2015	2019	Annual cumulative rate	Total increase	Share over total consumption, 1995	Share over total consumption, 2019
Oil	142	168	184	193	1,3%	50	36 %	31 %
Gas	76	99	125	140	2,6%	64	19 %	22 %
Coal	93	130	159	158	2,2%	64	23 %	25 %
Nuclear	23	27	24	25	0,3%	2	6 %	4 %
Hydro	25	28	35	38	1,7%	13	6 %	6 %
Renewables	39	46	62	74	2,7%	35	10 %	12 %
Total	399	498	589	627	1,9%	228	100 %	100 %

Source: own elaboration from BP Energy Outlook, 2023 edition.

When distinguishing between developed and emerging countries (table 3), a decreasing trend in the share of fossil sources is observed among developed nations, declining from 81% to 77%. Conversely, emerging countries increased their share of fossil sources in their total primary energy consumption from 75% to 79%. In this regard, a nascent energy transition is noticeable in developed countries due to the increased contribution of renewable sources (rising from 3% to 10%) and the decreasing consumption of coal (-1,4% accumulated rate) throughout the period. Notably, renewable sources grew at an annual rate of 5.4%, significantly outpacing the growth rate of total energy consumption, which stood at 0.4%. Moreover, the increase in energy consumption was significantly lower than the annual

cumulative GDP growth rate in high-income nations, which stood at 2.14% during the 1995-2019 period, as per the World Bank data. This indicates the decoupling between energy consumption and GDP growth.

Table 3: Primary Energy Consumption, Developed and Emerging Countries (Exajoules)

Source/Year		1995	2005	2015	2019	Annual cumulative rate	Share over total consumption, 1995	Share over total consumption, 2019
Oil	Developed	88	97	86	88	0,0%	41 %	38 %
	Emerging	54	71	98	105	2,8%	29 %	27 %
Gas	Developed	42	49	55	61	1,5%	20 %	26 %
	Emerging	34	50	70	80	3,6%	18 %	20 %
Coal	Developed	44	49	40	32	-1,4%	20 %	14 %
	Emerging	50	82	119	126	4,0%	27 %	32 %
Nuclear	Developed	21	23	19	18	-0,6%	10 %	8 %
	Emerging	2	3	5	7	4,8%	1 %	2 %
Hydro	Developed	13	12	12	11	-0,5%	6 %	5 %
	Emerging	12	16	24	26	3,2%	7 %	7 %
Renewables	Developed	7	10	20	25	5,4%	3 %	10 %
	Emerging	32	35	42	49	1,8%	18 %	13 %
Total	Developed	215	241	231	235	0,4%	100 %	100 %
	Emerging	184	257	358	393	3,2%	100 %	100 %

Source: own elaboration from BP Energy Outlook, 2023 edition.

In contrast, in developing countries, an opposite trend is observed with a cumulative annual growth rate of 1.8% for renewable sources, while total primary energy consumption experienced a notably higher growth rate of 3.2%, as shown in Table 3. In absolute terms, total primary energy consumption increased by 114% between 1995 and 2019.

From a global perspective, there is an increase in the share of coal in total primary energy consumption, rising from 23% in 1995 to 25% in 2019. This increase is primarily attributed to the growing consumption of coal in emerging countries, which went from 27% in 1995 to 32% in 2019 (4% annual cumulative rate). Out of the total increase in energy consumption volume by the year 2019, both coal and gas played a significant role in meeting this growth, contributing 64 exajoules each. Together, they accounted for more than half (56%) of the total 228 exajoules increase. Notably, gas increased its share in total energy consumption in both developed and emerging countries.

With more developing nations transitioning to lower GHG emissions, coal consumption is expected to slow down. Conversely, the demand for natural gas is anticipated to rise over the next few decades due to its use in displacing coal. This is because natural gas

emits 40% less GHG than coal, making it a transitional fuel with the lowest emission potential among fossil energy sources.

The rise in natural gas demand is closely related to technological advancements, particularly the expansion of liquefaction and regasification, enabling its maritime trade and greater commoditization. Despite the higher cost associated with the liquefied natural gas (LNG) value chain compared to gas pipelines (liquefaction, transportation, storage, regasification and distribution), LNG trade has been increasing due to its diversified and flexible supply, reducing reliance on a single supplier and improving energy security (Arceo et al., 2022).

While gas pipeline trade will remain crucial, these changes have made the natural gas market more flexible, presenting opportunities for a country with abundant gas resources. Argentina, in this new context, faces new opportunities and challenges in hydrocarbon resource development, especially with the potential of Vaca Muerta field. The development of Vaca Muerta could create exportable surpluses to alleviate the external restrictions that the country has faced in recent decades, and could support in financing the green transition. However, the utilization of Argentina's hydrocarbon resources has a limited time frame until alternative energies reduce the prominence of hydrocarbons in the global energy mix. This window of opportunity might be smaller for oil, as it may not serve as a transition fuel to mitigate GHG emissions.

The substantial capital needed for the comprehensive development of unconventional formations poses one of the principal challenges in this sector in the upcoming years. Another critical challenge associated with Vaca Muerta's development relates to the infrastructure essential for transporting hydrocarbons from the fields in the province of Neuquén, in the southern region of Argentina, to both domestic and international consumption hubs. During the summer, an excess supply of gas results from increased production, requiring the expansion of gas pipeline capacity within Argentina and to neighboring countries from Neuquén. Apart from Chile, Brazil has emerged as a potential importer of gas from Vaca Muerta, requiring the promotion of a large-scale project linking the fields in Neuquén to the southern region network in Brazil. Simultaneously, to provide to the extra-regional market, additional investments are imperative for the construction of liquefaction plants, enabling the export of LNG by ships. Without the development of this infrastructure to handle larger natural gas volumes, the production capacity at Vaca Muerta will remain restricted to current levels (Nercesian et al., 2022).

However, the challenge is not only due to the required investment volume needed for the development of the necessary infrastructure, but also because of the ongoing global energy transition, which limits the time to capitalize on Argentina's abundant hydrocarbon resources. Particularly in the case of oil, as gas, characterized as a transitional fuel, might still have a longer lasting window of opportunity due to its dynamic international demand. The global energy transition poses an infrastructure development challenge for the exploitation and exportation of hydrocarbons, potentially impeding the return on investments. Additionally, large-scale hydrocarbon exploitation directly impacts emissions related to fuel production, petroleum refining, and fugitive emissions in hydrocarbon production, compromising Argentina's commitments in terms of future emissions, as proposed in its NDC.

Furthermore, investments in the production and transportation of unconventional hydrocarbons carry the risk of carbon lock-in, as described previously, representing the persistence of specific carbon-intensive technological systems that hinder the adoption of lower-carbon alternatives. This limitation could restrict progress in Argentina's energy transition toward a more environmentally friendly energy matrix. The following subsections will delve into this concept, explaining how carbon lock-in may not only impede energy transition but also hinder the leveraging of opportunities related to green technologies. Such technologies not only enable a shift towards a lower environmental impact economy but also have the potential to drive dynamic comparative advantages, fostering upgrades in GVC.

This reflects a contradiction in leveraging Argentina's potential for unconventional hydrocarbons. While it can significantly contribute to energy import substitution and boost export volumes, easing the growth restriction imposed by the balance of payments, and providing necessary resources for advancing Argentina's green economy transition, there is a simultaneous risk. Investment in this sector may gradually establish a framework of political, market, and social elements that create significant barriers to transition away from hydrocarbons.

1.4.2 Sustainable development in Argentina: a three-gap model analysis of economic growth and GHG emissions

According to the Three-Gap Model (ECLAC, 2020), reducing poverty requires a high product growth rate (alongside other redistributive measures) denoted as y^S , which surpasses the growth rate consistent with the balance of payments equilibrium (y^E). Additionally, y^E is higher than the growth rate compatible with the environmental boundary (y^A). The disparity

between the growth rate required for equality and the growth rate compatible with the environmental boundary is known as the sustainability gap. Closing this gap ensures sustainable development across the economic, social, and environmental dimensions.

This assertion stems from the significance of economic growth for all countries, particularly those with lower relative incomes and considerable social debts in terms of poverty and social inequality. However, rapid economic growth will inherently demand a substantial increase in energy consumption, particularly in cases like Argentina, where reliance on fossil fuels will result in considerable CO₂ emissions. This scenario highlights the inherent tensions between environmental conservation and economic growth objectives.

In Argentina's context, y^S surpasses y^E , the last being determined by the ratio between the income elasticity of exports and the income elasticity of imports. This ratio, affected by the country's commercial specialization, is more restricted compared to that of more developed and diversified economies. As income grows, imports increase more than exports, imposing a balance of payments constraint. Exploiting unconventional energy sources like Vaca Muerta fields, could significantly boost y^E . Achieving energy self-sufficiency through domestic energy sources can reduce dependence on energy imports, thus reducing the income elasticity of imports. Moreover, increased energy exports would amplify the income elasticity of Argentine exports, thus reducing the gap between y^S and y^E , referred to as the social gap.

Conversely, the environmental gap, represented by the difference between y^E and y^A , would widen. Large-scale hydrocarbon exploitation for import substitution and exports would directly impact emissions related to energy production processes, including fuel production, petroleum refining, and fugitive emissions. Additionally, the resulting economic growth and increased energy demand would unavoidably escalate GHG emissions due to the dominance of fossil fuels in the current energy matrix. To close the environmental gap, a transition is imperative to decouple GHG emissions from economic growth. This transition presents several challenges, particularly in an economy heavily reliant on fossil fuels.

Notably, this situation is further complicated when considering the concept of a global carbon budget (Meinshausen et al., 2009), which pertains to the remaining carbon resources that cannot be burned to maintain a below 2°C scenario. Modelling exercises suggest that, in a scenario without widespread use of Carbon, Capture and Storage technologies, approximately 45% of all oil resources must remain unexploited (McGlade and Ekins, 2014), emphasizing the challenge for Argentine hydrocarbon shale reserves exploitation, particularly in the case of oil. However, for gas, as a transition fuel, the outlook may be more promising, especially if the

unconventional gas exports from Vaca Muerta aid in displacing more carbon-intensive sources worldwide, like coal.

1.4.3 Unlocking the green transition: challenges for overcoming carbon lock-in and path-dependence

Based on the preceding paragraphs and Argentina's commitments in its NDC, the necessity of transitioning towards an energy shift is emphasized, as well as a broader move toward environmental upgrading. Environmental upgrading is defined as any change towards a reduction in firm's ecological footprint, through decreased GHG emissions, reduced energy and other natural resources consumption, or a minimized impact on biodiversity (De Marchi et al., 2019). This entails a green transition, enabling the decoupling of economic growth from energy and material consumption.

In a fossil fuel-based energy and technological system as Argentinian, as evidenced by the significant share of fossil fuels on the total energy supply, accounting for 85%, with a transport system heavily concentrated on internal combustion engine trucks and passenger vehicles, the widespread adoption of renewable energy sources and electric vehicles requires costly modifications to current electricity grids and vehicle fleets, apart from the political economy challenges.

In this context, Hochstetler (2020) highlights, when analyzing the political economies of energy transition in other developing economies such as Brazil and South Africa, that market forces are unlikely to propel a low-carbon transition when fossil fuels are still readily available and widely diffused (as in the case of Argentina), emphasizing the necessity of government support.

Similarly, Landini et al. (2020) argue that policies from separate domains, such as energy, scientific, technological, and industrial sectors, need to be aligned and co-created across the energy-environmental and industrial spheres. According to Hochstetler (2020), when issues span different policy spheres, the initiatives in one domain can undermine the effectiveness of another. As an example, in the renewable energy sector, there might be a trade-off between ensuring faster and cheaper deployment of projects and developing a national industry, given the latter's additional costs. The rapid expansion of renewable energy sources often entails dependence on imported goods and suppliers, conflicting with the establishment of local industries. Hence, the alignment of different policy instruments from different spheres assumes crucial importance (Lütkenhorst et al., 2014).

In this scenario, Lütkenhorst et al. (2014) underline that the shift to sustainable practices demands substantial initial investments in new resources. Given the presence of carbon lock-in, the establishment of policy rents is vital to incentivize these green investments. Policy rents can serve as a potent instrument for driving structural change, especially within energy systems.

Nonetheless, in cases where the current electricity supply relies on fossil fuels, the fossil fuel sector has interests against the development of these green sources. Fossil fuel sectors possess significant structural and mobilizational influence, firmly entrenched within physical infrastructures, social institutions, political power dynamics, and prevailing norms (Unruh, 2000). Hence, managing the transition to more sustainable economies by instituting and withdrawing rents poses notable challenges (Johnson et al., 2014). Unruh (2000) shows how carbon lock-in is established at the firm's micro level, involving dedicated infrastructure, standards, and networks at the meso level, that become entrenched as a dominant design. All of these is reinforced by government policies. These issues are particularly critical for middle-income and developing countries where economic drivers are paramount and may or may not align with the climate change motivations that prompted many early adopters from developed economies (Hochstetler, 2020).

1.5 Final considerations and policy implications

In light of the above, we have seen how the technological gap in Argentina manifests itself in a productive structure characterized by a strong concentration of low-technology intensive sectors and lower relative productivity. This results in greater structural heterogeneity, affecting energy efficiency levels and the adoption and diffusion of green and digital technologies, all of which translate into higher GHG emissions. Thus, it becomes evident that the joint evolution of technology diffusion (highlighted within the evolutionary tradition) and the productive structure (emphasized by the structuralist tradition) gives rise to an environmental dimension related to energy efficiency levels and the adoption of green technologies.

Furthermore, as previously discussed, an economic structure focused on low-technology- intensive activities can hinder the prospects of generating dynamic competitiveness gains. This leads to a trade specialization based on static comparative advantages, stemming from relative abundance and the exploitation of natural resources. This is the case with Argentina's pattern of trade specialization, concentrated in primary products and resource-based

manufacturing. It's worth noting that while the production processes of these goods employ highly advanced technology elements, the increase in production volume to meet growing external demand results in the expansion of the agricultural frontier into new regions. This directly impacts GHG emissions due to changes in land use, as areas that were once forested are converted into soy monocultures or livestock establishments.

Thus, we observe the impacts of Argentina's trade specialization based on natural resources on the level of GHG emissions. However, it's worth noting that in the case where specialization was based on other types of products, such as medium or high-tech manufactures, this would also have an impact in terms of GHG emissions, primarily stemming from energy consumption related to these industries. Nevertheless, the potential benefits of this type of specialization for building technological and productive capabilities, technological diffusion, and thus reducing the technological gap, coupled with its greater dynamism in international markets, would lead to a higher diffusion of green and digital technologies that would promote greater energy efficiency and decarbonization of the energy matrix. This, in addition to reducing the pressure on the advancement of the agricultural frontier to generate the necessary foreign exchange to meet import demand and external financial commitments.

Additionally, and recognizing once again a point of convergence between the environmental dimension and the approaches presented in this work, it is worth noting that early adoption of green technologies and involvement in the production of equipment and products embodying these technologies can create new opportunities to add value in rapidly expanding international markets, providing "early mover" advantages in GVC (UNCTAD, 2009). From this perspective, China's advancement into electric vehicle, solar, and wind energy markets stands out as a leapfrog strategy towards the development of new short-cycle technology products (Lee, 2013). Similarly, the early penetration of Denmark into the wind energy sector and Germany's energy transition can be explained as strategies driven by both environmental and economic objectives, aiming to strengthen these countries' positions in global green technology markets (Allan et al., 2014).

The theoretical and qualitative case analysis presented in this essay offers several policy implications. In many cases, the policy recommendations of the theoretical approaches explored—Latin American structuralism, neo-Schumpeterian and the evolutionary perspectives—demonstrate significant convergence. However, when examining the green transition, the analysis uncovers points of synergy and mutual reinforcement that can be particularly useful in shaping policies aimed at driving this transition forward.

A central element shared by these approaches is the recognition of the critical role of the state and institutions in steering the shift toward an environmentally sustainable economy. Market mechanisms alone, even when accounting for externalities, are insufficient to address global warming, frequently cited as the greatest market failure in history (Stern, 2008).

Lema et al. (2020) highlight various green energy sectors that have benefitted from demand-pull policies. A key example of these policies is feed-in tariffs, designed to level the playing field between green energy and fossil fuels by subsidizing demand. Public procurement has also been used, either alongside or as an alternative to feed-in tariffs. For instance, in the hydropower sector, public procurement was instrumental in the early industry development across several countries (Landini et al., 2020; Zhou et al., 2020). Similarly, in the electric vehicle sector, municipal purchases of electric buses and light vehicles played a critical role in market formation in countries like China and India (Hain et al., 2020). Additionally, institutional windows can drive technological change through mission-oriented public research and development programs (Dai et al., 2020). Institutional and demand-driven green windows are more common than opportunities arising primarily from technological breakthroughs (Lema et al., 2020).

However, as Hain et al. (2020) note, market investments through green subsidies, without parallel investments in technical change, can lead to a market trap where latecomers may gain market leadership but remain technology followers. On the other hand, if induced technical change is not met with sufficient market demand, either domestic or external, even strong technological capabilities may remain underutilized. Landini et al. (2020) emphasize that while creating demand can drive latecomer learning, capability-building, and a potential catch-up process, this outcome is not guaranteed and depends on the presence of specific conditions at the right time. The authors highlight the risk of technological discontinuities emerging after a demand window has opened, which could lead developing countries to become locked into outdated technologies, rendering their market investments ineffective for attaining global competitiveness (Lema et al., 2020).

During the market development phase, beyond supporting the establishment of basic production capabilities through the acquisition of foreign technology, it is crucial to protect domestic demand from being dominated by imports and multinational companies operating locally (Landini et al., 2020). This protection can be achieved through industrial policies, such as requiring minimum local content in total project value and safeguarding infant industries—measures that are currently restricted under World Trade Organization (WTO) regulations. Given the urgency of the green transition, it is essential to discuss within the global climate

policy arena whether relaxing these trade-related prohibitions in green sectors could be beneficial.

Hansen and Hansen (2020) emphasize the importance of policies that foster supplier relationships and university-industry linkages, enabling knowledge spillovers from leading firms to other domestic companies. This diffusion of technological capabilities across a broader range of actors helps ensure that more firms can capitalize on specific windows of opportunity, ultimately enhancing the competitiveness of the entire sector. However, many of these recommendations for latecomer development are derived from the experiences of green sectors in China. The realities faced by many developing countries, particularly those in Latin America, may differ significantly from the Chinese context, especially in terms of technological and productive capabilities. The diffusion of knowledge through linkages, as discussed previously, may not be easily replicable in a context marked by structural heterogeneity, as outlined in Section 2. Therefore, it is essential to complement these policy recommendations with additional insights from structuralist perspectives. Without this, the policies might fail to achieve the desired effects or prove ineffective.

In this context, policies such as green public procurement, feed-in tariffs, and other measures focused on domestic demand as a driver for green sector development must be integrated into a comprehensive developmental strategy. This strategy should focus on macroeconomic priorities such as sustained high growth and increased public infrastructure investment (Medeiros and Majerowicz, 2025). Overcoming external constraints and securing the necessary resources to fund these policies is crucial. In this regard, implicit industrial policies, related to stable macroeconomic environment and sustained economic growth gain renewed importance to ensure the effectiveness of direct policies aimed at developing green sectors.

Establishing mechanisms for cooperation, funding, and standards adapted to national contexts is crucial. Increasing demand for high-value and green products from peripheral countries by core economies, through enhanced trade agreements, is especially pertinent. This is particularly relevant for lithium and other critical minerals for the energy transition, which South America exports as raw materials. A regional industrialization strategy aimed at adding value to these materials, backed by demand from developed economies, could significantly advance the green transition in peripheral countries. It could improve trade surpluses, support higher growth rates aligned with external constraints, and help avoid economic downturns.

Developing countries that successfully combine technological leadership with low-cost production resources will be well-positioned to provide affordable solutions for the global

green transition. The rise of latecomer countries in the green economy can have global benefits by lowering the costs of energy transition technologies. This, in turn, may help mobilize financial resources and technology, making the greening of energy systems more affordable for poorer nations in the Global South (Lema et al., 2018).

The exploitation of gas reserves in Vaca Muerta could provide resources to finance green industrial policies, provided that risks of carbon lock-in and state capture are carefully managed. Additionally, exporting LNG might help reduce global emissions, as long as the gas is used to displace oil or coal, which still dominate the global energy mix. Achieving these goals requires coordinated actions and strategies across both STI and energy policies.

However, it is important to note that there is a dimension related to consumption habits, which also has a significant impact on GHG emissions and, at the same time, is influenced by the factors resulting from the technological gap. As the level of productive and technological development impacts income levels (and distribution), it also affects final consumption levels, the distribution of consumption among different sectors, and consumer preferences regarding pollution. In this regard, an increase in income directly affects energy consumption, which can lead to higher emissions, but it can also trigger changes in consumer preferences, creating incentives for the adoption of more sustainable consumption patterns with greater energy efficiency and lower emissions intensity. This dimension goes beyond the focus of this work and is suggested as an agenda for future research.

Throughout this work, the points of convergence between the structuralist, neo-Schumpeterian and evolutionary traditions have been discussed, expanding the debate on the links between productive structure, technological gaps, and trade specialization as addressed by these approaches. We have also incorporated the environmental dimension and specified, in the case of Argentina, the channels through which these elements contribute to a greater environmental impact, measured in terms of GHG emissions.

In this context, the limited development of capabilities can hinder the adaptation of developing economies to the new context of climate change. This is particularly concerning given that rising temperatures have disproportionately affected the poorest countries, highlighting an unequal distribution of the costs of environmental degradation. According to the IPCC (2019), high temperatures significantly impact agricultural incomes, and economic losses related to natural disasters are two to three times higher for people living in poverty.

2 MAIN DRIVERS OF CHANGES IN GREENHOUSE GAS EMISSIONS IN ARGENTINA: A STRUCTURAL DECOMPOSITION ANALYSIS

2.1 Introduction

Environmental problems have increased and become more urgent over the last few decades. Climate change is one of the most urgent environmental problems generated by productive activities, potentiating the impacts of other environmental and social problems. The accumulation of carbon dioxide, methane and other GHG increased rapidly throughout the 20th century. The high (and growing) concentration of GHG observed in recent decades results, among other things, in an increase in global temperature that, in turn, has resulted in climate change.

These environmental challenges have spurred a range of international initiatives aimed at implementing policy measures, particularly green industrial policies, to curb or reverse the escalating trends of environmental issues. In this context, the Sustainable Development Goals 2030 of the United Nations stand out, together with the Paris Agreement and the Kyoto Protocol. The objective of these initiatives is to limit the rise in the global average temperature below 1.5°C or 2°C concerning pre-industrial levels. The IPCC (2019) emphasizes that the difference between 1.5 °C and 2 °C would increase the environmental risks considerably. However, this difference in temperatures implies significant reductions in the levels of GHG emissions, to the extent that to reach the 2 °C objective it is necessary for all countries to reduce GHG emissions by 25% by 2030, compared to 1990 levels, and 55% to reach the goal of 1.5°C.

The challenges of reducing or controlling the increasing global temperatures require significant transformations in energy, materials and food production and consumption systems, in addition to multilateral agreements in international trade. Since GHG emissions are primarily generated through production processes, the link between environmental degradation and economic growth has been a central topic of debate for the past three decades. The exponential rise in GDP per capita has paralleled a similarly steep trajectory in GHG emissions (Stern, 2013). If the consequences of pollution and the deterioration of ecological systems are already being observed, this pressure on the environment will likely continue in the coming years, as it is estimated that the world GDP will continue growing (OECD, 2019).

While developed countries are responsible for the majority of historical cumulative emissions, developing nations have exhibited faster CO₂ emissions growth in recent decades, contributing an increasing share to the world's total annual emissions (Ciais et al., 2013; International Energy Agency [IEA], 2018). The International Monetary Fund (IMF) projects

that by 2028, the GDP of developing countries could rise by 37% compared to 2023, reaching over \$60 trillion, with per capita GDP increasing by nearly 30%. Therefore, the trajectory of GHG emissions in the developing world will be pivotal in shaping global climate outcomes.

The critical limits of GHG emissions can be expressed in terms of a maximum rate in which the world economy can grow without placing the stability of the environmental ecosystems at risk, considering the evolution of GHG emissions per unit of GDP (ECLAC, 2021). In this context, technological advancements that decouple production from GHG emissions and resource consumption, alongside shifts in production and consumption patterns, are crucial for achieving environmentally sustainable growth.

The Environmental Kuznets Curve (EKC) has been widely used to explore the relationship between economic growth and environmental degradation. It posits an inverted U-shaped relationship, where environmental impacts initially rise with income but eventually decline as economies mature (Grossman and Krueger, 1991). However, the EKC has been subject to extensive criticism, particularly for its lack of empirical robustness at the national level and its failure to account for differences in production structures and trade dynamics (Churchill et al., 2018). In the case of developing economies, relying on this stylized trajectory can distort our understanding of the structural drivers of emissions and lead to misguided policy expectations. Therefore, a more granular approach is needed—one that identifies the determinants of emissions over time and captures how structural changes in the economy influence environmental outcomes. In this light, understanding the sources and drivers of GHG emissions, particularly in developing countries, is essential for effective management and mitigation of climate change. Assessing the relationship between structural changes in the economy and emissions is key to reconciling economic growth with sustainable development. This requires not only technological innovation but also policy frameworks that promote decarbonization while ensuring equitable growth.

The objective of this essay is to analyze the main drivers of changes in GHG emissions in Argentina from 2000 to 2016. These determinants encompass alterations in final demand, shifts in energy and emission intensity related to production processes, and the sectoral composition of the economy. The identification of these key drivers during the specified period aims to enhance our understanding of achieving the decoupling of economic growth from GHG emissions. Given Argentina's varied economic circumstances during this period, ranging from one of its most severe crises to periods of robust growth, this study offers valuable insights into the intricate relationship between economic growth and GHG emissions in developing economies. The central research question guiding this essay is: What are the key determinants

of GHG emissions in Argentina, and how can economic growth be decoupled from emissions in the context of a developing economy? This analysis contributes to the broader discussion on how developing nations can reconcile economic growth with environmental sustainability.

The methodology employed in this essay, a structural decomposition analysis (SDA) of environmentally extended input-output matrices, is highly relevant for understanding the structural changes in Argentina's GHG emissions during the 2000-2016 period. By using data from the Eora MRIO database (Lenzen et al., 2013), which incorporates satellite accounts of GHG emissions and complemented with energy consumption data from IEA, this approach allows for a detailed examination of the key drivers of emissions, such as shifts in final demand, energy intensity, and sectoral composition. This method is particularly valuable for analyzing Argentina's case, as it enables a granular investigation of how economic and structural transformations have influenced emissions trends over time. Given that no similar SDA study has been conducted for Argentina, this methodology offers a novel and comprehensive perspective on the country's emissions profile, providing insights that are relevant for formulating policies aimed at decoupling economic growth from GHG emissions.

This essay is organized as follows. Following the introduction, the second section reviews the literature related to studies relevant to this work. The third section develops the methodological aspects, presenting the foundational concepts of input-output and structural decomposition analysis along with the data used. Subsequently, the fourth section contains the results and discussion, followed by the final section, which provides conclusions and policy recommendations.

2.2 Literature review

Since the introduction of the analysis of the environmental impacts generated by economic activities through the input matrices proposed by Leontief (1970), this tool has been widely employed in empirical studies to investigate environmental and natural resource-related issues. Its utilization has greatly contributed to policy formulation in these areas (Zhu et al., 2018).

Among the methodologies commonly used to study energy and carbon footprints, the index decomposition analysis (IDA) and the SDA have gained prominence. IDA has been employed since the 1990s to examine CO₂ emissions and energy consumption, driven by growing concerns about global warming. It is based on the application of index number theory—such as the Laspeyres or Divisia indices—to decompose aggregate changes in emissions or energy use into the contribution of various driving factors. These typically include

activity level, energy intensity, fuel mix, and emission factors (Ang, 2015). However, it is worth noting that IDA primarily considers direct effects while neglecting indirect effects, those associated with final demand, and operates at a lower level of disaggregation compared to SDA (Zeng et al., 2014).

The SDA is a specialized method used to identify the contribution of different factors to observed changes in a given aggregate variable over time, typically within the input-output framework. Mathematically, it decomposes the variation of a variable (e.g., emissions, energy use) between two periods into changes attributable to components such as technology (input coefficients), final demand (volume and composition), and emissions or energy intensity. By analyzing the differences between two input-output matrices, SDA enables researchers to isolate the structural, technological, and consumption-related drivers behind the evolution of environmental indicators (Hoekstra and Van den Bergh, 2002; Miller and Blair, 2009). Studies employing SDA encompass a wide range of variables, including product breakdown, value-added analysis, and labor demand. In the context of environmental research, SDA is commonly used to examine changes in physical flows such as energy consumption, CO₂ emissions, and other resources and pollutants. According to Hoekstra and Van Den Bergh (2002), the input-output analytical framework is well-suited for environmental analysis as it enables the integration of detailed information on economic structures with data on physical flows, including materials, gases, fuels, among others.

While conducting studies using data from input-output matrices increases the information requirements, it also enables more in-depth and detailed analyses. This approach facilitates the identification of structural determinants from the perspective of production and final demand (Xie, 2014). In contrast, alternative approaches to SDA do not provide researchers with the same level of capability to thoroughly analyze the productive linkages within an economy and their implications for changes in CO₂ emissions and energy consumption (Brizga et al., 2014).

Additionally, as noted by Miller and Blair (2009), data from input-output matrices can be combined in both monetary and physical units, enabling the integration of both aspects into a hybrid input-output matrix. This approach ensures that the technological relationship between inputs and outputs remains unchanged despite variations in relative prices. Conversely, an alternative method for linking data in physical and monetary units involves integrating the input-output matrix in monetary units with a vector representing the material intensity per unit of output for each sector. This vector can include metrics such as emissions intensity, which captures the relationship between a product and its corresponding CO₂ emissions. Hoekstra and

Van Den Bergh (2002), highlight that this approach requires less data than hybrid unit models and is commonly employed in environmental SDA studies.

According to Miller and Blair (2009), the equivalence between the hybrid unit and intensity factor methods is applicable only when product prices remain uniform across all sectors and final consumers over time. However, if there are variations in product prices, the hybrid unit method is considered superior in addressing this issue.

The selection of the variable for conducting structural decomposition analysis relies on the research question and objectives. Hoekstra and Van Den Bergh (2002) suggest that studies investigating variations in CO₂ emissions or energy consumption often concentrate on changes in the absolute values of these variables, utilizing additive approaches in SDA. Conversely, Su and Ang (2012) point out that studies comparing the relative changes of economic or environmental indicators across countries typically employ approaches based on the growth rate of the variables, for which multiplicative SDA methods are used.

2.2.1 Global applications of SDA methodology

Common and Salma (1992) applied the SDA methodology to analyze changes in Australia's total CO₂ emissions from 1974 to 1987. The analysis focused on three components: changes in final demand, changes in technology, and changes in the fuel mix. The study considered six different types of fuels (wood, bagasse, brown coal, black coal, oil, and gas) and excluded electricity, as it was either a secondary source derived from combustion or a primary source that did not generate emissions (such as solar, hydroelectric, or wind sources). The results of the study revealed several noteworthy findings. Firstly, the total CO₂ emissions exhibited a stable trend throughout the examined period. However, the contributions to this overall trend attributed to final demand, technology, and the fuel mix displayed significant variations. Notably, the only determinant that consistently had a positive value and contributed to CO₂ emissions was the final demand for industrial products.

Peters et al. (2007) utilized the SDA methodology applied to China's input-output matrices (adjusted for constant prices using the double deflation method) to examine the impact of changes in economic structure, technology, urbanization, and population lifestyle on CO₂ emissions resulting from energy consumption. The analysis focused solely on emissions related to the production of goods and services (without considering energy use by households), and covered the period from 1992 to 2002. The findings suggest that the construction of infrastructure, coupled with urban household consumption driven by urbanization and changes

in lifestyles, led to an increase in emissions that outweighed the decrease in emissions resulting from technological advancements and improvements in energy efficiency.

Ferreira Neto et al. (2014) conducted a study utilizing SDA to examine the impacts of changes in final demand from households and productive structures on the use of different energy sources, including coal, oil and gas, renewable sources (such as hydroelectric, geothermal, solar, wind, and biomass), electric power, and other sources. The analysis focused on two groups of countries: developing countries (Brazil, China, India) and developed countries (Germany, the United Kingdom, and the United States), and covered the period from 1995 to 2005.

Based on the study, it can be inferred that the final demand of households makes a positive contribution to energy usage in all countries, with notable significance observed in Brazil, China, India, and the United States. Additionally, the volume effect of household demand was positive, indicating an increase in energy consumption due to an overall rise in household consumption. However, the composition effect was negative, indicating that changes in household consumption patterns during the analyzed period led to a reduction in energy consumption. Despite this, the increase in volume outweighed the composition effect, resulting in a positive overall impact from household final demand on energy consumption. Furthermore, it is worth noting that the contribution of changes in the productive structure to energy consumption was positive only in Brazil.

Lan et al. (2016) conducted an analysis on the energy consumption of 186 countries from 1990 to 2010 using environmentally extended interregional input-output matrices obtained from the EORA MRIO database. The main objective was to identify the factors influencing energy consumption and examine the countries and sectors that experienced changes in energy consumption during this period. The study also investigated the effects of international trade in transferring energy-intensive production processes to other countries.

To analyze these aspects, the researchers employed the SDA method. They converted the input-output matrices to constant 1990 USD dollars to mitigate biases resulting from Price variation and fluctuations in exchange rates. The change in energy consumption was broken down into six effects: energy intensity, technological effect (changes in the Leontief inverse), demand structure (product mix), destination of final demand, GDP per capita, and population effects.

Furthermore, the study conducted a comprehensive analysis of various SDA methods, considering their theoretical foundations, adaptability, ease of calculation, and interpretation of results. After evaluating these factors, the study recommends two specific methods: the simple

average method developed by Dietzenbacher and Los (1998) and the logarithmic mean division index proposed by Ang and Liu (2001). These recommendations align with the findings of Su and Ang (2012).

The results of the study indicate that, for the majority of countries examined, population and economic growth were the primary drivers of increased energy consumption. However, this increase was partially offset by a decrease in industrial energy intensity. Furthermore, the study reveals that as GDP per capita rises, country's energy consumption footprint is increasingly concentrated in imports and consumption.

Su and Ang (2012) carried out an extensive review of empirical studies conducted between 1999 and 2010, shedding light on several key findings. Their analysis revealed that while these studies encompassed a wide range of economies, approximately 40% of them (18 out of 43 studies analyzed) focused primarily on China and/or Japan. Additionally, the majority of these studies examined the decomposition of changes in energy consumption and emissions within a specific country over time, with only a small number of studies exploring spatial decompositions among countries and regions.

The review also highlighted that there are more studies on emissions than on energy consumption, and more than half of the studies focus on CO₂ emissions. Another aspect emphasized in the review is the time lag between the publication of these studies and the availability of the data used, primarily due to the time-intensive process of constructing input-output matrices. This temporal discrepancy needs to be considered when interpreting the findings and their relevance to current circumstances.

Among other SDA studies applied to the determinants of changes in emissions and energy consumption over time, Hu et al. (2017), Zhang et al. (2017), Shao et al. (2018) specifically examine the case of China. Wang et al. (2017) conduct a global-level study on emission determinants, while Zhu et al. (2018) focus on India, Su et al. (2017) on Singapore, Seibel (2003) and Proops et al. (2012) on Germany, and Wier (1998) on Denmark.

2.2.2 Input-output approaches and alternative methodologies for GHG emissions analysis in Argentina

Various studies have analyzed Argentina's emissions and energy trends using different modeling frameworks, including computable general equilibrium (CGE) models, Social Accounting Matrices (SAM), LEAP-based projections, and input-output models. Each of these approaches provides distinct insights: CGE and SAM-based models allow for economy-wide

simulations under different policy scenarios, while LEAP and partial equilibrium tools often focus on sector-specific energy dynamics. Input-output framework, by contrast, are particularly well-suited to capture intersectoral linkages and embodied emissions, enabling structural decomposition over time.

Empirical studies using the input-output framework to analyze Argentina include the work of Chisari et al. (2020), who present a Social Accounting Matrix for the country for the year 2017. This SAM provides detailed data on 30 productive sectors, 10 household groups differentiated by income deciles, a central government entity, and a representative agent for the rest of the world. Their analysis is further enriched by examining sectoral linkages, emphasizing the interconnections within the economy.

Building on the SAM estimated by Chisari et al. (2020), Mastronardi et al. (2022) construct input-output matrices for Buenos Aires City and the rest of Argentina, analyzing sectoral linkages and carbon footprints for each region. They also present a comparative table that contrasts sectoral carbon footprints at the national level, calculated using the input-output matrix, with sectoral emissions reported in Argentina's National GHG Inventory, which was prepared by the Ministry of Environment and Sustainable Development. The table reveals significant sectoral differences, even though both methodologies yield the same total emissions at the aggregate level. According to the input-output approach, the industrial sector accounts for 43% of emissions, while the GHG inventory attributes only 16% to this sector. Conversely, the GHG inventory estimates that the agricultural sector is responsible for 38% of emissions, whereas the input-output matrix estimates only 10%. Other sectors contributing significantly to emissions include construction (11%) and water, electricity, and gas (9%).

In this sense, Accorsi et al. (2018) compare two methodologies for measuring and allocating the carbon footprint across productive sectors in Chile (2008-2013): the energy balance methodology (similar to that used in the GHG inventory for Argentina), and the input-output framework. While both methodologies converge at the aggregate level, they produce different emission estimates at the sectoral level. The authors emphasize that, unlike the energy balance approach, the input-output methodology captures both intra- and intersectoral interactions through input-output flows, providing a more accurate indicator of the carbon footprint attributable to each sector. They also point to the implications of these differences for the design of mitigation policies, including the effects of carbon tax schemes.

Romero et al. (2022) extend the work of Mastronardi et al. (2022) by adding employment and greenhouse gas (GHG) vectors to the SAM, enabling an assessment of the impact on gross output, employment, and GHG emissions from various climate change

mitigation policies toward 2030. These simulations focus primarily on the incorporation of non-conventional renewable energy into the electricity grid, increasing the biofuel blend percentage, promoting reforestation, transforming the transportation industry, and improving energy efficiency, among other measures. They conclude that improving energy efficiency in productive activities leads to an economic cost for the energy sector due to the decrease in demand for this service, and for the overall economy, as increases in other sectors do not fully offset the negative impact on the energy sector. Nevertheless, the simulated policy boosts employment in the rest of the economy as a result of this efficiency improvement. Moreover, the significant reduction in GHG emissions (primarily CO₂), closely aligned with the 2030 NDC targets, stems from all sectors of the economy reducing their energy consumption.

Harari et al. (2022) quantify the impact on production, employment, and GHG emissions from five specific energy efficiency policies or targets by 2030, using an input-output analysis based on the SAM constructed by Chisari et al. (2018). The simulation scenarios are broken down into three stages: (i) the necessary infrastructure investment or spending to implement the measures, (ii) energy efficiency improvements or fossil fuel substitution, and (iii) the rebound effect on the economy due to potential reductions in energy costs and the resulting increase in demand for other goods and services. Under a potential scenario of 10% economic growth (and emissions) from 2017 to 2030, their results suggest these measures would contribute to 11.56% of the reductions needed to meet the NDC target of 349 MtCO₂eq by 2030. While there are no aggregate tensions between emissions reductions and economic activity, sectoral tensions arise, particularly in fossil-fuel-based energy generation and distribution sectors.

Sheinbaum et al. (2011) analyze primary energy consumption and energy-related CO₂ emissions in Argentina, Brazil, Colombia, Mexico, and Venezuela from 1990 to 2006, using the logarithmic mean Divisia index (LMDI), an index decomposition analysis method based on the input-output framework. Their results show that while significant reductions in energy intensity were achieved in Colombia, Mexico, and to a lesser extent in Brazil and Argentina, these reductions did not lead to substantial decreases in CO₂ emissions due to a growing reliance on fossil fuels in the energy mix. In Argentina, CO₂ emissions increased by 1.7 times between 1990 and 2006, with GDP growth being the main contributor. Additionally, changes in the composition of GDP (the structure effect), particularly the growing share of the transport sector, also contributed to the rise in emissions. Energy intensity slightly reduced emissions, while the carbon intensity of energy remained nearly unchanged.

Peng et al. (2024) compile a comprehensive inventory of CO₂ emissions from fossil fuels for South American countries, including Argentina, using a bottom-up approach and multiple data sources. They analyze the temporal evolution of emissions and the driving forces behind them through the LMDI decomposition method, focusing on factors such as population, GDP growth, energy intensity, carbon intensity, and energy mix. Their findings reveal that, from 2010 to 2015, an increase in carbon intensity was the main driving factor of CO₂ emissions in Argentina. However, between 2015 and 2020, the economic downturn led to a decrease in per capita GDP, which contributed to a reduction in CO₂ emissions across most countries, particularly in Argentina, although high carbon intensity remained a significant contributor to emissions.

Mardones and Andaur (2024) analyze the potential impact of implementing a broadly applied carbon tax on CO₂ equivalent emissions. Their approach integrates a model with microeconomic foundations with an input-output framework. Specifically, they estimate a system of demand functions for products with high GHG intensity, drawing on data from the 2018 national household expenditure survey. Additionally, they calibrate the environmental extension of the Leontief price model using sectoral data from the 2018 Supply and Use Tables, allowing them to simulate GHG emission changes under different tax rates. The study's main finding is that household demand for goods with high GHG emissions is sufficiently responsive to price changes, meaning a carbon tax could lead to significant reductions in the consumption of these goods. Additionally, the study finds that implementing a broadly applied carbon tax on CO₂ equivalent emissions in Argentina would result in a percentage reduction in emissions ranging from one-fifth to one-quarter of the imposed tax rate.

Di Sbroiavacca et al. (2016) employ various simulation models, including a bottom-up simulation model and global integrated assessment models, to assess the impact and economic costs of different climate change mitigation policies, such as carbon pricing and emission constraints, on Argentina's energy sector from 2010 to 2050. Their analysis examines primary and final energy consumption, electricity sector development, and CO₂ emission reductions. Despite differences in the models, all converge on the finding that natural gas will continue to play a significant role in the electricity matrix, and that carbon capture and storage technologies will be essential to achieve more stringent emission reductions.

Lallana et al. (2021) use a CGE model, complemented by other modelling tools, to simulate two alternative energy and environmental scenarios aimed at achieving deep decarbonization by 2050. By integrating these models, they quantify the energy, land use, and socio-economic dimensions of each pathway. Both scenarios entail significant transformations

in the energy sector and the broader economic system, while adhering to constraints that ensure alignment with other development goals. In one scenario, natural gas is used alongside CO₂ capture and storage technologies, whereas the other scenario envisions its replacement with hydro-nuclear energy. However, neither scenario proposes natural gas exports as an explicit energy policy objective, as limited space is foreseen for fossil fuels in external markets under a global decarbonization framework.

Le Treut et al. (2021) integrate a CGE model with the LEAP energy model (software tool for energy policy analysis and climate change mitigation assessment) to assess the economic impacts of decarbonization strategies on Argentina's energy system, building on the work of Lallana et al. (2021). Their findings suggest that while the overall impacts on GDP and welfare are limited, there are significant structural effects on specific industries. Notably, they estimate net job creation in upstream industries that supply low-carbon infrastructure, alongside a risk of job losses in carbon-intensive sectors vulnerable to decarbonization.

Ramos (2018) employs a CGE model calibrated with a Social Accounting Matrix for 2016, to study Argentina's opportunities and risks in actively participating in plurilateral negotiations on environmental goods trade. The study evaluates potential scenarios for Argentina with the aim of identifying both the benefits and risks of engaging in such negotiations. The results suggest that Argentina's non-participation limits potential trade and welfare gains, but also mitigates some risks, as no scenario demonstrates long-term increases in GDP or welfare. Nonetheless, a trade agreement on environmental goods could create specific opportunities for certain sectors.

In the same vein, Ramos et al. (2017) develop a CGE model to estimate the economic and environmental outcomes under two different scenarios of trade liberalization for environmental goods and services. Their findings indicate that Argentina's active participation in the liberalization of environmental goods results in higher GDP, increased trade, improved welfare, and lower unemployment. However, this comes at the cost of rising total carbon emissions, driven by significant negative composition and technique effects. These effects intensify and ultimately outweigh the positive scale effect, particularly when greater capital mobility across sectors is allowed.

Chisari and Miller (2014) use a CGE model to estimate the effectiveness of carbon taxes in Mexico and Argentina, considering the possibility that firms may adapt by altering their scale of operations or shifting to more informal segments of their industry, where tax enforcement and regulation are weaker. The study's main conclusion is that designing carbon taxes without

considering the potential for firms to engage in such strategic behavior could result in higher emissions, rather than the intended reductions.

Yuping et al. (2021) evaluate the dynamic effects of globalization, renewable energy consumption, non-renewable energy consumption, and economic growth on CO₂ emissions in Argentina from 1970 to 2018. Using an econometric methodology, the study aims to reveal long-run associations between these variables. The findings show that the EKC hypothesis holds in the long run, though not in the short run. Additionally, the study reveals that renewable energy consumption and globalization contribute to reducing CO₂ emissions in Argentina.

Peng et al. (2024) compiles a comprehensive inventory of CO₂ emissions for South American countries (Argentina included), based on a bottom-up approach and multiple data sources, followed by an analysis of their temporal evolution patterns and the driving forces behind them, by means of LMDI decomposition method. Among these drivers, they analyze population, GDP growth, Energy intensity, Carbon intensity and energy mix. Their findings point that from 2010 to 2015 an increase in carbon intensity was the leading driving factor in Argentina, while between 2015 and 2020, due to the economic downturn, a decrease in per capita GDP contributed to CO₂ emission reduction in most countries, especially in Argentina, while high carbon intensity remained a major cause in Argentina.

Arrieta and González (2018) estimate the carbon footprint of the Argentinian diet, analyzing the impacts of various scenarios of changes in dietary patterns. Their findings show that GHG emissions associated with the Argentinian diet are largely driven by the significant role of beef consumption, with Argentina being one of the highest per capita consumers of beef globally. According to their estimates, beef consumption accounts for 71% of diet-related emissions. They also suggest that if national dietary guidelines were followed, which recommend a 50% reduction in daily meat intake compared to current levels, diet-related GHG emissions could be reduced by 28%.

Table 4: Overview of empirical studies on GHG emissions in Argentina

Paper	Period	Methodology	Variables	Main Results/ Conclusions
Mardones and Andaur (2024)	Simulations on the 2018 Supply and Use Tables	Model with an input-output framework	GHG emissions, carbon taxes	Household demand for goods with high GHG emissions is sufficiently responsive to price changes, meaning a carbon tax could lead to significant reductions in the consumption of these goods.
Chisari and Miller (2014)	2010	CGE model	Carbon taxes	Designing carbon taxes without considering the possibility of firms' strategic change in scale of operation and deformalization could lead to higher, rather than lower, emissions.

Le Treut et al. (2021)	2050	CGE and LEAP models	GHG emissions	While the overall impacts on GDP and welfare are of deep decarbonization strategies are limited, there are significant structural effects on specific industries
Chisari et al. (2020)	2017	input-output	Sectoral linkages	Social Accounting Matrix (SAM) for Argentina, for the year 2017
Romero et al. (2022)	2030	input-output	Output, Employment and GHG emissions	Strategies to increase energy efficiency have a negative economic impact on the energy sector due to the decrease in demand for this service, and for the overall economy. Conversely, employment increases, and GHG emissions significantly decrease.
Mastronardi et al. (2022)	2017	input-output	Sectoral linkages and GHG emissions footprint	Industry sector represents 44% carbon footprint, construction 11%, agriculture 10%, water electricity and gas 9%.
Arrieta and González (2018)	2012-2013	Life Cycle Inventory studies	GHG emissions.	Beef consumption accounts for 71% of diet-related emissions.
Harari et al. (2022)	2017-2030	input-output	Output, Employment and GHG emissions	There are no aggregate tensions between emissions reductions and economic activity, sectoral tensions arise, particularly in fossil-fuel-based energy generation and distribution sectors
Di Sbroiavacca et al. (2016)	2010-2050	Simulation models (CGE)	GHG emissions	Natural gas will continue to play a significant role in the electricity matrix, and that carbon capture and storage technologies will be essential to achieve more stringent emission reductions
Lallana et al. (2021)	2050	CGE model	GHG emissions	Two alternative energy and environmental scenarios aimed at achieving deep decarbonization by 2050. To reach deep decarbonization, in one scenario natural gas is used alongside CO ₂ capture and storage technologies, whereas the other scenario envisions gas replacement with hydro-nuclear energy.
Yuping et al. (2021)	1970-2018	Econometric model	Globalization, renewable and non-renewable energy consumption, and economic growth on CO ₂ emissions.	Environmental Kuznets Curve (EKC) hypothesis holds in the long run, though not in the short run. Renewable energy consumption and globalization contribute to reducing CO ₂ emissions in Argentina.
Ramos et al. (2017)	2006	CGE model	Trade, GDP, employment, GHG emissions.	Argentina's active participation in the liberalization of environmental goods results in higher GDP, increased trade, improved welfare, lower unemployment and increased total carbon emissions.
Ramos (2018)	2016	CGE model	GDP	Trade agreement on environmental goods could create specific opportunities for certain sectors

Peng et al. (2024)	2010-2020	LMDI decomposition through input-output.	Population, GDP, energy intensity, energy mix, and carbon intensity drivers of carbon emissions from fossil fuels.	From 2010 to 2015, an increase in carbon intensity was the main driving factor of CO ₂ emissions in Argentina. Between 2015 and 2020, the economic downturn led to a decrease in per capita GDP, which contributed to a reduction in CO ₂ emissions across most countries, particularly in Argentina
Sheimbaum et al. (2011)	1990-2006	LMDI decomposition through input-output.	GDP (level and composition), energy intensity, carbon intensity drivers of GHG emissions.	GDP growth and changes in its composition were the main contributor to growing emissions. Energy intensity slightly reduced emissions, while the carbon intensity of energy remained nearly unchanged.

Source: own elaboration.

As shown in Table 4, most empirical studies on GHG emissions in Argentina focus on simulating various scenarios, either through CGE models (Mardones and Andaur, 2014; Chisari and Miller, 2014; Le Treut et al., 2021; Ramos et al., 2022; Di Sbroiavacca et al., 2016; Lallana et al., 2021; Ramos, 2018; Ramos et al., 2017) or through impact analysis using input-output matrices (Romero et al., 2022).

In contrast, studies that conduct retrospective analyses of time series include Yuping et al. (2022), who perform an econometric analysis, while Sheimbaum et al. (2011) and Peng et al. (2016) utilize the Index Decomposition Analysis methodology for the periods 1990-2006 and 2010-2020, respectively. Additionally, some studies estimate a matrix for a specific period, such as Chisari et al. (2020) and Mastronardi et al. (2022).

Despite these contributions, up to our understanding, no studies have applied SDA using environmentally extended input-output tables for Argentina, offering a longitudinal decomposition over multiple benchmark years. This gap is especially relevant given the need to understand how structural changes in the economy shape emissions profiles over time. This study contributes to filling this gap by applying SDA to decompose Argentina's CO₂ emissions between 2000 and 2016, providing a replicable and policy-relevant methodological approach that complements existing CGE and SAM-based studies.

2.3 Methodology and data

In the subsequent section, we outline the methods and data employed in this study. This includes an introduction of SDA form and methodology (Section 3.1), and a description of the EORA MRIO database, detailing the selected procedure for converting time series data into constant prices and the selection of the time periods for analyses (Section 3.2).

2.3.1 Additive SDA methodology

Generally, empirical studies that analyze the relationships between structural change, international trade and the environment are based on the use of environmentally extended input-output matrices, which incorporate certain measures related to pollution (such as GHG emissions and/or waste from different types). One of the methods used to perform this type of analysis is the structural decomposition.

Starting from the basic equation of the input-output model with a matrix of technical coefficients A , a final demand vector f , an identity matrix, I (a square matrix where all the diagonal elements are 1, and all other elements are 0), and a sectoral output vector x , we have:

$$Ax + f = x \quad (2a)$$

$$f = (I - A)x \quad (2b)$$

$$x = (I - A)^{-1} f \quad (2c)$$

We consider the following equation, where the levels of GHG emissions and energy consumption are directly related to the value of production²:

$$C = \frac{C}{EN} \frac{EN}{x} (I - A)^{-1} f \quad (3)$$

where C denotes a GHG emissions vector for each of the n sectors and EN represents the vector of energy consumption for each of the sectors, therefore C/EN denotes a vector with the relative content of GHG emissions through the relationship between emissions and energy consumption of each sector and is called emission intensity. Following Seibel (2003), there are different energy forms without any carbon content, such as hydro or nuclear power, as well as other sources containing much more carbon, like coal. In this sense, the relative content of carbon expressed by the ratio of carbon dioxide emissions (CO_2) to energy input (EN) is influenced by the energy mix of production. The second element, EN/x , is a vector called energy intensity, and represents the amount of energy consumed to produce a unit of output value by each sector (energy/sectoral output). $(I - A)^{-1}$ is the Leontief inverse matrix, also called the total requirements matrix, which accounts for both direct and indirect input requirements across all sectors.

According to Seibel (2003), the starting point for any decomposition analysis is an equation in which the variable whose observed changes will be analyzed is written as the product of the factors considered as determining factors. The choice of factors depends on two

² The calculation of the overall greenhouse gas (GHG) emissions stems from the summation of emissions originating from productive activities conducted within Argentina's borders, commonly referred to as "Production-Based Accounting" in literature.

aspects: i) the conceptual framework used, which defines which factors can reasonably be considered as having an impact on the variable of interest; ii) the availability of data. The factors used must adjust to each other in the sense that their product is equal to the variable to be analyzed. In practice, this condition is achieved in many cases by choosing factors that are ratios where the denominator of one factor is equal to the numerator of the next. Note that in the case of equation 2, the denominator of the element $\frac{C}{EN}$ vanishes with the numerator of $\frac{EN}{x}$, in the same way that the denominator of this last term (x) vanishes with $(I - A)^{-1} f$.

To simplify the notation, we have:

$$C = \frac{C}{EN} \frac{EN}{x} (I - A)^{-1} f = \hat{c} \hat{e} L f \quad (4)$$

where $\hat{c}$ is a diagonal matrix of dimension $n \times n$ representing emission intensity, $\hat{e}$ is a diagonal matrix of dimension $n \times n$ representing energy intensity, L is the Leontief inverse matrix, and represents the structure of intermediate consumption by each branch, the so-called “recipe” each sector uses for its production process. Changes in this structure are mainly due to changes in production techniques and serves as a proxy of the technical change. Finally, f represents the final demand vector.

The next step is to decompose the changes in emission levels at two different points in time, according to the variations in the determining factors $\hat{c} \hat{e} L f$. For this, the method developed by Dietzenbacher and Los (1998) can be used, which takes the average of polar decompositions, and avoids the process of making exhaustive decompositions³. In this way, the change in the variations of C (Δc), can be decomposed as follows:

$$\Delta c = \hat{c}^1 \hat{e}^1 L^1 f^1 - \hat{c}^0 \hat{e}^0 L^0 f^0 \quad (5)$$

where the supra index represents the time. Through algebraic manipulations of equation 4 and substituting $\hat{c}^1, \hat{e}^1, L^1, f^1$ e $\hat{c}^0, \hat{e}^0, L^0, f^0$ for $\Delta \hat{c} = \hat{c}^1 - \hat{c}^0$; $\Delta \hat{e} = \hat{e}^1 - \hat{e}^0$; $\Delta L = L^1 - L^0$; $\Delta f = f^1 - f^0$, equation 4 can be expressed as follows, starting the decomposition from one of the extremes:

$$\Delta c = \Delta \hat{c} \hat{e}^1 L^1 f^1 + \hat{c}^0 \Delta \hat{e} L^1 f^1 + \hat{c}^0 \hat{e}^0 \Delta L f^1 + \hat{c}^0 \hat{e}^0 L^0 \Delta f \quad (6)$$

³ According to Dietzenbacher and Los (1998), the number of possible decompositions is equal to the factorial of the number of variables considered ($n!$). Thus, in the present case, the number of possible decompositions would be 24 ($4! = 4 \times 3 \times 2 \times 1 = 24$).

or starting the decomposition from the other extreme,

$$\Delta c = \Delta \hat{c} \hat{e}^0 L^0 f^0 + \hat{c}^1 \Delta \hat{e} L^0 f^0 + \hat{c}^1 \hat{e}^1 \Delta L f^0 + \hat{c}^1 \hat{e}^1 L^1 \Delta f \quad (7)$$

However, according to Miller and Blair (2009), equations 6 and 7 will differ because they measure different phenomena. Dietzenbacher and Los (1998) show that taking the average of equations 5 and 6 it is possible to have a result very close to the average of the 24 decompositions that should be done to have an exhaustive decomposition. In this way, it is possible to obtain:

$$\Delta c = \Delta \hat{c} \frac{1}{2} [\hat{c}^1 L^1 f^1 + \hat{e}^0 L^0 f^0] \quad (8.1)$$

$$+ \frac{1}{2} [\hat{c}^0 \Delta \hat{e} L^1 f^1 + \hat{c}^1 \Delta \hat{e} L^0 f^0] \quad (8.2)$$

$$+ \frac{1}{2} [\hat{c}^0 \hat{e}^0 \Delta L f^1 + \hat{c}^1 \hat{e}^1 \Delta L f^0] \quad (8.3)$$

$$+ \frac{1}{2} [\hat{c}^0 \hat{e}^0 L^0 + \hat{c}^1 \hat{e}^1 L^1] \Delta f \quad (8.4)$$

(8)

The specific interpretation of each term in equation 8 can be described as follows:

(8.1) Emission intensity effect: variations in GHG emissions due to changes in the ratio of MtCO₂eq per unit of energy consumption (thousand tons of oil equivalent) of a given sector.

(8.2) Energy intensity effect: variations in GHG emissions due to shifts in the ratio of energy consumption per unit of gross output of a given sector.

(8.3) Intermediate demand (or technology) effect: variations in emissions due to shifts in the combination of inputs used in the production of a given sector.

(8.4) Final demand effect: emissions variation due to changes in the total final demand.

In order to separate the effects of domestic demand from exports, we split the final demand vector, f , in such a way that f_d is domestic final demand, and f_f , foreign final demand given by exports. So,

$$f = f_f + f_d \quad (9)$$

Substituting equation (9) into (8.4) yields the contribution of exports and domestic final demand, respectively, to GHG emissions.

$$\begin{aligned} & \frac{1}{2} [\hat{c}^0 \hat{e}^0 L^0 + \hat{c}^1 \hat{e}^1 L^1] \Delta f = \\ & \frac{1}{2} [\hat{c}^0 \hat{e}^0 L^0 + \hat{c}^1 \hat{e}^1 L^1] \Delta f_f \end{aligned} \quad (10.1)$$

$$+ \frac{1}{2} [\hat{c}^0 \hat{e}^0 L^0 + \hat{c}^1 \hat{e}^1 L^1] \Delta f_d \quad (10.2)$$

(10.1) Foreign final demand effect: emissions variation due to changes in the total exports.

(10.2) Domestic final demand effect: emissions variation due to changes in the total domestic final demand.

Furthermore, we split the domestic final demand vector, f_d , into its components: Household final consumption (c_h), Non-profit institutions serving households (n), Government final consumption (c_g), Gross fixed capital formation (k), and changes in inventories (s), such that:

$$f_d = c_h + c_g + n + k + s \quad (11)$$

Replacing equation (11) into (10.2) yields the contribution of each component of the domestic final demand vector to GHG emissions:

$$\frac{1}{2}[\hat{c}^0 \hat{e}^0 L^0 + \hat{c}^1 \hat{e}^1 L^1] \Delta f_d = \frac{1}{2}[\hat{c}^0 \hat{e}^0 L^0 + \hat{c}^1 \hat{e}^1 L^1] \Delta c_h \quad (12.1)$$

$$+ \frac{1}{2}[\hat{c}^0 \hat{e}^0 L^0 + \hat{c}^1 \hat{e}^1 L^1] \Delta c_g \quad (12.2)$$

$$+ \frac{1}{2}[\hat{c}^0 \hat{e}^0 L^0 + \hat{c}^1 \hat{e}^1 L^1] \Delta n \quad (12.3)$$

$$+ \frac{1}{2}[\hat{c}^0 \hat{e}^0 L^0 + \hat{c}^1 \hat{e}^1 L^1] \Delta k \quad (12.4)$$

$$+ \frac{1}{2}[\hat{c}^0 \hat{e}^0 L^0 + \hat{c}^1 \hat{e}^1 L^1] \Delta s \quad (12.5)$$

(12)

(12.1) Household final consumption effect: emissions variation due to changes in the total final consumption from households.

(12.2) Government final consumption effect

(12.3) Nonprofit institutions serving households effect

(12.4) Gross fixed capital formation effect

(12.5) Changes in inventories effect

In addition, this essay decomposes the domestic final demand effect in such a way that it is the result of the product of the multiplication of three elements (Miller and Blair, 2009), as follows:

$$f_d = lBd \quad (13)$$

Where l is a scalar representing the level (total amount) of domestic final demand expenditure over all sectors. d is the vector that indicates the distribution of the total amount of domestic final demand across the different final-demand categories. Finally, matrix B indicates the proportion of total expenditures by final-demand category that was spent on the product of each Argentinian sector. In this order, we have,

$$\Delta f_d = f_d^1 - f_d^0 = l^1 B^1 d^1 - l^0 B^0 d^0 \quad (14)$$

After some rearrangements, we obtain the following:

$$\Delta f_d = (\Delta l) B^0 d^0 + l^1 (\Delta B) d^0 + l^1 B^1 (\Delta d) \quad (15)$$

$$\Delta f_d = (\Delta l) B^1 d^1 + l^0 (\Delta B) d^1 + l^0 B^0 (\Delta d) \quad (16)$$

Again, taking the average of equations (15) and (16) (Dietzenbacher & Los, 1998) we have the following equation:

$$\begin{aligned} \Delta f_d &= \left(\frac{1}{2}\right)(\Delta l) [B^0 d^0 + B^1 d^1] \\ &+ \left(\frac{1}{2}\right)[l^0 (\Delta B) d^1 + l^1 (\Delta B) d^0] \\ &+ \left(\frac{1}{2}\right)(l^0 B^0 + l^1 B^1)(\Delta d) \end{aligned} \quad (17)$$

The first term in equation (17) represents the effect of the total amount of all expenditures for domestic final demand (level effect) on final demand. The second term reflects the impact of changes in the proportion of consumption among different products on final demand (mix effect). The last term captures the effect of the distribution of total expenditure across different final demand categories (distribution effect).

Replacing equation (17) into equation (10.2), reveals the contribution of these three drivers related to domestic final demand—level, mix, and distribution effects—to the change in GHG emissions.

$$\begin{aligned} \frac{1}{2}[\hat{c}^0 \hat{e}^0 L^0 + \hat{c}^1 \hat{e}^1 L^1] \Delta f_d &= \\ \frac{1}{2}[\hat{c}^0 \hat{e}^0 L^0 + \hat{c}^1 \hat{e}^1 L^1] \left(\frac{1}{2}\right)(\Delta l) [B^0 d^0 + B^1 d^1] &\quad (18.1) \end{aligned}$$

$$+ \frac{1}{2} [\hat{c}^0 \hat{e}^0 L^0 + \hat{c}^1 \hat{e}^1 L^1] \left(\frac{1}{2} \right) [l^0 (\Delta B) d^1 + l^1 (\Delta B) d^0] \quad (18.2)$$

$$+ \frac{1}{2} [\hat{c}^0 \hat{e}^0 L^0 + \hat{c}^1 \hat{e}^1 L^1] \left(\frac{1}{2} \right) (l^0 B^0 + l^1 B^1) (\Delta d) \quad (18.3)$$

(18)

(18.1) Domestic final demand level effect: variations in GHG emissions resulting from changes in the total amount of all expenditures for domestic final demand.

(18.2) Domestic final demand mix effect: variations in GHG emissions due to changes in the composition of domestic consumption patterns. For example, changes in GHG emissions as a result of reducing the proportion of expenditure allocated to agricultural products or increasing the proportion spent on energy products.

(18.3) Domestic final demand distribution effect: variations in GHG emissions due to shifts in the distribution of expenditure across different categories of domestic final demand. For instance, changes in emissions driven by an increase in the share of household final consumption at the expense of a reduction in the share of gross fixed capital formation in total domestic final demand. It should be noted that the SDA deals with production-based emissions pertaining to final demand component supply chains, as captured in the EORA database. Emissions from final consumption activities directly (i.e., fuel combustion by households) are not explicitly covered in the analysis. Even though this is a limitation, the breakdown still captures the majority of the emissions embodied in the production and supply of goods and services that are necessary to determine the structural drivers of GHG emissions in the Argentine economy.

Furthermore, while the decomposition method considers final demand categories (household and government consumption, gross fixed capital formation and exports) as independent drivers, we acknowledge that, in practice, these elements are often interdependent—for instance, investment may be induced by trends in consumption. Therefore, the interpretation of results must take into account these economic interlinkages and their potential feedback effects on emission trends.

Finally, this essay further decomposes ΔL , into the changes in the underlying direct inputs matrices ΔA , following Miller and Blair (2009). Given $L^1 = (I - A^1)^{-1}$ and $L^0 = (I - A^0)^{-1}$, after some rearrangements we arrive to the following equation:

$$\Delta L = L^1 - L^0 = L^0 A^1 L^1 - L^0 A^0 L^1 = L^0 (\Delta A) L^1 \quad (19)$$

As each column in A reflects a sector's production recipe, then identifying the changes column by column is one way of estimating the effects of input changes in each of the sectors in the economy, which we will refer to as technology change. In this sense, we have that ΔA equals the sum of the technology change in sector j . Then, we have the following, where the subscript "(j)" identifies the sector (column) in which coefficients change:

$$\Delta A = \Delta A_1 + \dots + \Delta A_j + \dots + \Delta A_n = \sum_{j=1}^n \Delta A_j \quad (20)$$

This decomposition of ΔA can be introduced into (19), and the resulting expression for ΔL can then be replaced in (8.3), which yields:

$$\begin{aligned} \frac{1}{2} [\hat{c}^0 \hat{e}^0 \Delta L f^l + \hat{c}^1 \hat{e}^1 \Delta L f^0] = \\ \frac{1}{2} [\hat{c}^0 \hat{e}^0 L^1(\Delta A_1) L^0 f^l + \hat{c}^1 \hat{e}^1 L^1(\Delta A_1) L^0 f^0] \quad (21.1) \\ + \frac{1}{2} [\hat{c}^0 \hat{e}^0 L^1(\Delta A_2) L^0 f^l + \hat{c}^1 \hat{e}^1 L^1(\Delta A_2) L^0 f^0] \quad (21.2) \\ + \dots \\ + \frac{1}{2} [\hat{c}^0 \hat{e}^0 L^1(\Delta A_n) L^0 f^l + \hat{c}^1 \hat{e}^1 L^1(\Delta A_n) L^0 f^0] \quad (21.n) \end{aligned} \quad (21)$$

(21.1) The change in GHG emissions resulting from variations in the intermediate consumption structure of sector 1, reflecting changes in the combination of inputs used to produce the output of sector 1.

(21.2) The change in GHG emissions resulting from variations in the intermediate consumption structure of sector 2.

(21.n) The change in GHG emissions resulting from variations in the intermediate consumption structure of sector n .

It is worth noting that technical coefficients matrix changes reflect not only domestic technology changes but also structural changes in the sourcing of intermediate inputs, including import substitution or increased foreign input penetration. It thus captures both technological and trade-related changes in the production structures in the period.

2.3.2 Structural indicators

To better account for the characteristics of the Argentine economic and emissions structure, we complement the SDA with emissions multipliers, energy consumption multipliers, and backward linkages. These indicators help to deepen the understanding of Argentina's economic structure across the different periods under analysis.

Emissions multipliers are derived incorporating emissions per unit of output into the technical structure of the economy. Specifically, the direct emissions coefficient vector δ (where each element represents emissions per unit of sectoral output) is premultiplied by the Leontief inverse matrix L to obtain total (direct and indirect) emissions per unit of final demand:

$$\text{Emissions per unit of final demand} = \delta L \quad (22)$$

Each element of the resulting vector represents the total GHG emissions generated throughout the entire economy in response to a one-unit monetary increase in final demand for a given sector's output. Higher values indicate sectors that are environmentally intensive, both in their direct production processes and through their upstream supply chains (Blair and Miller, 2009).

Analogously, energy consumption multipliers are calculated using the vector of direct energy coefficients e , where each entry denotes the amount of energy used per monetary unit of sectoral output. The total energy requirement per unit of final demand is obtained as:

$$\text{Energy per unit of final demand} = e L \quad (23)$$

This vector captures both direct and indirect energy requirements embedded in final demand for each sector. Such multipliers are particularly useful for evaluating the energy implications of structural change or demand shifts across sectors. Furthermore, we use backward linkages to assess the degree of interdependence between sectors, and are obtained from the column sums of the Leontief inverse matrix L (Rasmussen, 1957).

$$B = i'L \quad (24)$$

where i is an identity vector. Sectors with high backward linkages are important demand drivers across the economy. This indicator is widely used to assess structural interdependencies and identify sectors with high potential for generating economic spillovers (Blair & Miller, 2009).

2.3.3 Data sources

The matrices used for this empirical study are based on data from the EORA MRIO database. This database has global multi-regional input-output tables for 189 countries

(including Argentina) with a division of 26 sectors. Satellite accounts include information, among others, on direct environmental pressures (including CO₂) and socio-economic accounts (including gross value added), with data available from 1990 to 2016, on an annual basis. While widely used alternatives such as WIOD and EXIOBASE offer detailed sectoral and environmental accounts, they do not include Argentina in their country panels, thus limiting their applicability to this study. The OECD's ICIO database, on the other hand, includes Argentina but does not provide readily accessible GHG satellite accounts at the sectoral level, making its use for structural decomposition of emissions less feasible. EORA, by contrast, offers both global MRIO tables and environmental extensions—including GHG emissions by sector—covering Argentina consistently across time, and has been frequently used in the empirical literature on carbon footprints and trade-related emissions (Lenzen et al., 2013; Wiedmann et al., 2015).

However, this database has some important limitations. There is no information on specific cell deflators for different countries, leaving the only choice of using gross output deflators. Furthermore, the data related to GHG emissions is taken from PRIMAP database, which does not account for emissions related to land use change, which in the case of Argentina are very significant on certain periods. Additionally, the satellite accounts related to energy consumption are outdated as of 2011. To neutralize the influence of price changes, this study transforms the relevant data into constant prices of 2010, utilizing the World Bank's GDP deflator (for more information about deflation procedures see Appendix C, and Lan et al. 2016). Due to the outdated nature of the satellite accounts of energy consumption from EORA MRIO database, we augmented the energy consumption vectors by incorporating data sourced from the energy balances provided by the International Energy Agency (IEA). To reconcile the sector distribution of EORA MRIO and the energy balances from IEA, we aggregated them as exhibited in Appendix B. We use the US dollar as the unit of account because it is the standard currency in most global economic transactions and also the currency used in the database employed for this study. It should be noted that GHG emissions measured by million tons of CO₂ equivalent (Mt) will be used as a measure of environmental pollution, insofar as they allow for more systematic analyses since they constitute a relatively homogeneous measure that allows comparative analyses between different economic activities, regions, countries, etc., and that its data is available in a disaggregated form, which facilitates the relatively accurate identification of the sources of these emissions. On the other hand, the use of this dimension of environmental pollution is justified insofar as it is the principal cause of climate change, which

constitutes one of the main environmental problems to be solved, within the scope of the Paris Agreement and the established Sustainable Development Goals by the United Nations.

The choice of the period 2000-2016 is justified because it represents a temporary cut in which Argentina experienced different economic phenomena. On the one hand, the depreciation of the domestic currency that took place at the end of 2001 and its consequent change in relative prices, configured a scheme that reoriented the allocation of resources to the domestic production of tradable goods and a greater use of labor-intensive processes, which manifested in significant increases in industrial production. But there was also a cycle of strong increases in commodities' international prices (Erten and Ocampo, 2013), which significantly favored activities based on the export of food and raw materials. Finally, during most of the period, the implementation of policies to stimulate the domestic market stood out, which had a direct impact on the level of final demand.

In this sense, the period between 2000 and 2016 can be divided into four sub periods, according to the growth pattern observed. The first period comprises the years of 2000 to 2002, characterizing a recession period, with an accumulated contraction of 15% of the domestic product up to year 2002. The period between 2002 and 2005, characterized by acceleration of consumption and production growth, is the growth acceleration period, with a 9% average yearly increase of the domestic product. In the third sub period, between 2005 and 2010, although the product keeps growing at very high rates, there is a mild reduction if compared to the growth acceleration period, configuring a deceleration of output growth, hence we will call this the growth period. It should be noted that the year 2009, as it is a crisis year, could cause distortions in the case it was defined as an extreme of the interval in the SDA. For this reason, this last period goes up to year 2010. The last period comprises from years 2010 to 2016, characterizing a stagnation period, in which the product alternated between years of growth and years of contraction, falling slightly (0,6%) during the whole period.

Regarding the selection of periods, it is common practice to use five-year intervals in SDA studies to better understand structural shifts. Although the selection of the periods 2000-2002 and 2002-2005 may seem arbitrary, as they might not capture significant structural changes, this periodization allows for a more accurate representation of emission changes during times of recession and strong recovery. In contrast, the aggregated period from 2000 to 2005 fails to reflect these dynamics, which, as we will discuss later, are essential for policy analysis. An SDA was also conducted over the period 2000-2005 and 2000-2016 to investigate whether more substantial changes would be observed, with the results presented in Appendix D. However, these changes were not particularly significant, remaining largely similar in

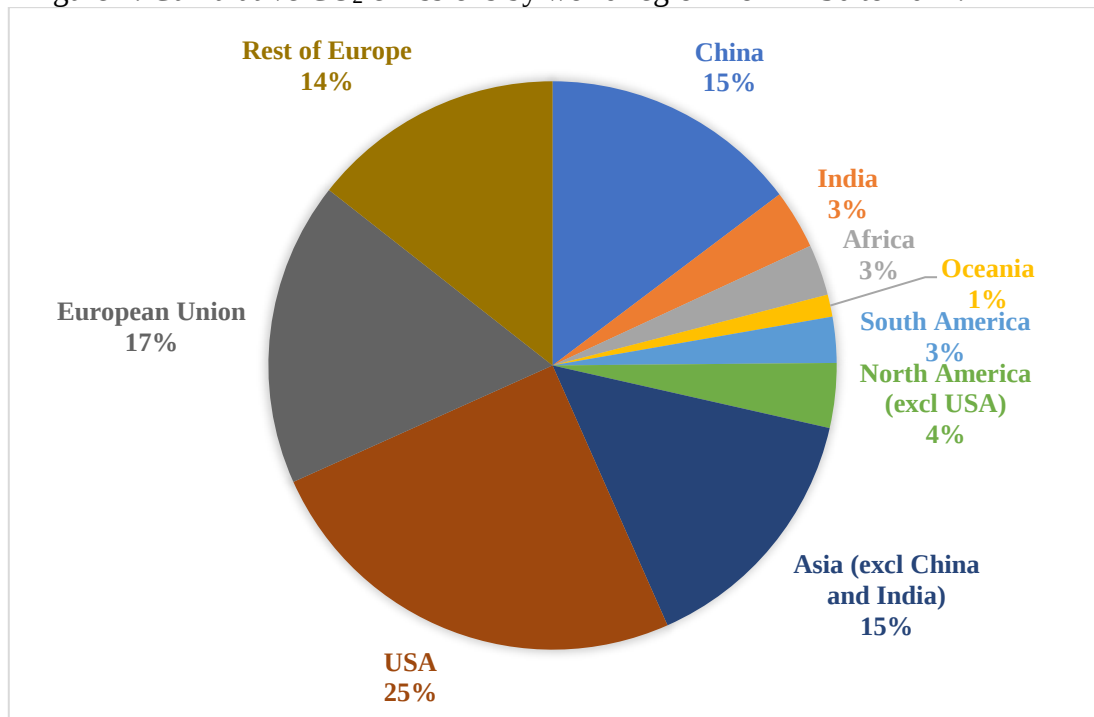
aggregate terms and failing to capture the nuances brought about by the recession and recovery contexts. For the period 2010-2016, the final year was included to ensure the analysis covered the most recent data available.

2.4 Argentinian and World GHG emissions overview

NDCs are the efforts that all Parties to the UNFCCC, which have ratified the Paris Agreement, must undertake to intensify their actions against climate change, either by reducing GHG emissions and/or increasing carbon sinks (mitigation actions), or by adapting to the impacts caused by this phenomenon (adaptation actions). Contributions are established by countries based on common but differentiated responsibilities and respective capabilities in light of their national circumstances.

The differentiated responsibility of developed countries regarding the generation of GHG emissions is evident when considering the accumulated stock of emissions, taking the year 1750 as a starting point, up to 2021. It becomes apparent that regions with higher development account for the vast majority of the prevalent greenhouse gas stock in the atmosphere, as shown in Figure 2.

Figure 2: Cumulative CO₂ emissions by world region from 1750 to 2021.



Source: own elaboration in base of ourworldindata.org⁴

⁴ Figures are based on Production Based Accounting, measuring CO₂ emissions from fossil fuels and industry only, land use change is not included.

Europe accounts for 31% of the global emissions accumulated as of 2021, followed by the United States (25%). Therefore, 56% of the accumulated greenhouse gas emissions since 1750 correspond to highly developed economic regions. On the other hand, regions such as South America and Africa each account for only 3% of the total accumulated emissions. Other insights from the preceding figure indicate that the United States has emitted more CO₂ than any other country to date, nearly twice as much as China, the world's second-largest national contributor.

Many of the significant emitters today, including India and Brazil, have not historically been major contributors. Conversely, since the pre-industrial era, Europe has led global emission levels, although its share has been decreasing. This is partly due to a reduction in emissions from the European continent, but more significantly, to the increased contributions of other countries such as the United States, China, India, and the Asia-Pacific region. The growing participation of middle-income and developing countries in the global economy has led to an increasing environmental footprint for these nations.

Table 5: GHG emissions (CO₂ equivalent) per country and region (total in kilotons, and per capita in metric tons)

Country	Total 1990 (share)	Per Capit a 1990	Total 2000 (share)	Per Capit a 2000	Total 2019 (share)	Per Capit a 2019
Argentina	249.189 (1%)	3,1	294.271 (1%)	3,6	374.524 (1%)	3,7
Brazil	592.497 (2%)	1,3	772.340 (2%)	1,8	1.069.919 (2%)	2,1
Canadá	543.049 (2%)	15,1	648.194 (2%)	16,8	726.904 (2%)	15,1
China	3.238.859 (11%)	1,9	4.567.274 (13%)	2,7	12.732.245 (27%)	7,6
India	1.237.963 (4%)	0,6	1.719.665 (5%)	0,9	3.412.419 (7%)	1,8
European Union	4.477.034 (15%)	8,5	4.162.342 (12%)	7,8	3.397.614 (7%)	6,1
Latin America and Caribbean	2.0681.81 (7%)	2	2.608.217 (8%)	2,4	3.257.187 (7%)	2,5
United States	5.855.541 (19%)	19,4	6.810.656 (20%)	20,5	6.039.739 (13%)	14,7
East Asia and Pacific	6.445.876 (21%)	2,4	8.683.082 (25%)	3	18.174.628 (38%)	6,2
World	30.629.971	4	34.208.319	4	48.089.617	4,6

Source: own elaboration from data from World Bank

As evidenced by the preceding table, China has notably increased its total GHG emissions, becoming the largest emitter by 2019, accounting for 26% of the total emissions. Additionally, the increase in emissions from the East Asia and Pacific region (including China) almost tripled its total emissions volume between 1990 and 2019. This region includes countries

that have experienced significant economic growth in recent decades, such as Vietnam, Indonesia, Malaysia, and Thailand, among others. However, it is worth noting that when analyzing per capita emissions, both China and the East Asia and Pacific region have significantly lower volumes compared to the United States and Canada, and only slightly higher than those of the European Union. India's case is notable when considering per capita emissions, as it is the lowest emitter among the group of countries analyzed, while experiencing a significant increase in absolute terms over the last few decades, driven by its economic growth, accounting for 7% of global emissions in 2019.

In this context, Argentina is positioned as a country with low emissions per capita (3.7), surpassing the Latin America and Caribbean region (2.5) and Brazil (2.1). The lower value for Brazil is explained by the high share of hydropower in the total primary energy supply. In absolute terms, in 2019, Argentine emissions represented only 0.8% of global emissions, with a stable share throughout the 1990-2019 period. Finally, the performance of the European Union is noteworthy, as it reduced its share of emissions from 15% in 1990 to 7% in 2019.

Table 6: National carbon footprint (MtCO₂ equivalent), 2016

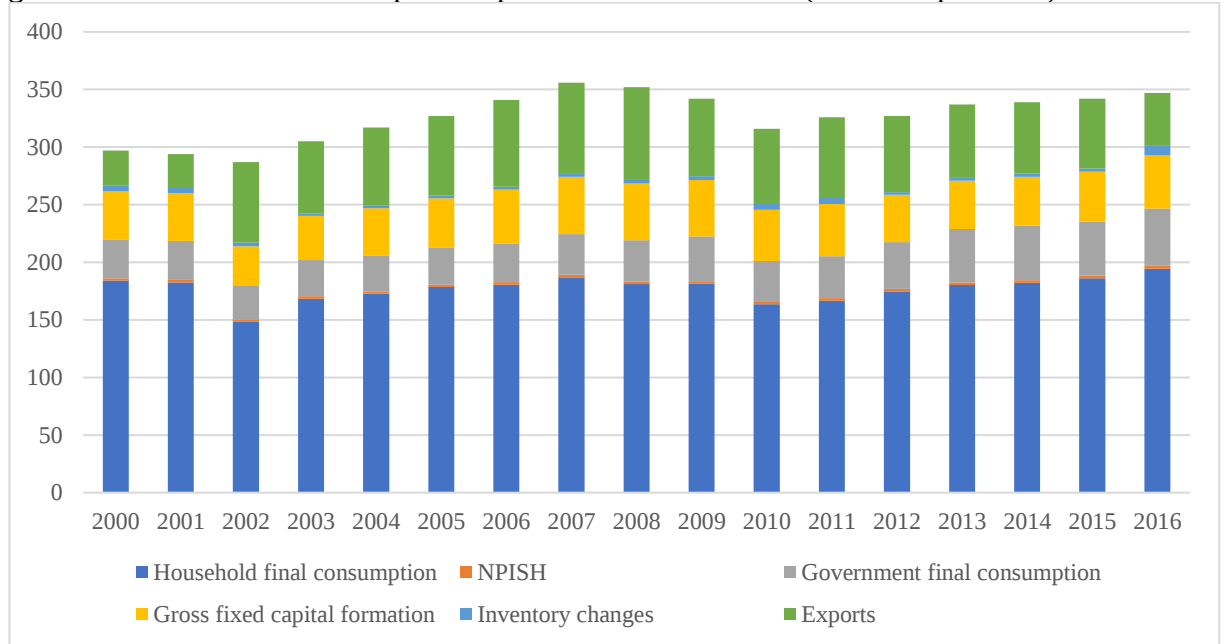
Sector	Carbon footprint	Share (%)
Agriculture, forestry and hunting	36,96	10%
Fishing	0,71	0%
Mining and quarrying	5,31	1%
Industry	158,1	43%
Water, electricity and gas	34,08	9%
Construction	38,9	11%
Commerce	13,41	4%
Hotels and restaurants	8,85	2%
Transport and communication	17,97	5%
Financial intermediation	0,24	0%
Real estate, renting and business	6,75	2%
Public administration	11,73	3%
Education, health and social services	7,57	2%
Other services	23,88	7%
Total	364,46	100%

Source: Mastronardi et al. (2022)

According to Table 6, most emissions in Argentina are attributed to the industrial sector, which accounts for 43% of total emissions, followed by the construction sector (11%), agriculture, forestry, and fishing (10%), and water, electricity, and gas (9%). As previously mentioned, these estimates differ significantly from Argentina's National GHG Inventory, even though both methodologies produce the same total emissions at the aggregate level. In the inventory, emissions from the agricultural sector account for 38% of total emissions, followed

by water, electricity, and gas at 19%, while industry represents only 16%. This discrepancy arises because the input-output methodology captures both intra- and intersectoral interactions through input-output flows.

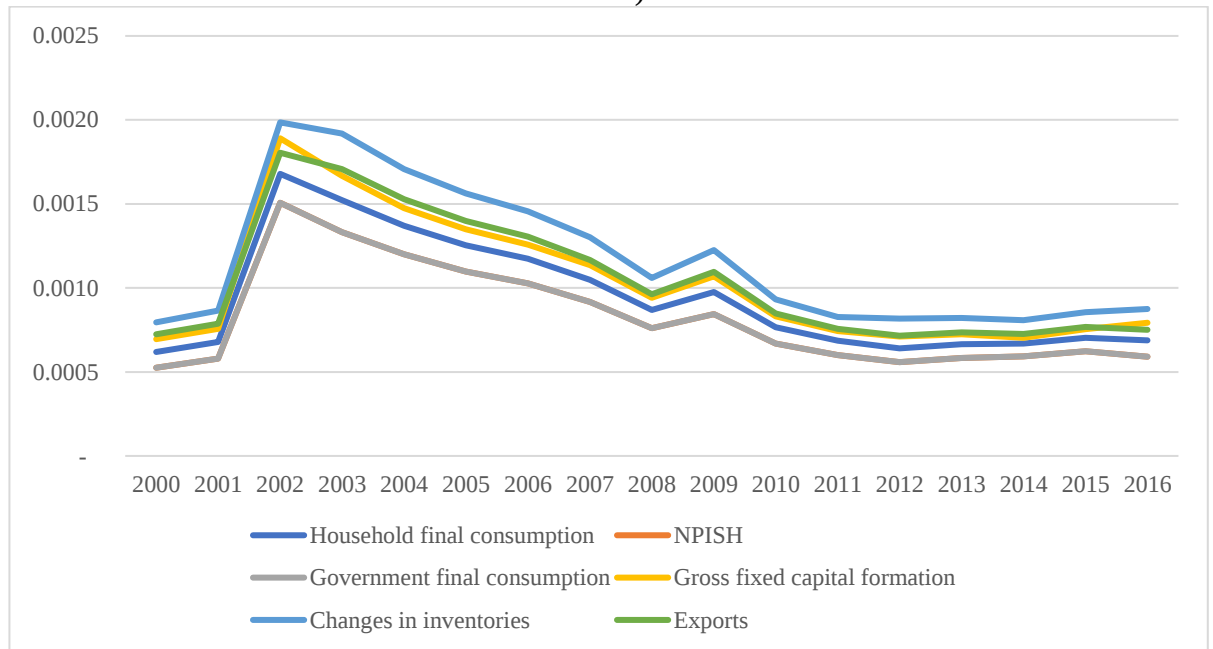
Figure 3: Total GHG emissions per component of final demand (MtCO₂ equivalent)



Source: own elaboration from EORA MRIO database.

Figure 3 shows that the majority of emissions linked to final demand originate from household consumption, which reached 184 Mt in the year 2000. These emissions decreased significantly in 2002 due to the economic crisis, dropping to 148 Mt. Afterward, household final consumption (HFC) emissions increased steadily over time, reaching 194 Mt in 2016. Gross fixed capital formation (GFCF) maintained a relatively stable share throughout the period, representing between 12% and 14% of total emissions. Exports peaked in 2007, with emissions of 79 Mt, and their share saw a notable rise after 2002, accounting for 24% of emissions, remaining around 20-23% until 2012, when they began to lose ground to government final consumption (GFC). The latter accounted for around 10-12% of emissions until 2012, after which it increased to represent 14% of total emissions, peaking at 49 Mt in 2016. Emissions related to non-profit institutions serving households (NPISH) and inventory changes had marginal values along the period.

Figure 4: Coefficient of GHG emissions per component of final demand (MtCO₂eq / Million US dollars)



Source: own elaboration from EORA MRIO database.

Figure 4 illustrates how the GHG emissions coefficient per component of final demand increased significantly for all components in 2002. This can be explained by the economic crisis during that period, which led to a drastic reduction in the monetary values of all final demand components. As a result, even though total GHG emissions decreased that year (287 Mt, compared to 297 Mt in 2000), the coefficient rose sharply. Afterward, as the monetary values of final demand began to recover over time due to the economic rebound, the coefficient gradually decreased. There was a temporary increase between 2008 and 2009, driven by the global financial crisis, which again caused a drop in the monetary values of final demand. Following that, the coefficient declined in 2010 as final demand recovered and remained relatively stable through 2016.

2.5 Empirical results and discussion

In Argentina, carbon dioxide equivalent emissions related to productive activities, accounted for in the EORA MRIO database, increased from 297 Mt in 2000 to 347 Mt in 2016. This increase of 50 Mt is broken down in table 1 below. As can be seen in the last column of the table, where the total effects of each of the elements under analysis are displayed, this increase in the total volume of emissions responds mostly to the effect of energy intensity, which is at the core of both positive and negative results. The effect of final demand varies significantly over the periods, adding up on a small negative value in the aggregate period. At

the same time, the total final demand can be disaggregated into two main elements: domestic demand and exports.

Table 7: Contributions of decomposition factors to GHG emissions changes (Mt and percentage of total change)

Effect of	2000-2002	2002-2005	2005-2010	2010-2016	Sum 2000-2016
Domestic demand level effect (DDLE)	-348,5 (100%) ⁵	114,1 (100%)	122,5 (100%)	80,3 (101%)	-32
Domestic demand mix effect (DDME)	0 (0%)	0 (0%)	-0,1 (0%)	0,9 (1%)	1
Domestic demand distribution effect (DDDE)	-0,2 (0%)	0,3 (0%)	0 (0%)	-1,6 (-2%)	-1
Domestic demand (DD)⁶	-348,8	114,4	122,4	79,6	-32
HFC	-240,4 (69%)	79,1 (69%)	72,3 (59%)	51,1 (64%)	-38
NPISH	-2,8 (1%)	1 (1%)	0,9 (1%)	1 (1%)	0
GFC	-44,5 (13%)	12,5 (11%)	21,3 (17%)	19,1 (24%)	8
GFCF	-55,4 (16%)	22,1 (19%)	23,4 (19%)	4 (5%)	-6
Changes in inventories	-5,7 (2%)	-0,3 (0%)	4,5 (4%)	4,4 (6%)	3
Exports	-5,3	18	31	-15	28
Final Demand (FD)	-354	132	153	65	-4
Emission intensity	0,5	16	-11	-119	-114
Energy intensity	363,4	-112	-151	80	180
Intermediate consumption structure	-19,8	4	-2	5	-12
Sum (total emission change)	-10	40	-11	31	50

Source: Own elaboration from EORA MRIO database

During recession and stagnation periods, exports made negative contributions, whereas, during growth periods, they contributed significantly to GHG emissions, totaling 28 Mt over the entire period. On the other hand, domestic demand had a substantial impact on total emissions across different periods. Further breaking down domestic demand into its five components (household final consumption, non-profit institutions serving households, government final consumption, gross fixed capital formation, and changes in inventories), we observe that household final consumption was the most dynamic component, along with

⁵ The figures in parentheses indicate the percentage that the value represents of the total change in domestic demand.

⁶ DD = DDLE + DDME + DDDE
HFC+NPISH+GFC+GFCF+CII=DD
DD + X = FD

significant contributions from government consumption and gross fixed capital formation (GFCF). As shown in Table 1, these three components explained a significant percentage of the contribution of domestic demand to total GHG emissions change. Household final consumption (HFC) accounted for 59% to 69% of the total emission change related to domestic demand, while government final consumption and GFCF accounted for 11% to 24% and 5% to 19% of the emissions change derived from domestic demand, respectively.

Additionally, by decomposing domestic final demand into three drivers (level, mix, and distribution effects), we find that the level effect accounted for all domestic final demand contributions to GHG emissions, explaining 100% of emissions change in every period.

The emission intensity contributed to a reduction in emissions during the whole period under analysis, with a decrease of 114 Mt. Furthermore, the structure of intermediate demand in the productive sectors of the Argentine economy contributed to a reduction of approximately 12 Mt. However, it is essential to note that significant differences exist when analyzing the contribution of each of these effects during the various sub-periods.

2.5.1 Recession period: 2000-2002

During the 2000-2002 period (recession period), a significant impact from the final demand effect stands out, contributing to reducing -354 Mt in GHG emissions. This effect is often referred to as the scale effect, explaining the changes in emissions due to changes in the size of the final demand. An increase (decrease) in the final demand implies a higher (lower) production and therefore, greater (lower) emissions. In this case, the decrease can be primarily attributed to the constrained levels of internal absorption, which resulted from the decline in real wages due to the 2001-2002 crisis. This economic downturn was further exacerbated by a contraction in government spending and investment, taking place amidst a context of fiscal austerity and high financial instability.

Table 8: Sectoral structure of GHG emissions, 2000-2002 -recession period (Mt)

Sector/Effect of	Final demand							
	Domestic demand			Total DD	Exports	Carbon intensity	Energy intensity	Technology
	DDL E	DDM E	DDD E					
Agriculture	-13,5	-0,1	-0,1	-13,7 (4%)	-1,3 (25%)	0,5 (107%)	17,1 (5%)	-2,8 (14%)
Mining and quarrying	-3,8	0,0	0,0	-3,8 (1%)	-0,6 (11%)	1,8 (370%)	4,4 (1%)	-1,6 (8%)
Food	-29,4	-0,1	-0,1	-29,7 (9%)	-1,1 (21%)	1,3 (270%)	29,6 (8%)	-1,1 (5%)

Textiles	-9,9	0,0	-0,1	-9,9 (3%)	-0,1 (2%)	1 (210%)	9,5 (3%)	-0,7 (4%)
Wood and paper	-8,5	0,0	0,0	-8,5 (2%)	-0,1 (2%)	0,7 (137%)	8,4 (2%)	-0,6 (3%)
Metal products	-6,4	0,0	0,0	-6,4 (2%)	-0,4 (8%)	0,7 (141%)	7,9 (2%)	-1,8 (9%)
Chemical and petrochemical	-18,9	-0,1	-0,1	-19 (6%)	-1,7 (32%)	-2,5 (-	26,5 (7%)	-2,8
Transport equipment and machinery	-14,1	-0,1	0,0	-14,3 (4%)	-0,9 (17%)	10,6 (2178%)	6,8 (2%)	-1,1 (6%)
Other Manufacturing	-28,4	0,2	-0,1	-28,2 (8%)	-0,2 (4%)	-1,8 (-	28,6 (8%)	0,1 (0%)
Transport	-18,3	-0,1	-0,1	-18,4 (5%)	-0,3 (6%)	2 (420%)	17,6 (5%)	-1,6 (8%)
Commercial and public services	188, 9	0,1	0,4	-188,3 (54%)	1,4 (-	-13,7 (-	198,1 (55%)	-5,2 (26%)
Electricity and gas	-8,4	0,0	0,0	-8,5 (2%)	0 (1%)	-0,2 (-32%)	8,7 (2%)	-0,5 (3%)
Total	348, 5	0,0	-0,2	-348,8	-5,3	0,5	363,4	-19,8

Source: Own elaboration from EORA MRIO database

The adverse economic conditions during this period manifested in reducing emissions from various sources. Specifically, household consumption contributed the most, representing 69% of total emissions change from domestic demand, together with government final consumption, representing 13% of DD, under the contraction of public spending because of the financial crisis, and GFCF contributing 16% of the reduction in DD, as exhibited in table 4.

Exports also contributed to the reduction in emissions, with a decrease of 5.3 Mt, which, compared to the total magnitude of domestic demand, results in very marginal values. The sectors that contributed the most to this decrease were the primary sectors (agriculture, fishing, and mining, with a 36% share in the total reduction explained by exports of 5.3 Mt), food (21%), and chemicals and petrochemicals (32%).

Regarding the determinant of carbon intensity, it shows a marginal value of 0.5 Mt for the period. Despite this small value, analyzing the contribution of different sectors reveals the opposing effects of commercial and public services, with a negative value of 13.7 Mt, and, on the other hand, a positive contribution from the machinery and equipment industry, with 10.6 Mt. The rest of the sectors exhibit values ranging between -2.5 Mt and 2 Mt.

Notably, the energy intensity effect contributed significantly to rising emissions, adding 363 Mt, which offset the negative impact of the final demand effect. The sectors that played a key role in this dynamic—where emissions decreased due to final demand but increased due to energy intensity—were commercial and public services, the food industry, the chemical and petrochemical sector, and other manufacturing industries. This pattern of rising emissions

driven by the energy intensity effect and declining emissions from the final demand effect was consistently observed across all sectors throughout the analyzed period. These results suggest that periods of economic crisis are associated with a loss of energy efficiency. It is relevant to emphasize that the energy intensity variable is determined by the amount of energy per unit of output value (Energy/total output). In this sense, the values of this determinant seem to indicate the existence of a fixed emission level generated by energy use that continues to produce emissions regardless of the pace of economic activity.

Two broad mechanisms explain why this happened. First, there is a technological and operational rigidity in basic infrastructure: large parts of the power-and-gas system, together with many essential facilities, must keep running even when overall production drops sharply, so a significantly smaller GDP is distributed across nearly the same underlying energy use. Second, the crisis was managed with price-insulation policies—tariff freezes and fuel subsidies—that kept retail energy prices low (Bril-Mascarenhas and Post, 2015). Those measures mitigated the impact on households and firms but also reduced their incentive to cut consumption, leading to a weaker fall in energy demand than in economic activity.

SDA results in Table 8 show that this pattern was far from uniform across the economy. Four branches account for almost four-fifths of the increase in energy intensity. Commercial and public services dominate, followed—at a distance—by other manufacturing, the food industry, and chemical and petrochemical products. All four saw their output contract, yet their collective energy use fell only marginally, so their energy per unit of output rose steeply. By contrast, sectors that can turn plants on and off more flexibly—such as mining, wood, and paper—registered much smaller contributions to the energy-intensity effect.

In short, the rise in economy-wide energy intensity during the recession is driven by a handful of large, relatively inelastic sectors whose baseline operations cannot be scaled down quickly. This evidence helps clarify why energy-efficiency losses tend to coincide with severe downturns and underscores the need for policies that target those structurally rigid branches when economic activity contracts.

The technology effect, reflecting changes in emissions due to changes in inter-sectoral dependencies—i.e., changes in the composition of inputs used by different sectors—contributed to reducing emissions across all sectors, with a total reduction of 19.8 Mt. The sectors that contributed the most, as in previous cases, were agriculture, chemicals and petrochemicals, and commercial and public services, contributing 14%, 14%, and 26% in reducing emissions, respectively.

Several studies show that an expanding final demand usually pushes emissions upward, while technology and efficiency gains only partly offset that rise (Common and Salma 1992; Peters et al. 2007; Sheinbaum et al. 2011). Our decomposition confirms that basic logic but in an opposite economic phase: during the 2000-02 contraction, final-demand shrinkage produced the single biggest drop in Argentina's emissions (−354 Mt), replicating those authors' scale-effect mechanism—but with the sign reversed. In other words, table 8 reveals the mirror image of the growth-period evidence: cut aggregate demand sharply and the scale effect works just as powerfully, only now in a mitigating direction.

Peters et al. (2007) and Lan et al. (2016) note that, in boom years, final demand and energy intensity often pull in opposite directions—the former raising emissions, the latter lowering them. Our recession results extend that pattern: energy intensity moved against final demand as well, but because demand was falling, the intensity effect drove emissions up (+ 363 Mt). Thus, the sign of the trade-off reverses, yet the opposing relationship between the two drivers remains—a symmetry that reinforces their analytical framework while highlighting the special vulnerability of energy efficiency in downturns.

Ferreira Neto et al. (2014) and Lan et al. (2016) stress the centrality of energy-efficiency policies—a conclusion that table 8 further reinforces. In the recession the scale effect removed 354 Mt of emissions, yet 363 Mt were re-added because many large sectors could not scale down their baseline energy demand. Commercial and Public Services alone offset 198 Mt of the demand-driven decline. This persistent component of energy can substantially offset much of the environmental relief typically associated with an economic downturn.

Finally, the employment-oriented work of Garrett-Peltier (2017), Ungar et al. (2020) and Harari et al. (2022) is directly relevant to the Argentine case. Because energy intensity jumped in the crisis, any counter-cyclical retrofits or renewables projects would have attacked the main positive driver of emissions in table 8 and delivered jobs in construction, installation and maintenance—an especially valuable combination when unemployment peaks. Our findings therefore provide empirical support for the environmentally oriented economic recovery argument: targeting the rigid energy-intensive service and manufacturing branches that kept energy demand high during the recession could simultaneously cut emissions and stimulate employment.

In sum, relating our recession evidence to prior growth-phase studies shows a consistent underlying logic: the scale effect dominates in absolute terms, but its environmental sign mirrors the business cycle, while energy-intensity dynamics—and the policies to mitigate them—gain importance precisely when the economy contracts.

2.5.2 Growth acceleration period: 2002-2005

During the period from 2002 to 2005, the evolution of the Argentine economy witnessed a distinctive impact on emissions, primarily driven by the expansive role of final demand. Following the 2001-2002 crisis, the Argentine government implemented measures with redistributive effects, initially centered around labor market dynamics, such as wage increases and policies favoring workers' bargaining positions. Subsequently, these measures were reinforced by the extension of the social protection system, including pension moratorium policies and conditional transfer programs. The combined effect of these initiatives spurred private consumption, emerging as the key driver behind the overall expansion of aggregate demand throughout the post-crisis period (Porta, 2015).

Table 9: Sectoral structure of GHG emissions, 2002-2005 -growth acceleration period (Mt)

Sector/Effect of	Final demand					Carbon intensity	Energy intensity	Technology
	Domestic demand			Total DD	Exports			
	DDL E	DDM E	DDD E					
Agriculture	4,3	-0,2	-0,1	4 (4%)	2,5 (14%)	-3,6 (-22%)	-0,6 (1%)	0,5 (14%)
Mining and quarrying	1,1	-0,1	0,1	1,1 (1%)	1,7 (10%)	-2,1 (-13%)	0,7 (-1%)	-0,2 (-5%)
Food	9,5	-0,2	-0,1	9,2 (8%)	2,6 (15%)	1,8 (11%)	-9,2 (8%)	-0,3 (-7%)
Textiles	3,3	0,2	-0,1	3,3 (3%)	0,3 (2%)	-1,3 (-8%)	-1,3 (1%)	0,1 (4%)
Wood and paper	2,8	0,0	0,0	2,9 (3%)	0,4 (2%)	0,5 (3%)	-3 (3%)	0,3 (9%)
Metal products	2,0	0,2	-0,1	2,1 (2%)	1,4 (8%)	-0,2 (-2%)	-2,1 (2%)	0 (1%)
Chemical and petrochemical	6,1	0,0	-0,2	5,9 (5%)	3,1 (17%)	26,9 (166%)	-32,9 (29%)	0,4 (11%)
Transport equipment and machinery	4,7	0,0	0,4	5,2 (5%)	1,8 (10%)	-1 (-6%)	-4,2 (4%)	0,5 (14%)
Other Manufacturing	9,6	0,0	1,4	11,1 (10%)	-0,3 (-2%)	2,6 (16%)	-10,5 (9%)	0,2 (5%)
Transport	5,9	-0,1	0,1	5,9 (5%)	1,6 (9%)	0,2 (1%)	-5,5 (5%)	0,2 (5%)
Commercial and public services	62,0	0,2	-1,0	61,1 (53%)	2,3 (13%)	-6,9 (-43%)	-42,2 (38%)	1,8 (47%)
Electricity and gas	2,7	0,0	0,0	2,7 (2%)	0,3 (2%)	-0,7 (-4%)	-1,6 (1%)	0,1 (3%)
Total	114,1	0,0	0,3	114,4	17,8	16,3	-112,3	3,9

Source: Own elaboration from EORA MRIO database

In this context, the contribution to increasing emissions of 132 Mt from final demand is highlighted, being impulsed by the domestic demand (114,4 Mt). A substantial portion of the positive change in GHG emissions induced by domestic demand was attributed to household final consumption, contributing 69% to this change (table 7), particularly influenced by the commercial and public services and food industry sectors. GFCF gained prominence in driving emissions upward (19%), reflecting the positive trajectory of investments in the context of rapid

economic recovery. Notably, food (8%), other manufacturing (10%), and commercial and public services (53%) played a significant role in this surge, with significant contributions to emissions due to domestic demand, as exhibited in table 9.

Exports, for its part, also contributed to increasing emissions, pushed by the favorable context in international markets given by the increase in commodities prices, and by a growth in exports of manufactured products. The main industries contributing to this increase in emissions related to exports were agriculture (14%) and mining (10%), food (15%), metal products (8%), chemical and petrochemical (17%), and transport equipment (10%). The accelerated expansion of manufacturing exports was a prominent feature of the industrial performance during the period of accelerated growth, leading to a new level in the value of external sales. This export surge was mainly driven by an increase in sales volume, both of agricultural-based manufactures and industrial-based manufactures (Porta, 2015).

Throughout this period, there was a notable 16 Mt surge in emissions linked to emission intensity, however this rise did not come from the Electricity and Gas sector. Coal's share of primary energy did increase—from 0.8 % to 1.4 %—yet it remained marginal, and efficiency gains in combined-cycle gas turbines together with higher hydro output more than compensated for that change, yielding a small negative contribution for electricity (-0.7 Mt in table 9). The bulk of the carbon-intensity surge originated in energy-intensive manufacturing—most notably Chemical and Petrochemical (+26.9 Mt), followed by Food (+1.8 Mt) and Other Manufacturing (+2.6 Mt)—where the rebound in activity relied heavily on fuel oils and high-temperature process heat.

The emissions stemming from final demand and carbon intensity effects were partially offset by a notable reduction resulting from energy intensity (-112 Mt). Except for mining and quarrying, every industry exhibited negative contributions to this effect, especially food, other manufacturing, chemicals and petrochemicals, and commercial and public services, representing 8%, 9%, 29%, and 38% of emissions reduction from this driver, respectively.

The contribution of the effect of the change in the demand for intermediate consumption (technology effect) was marginal (3,9 Mt), closing the balance of the period at an increase of 40 Mt. Among the different sectors, the contribution of commercial and public services stands out, explaining 47% of increasing emissions.

In summary, final demand (both domestic and foreign) was the major contributor to rising emissions during the period of accelerated economic growth. Despite improvements in energy efficiency, reflected by the reduction in emissions due to the energy intensity effect, these were insufficient to fully counterbalance the escalating emissions driven by the final

demand effect. These results are consistent with those of Peters et al. (2007) and Lan et al. (2016). This underscores the complexity of achieving environmental sustainability in the context of strong economic growth, emphasizing the need for integrated policies that consider both economic and environmental factors.

Given the significant role that certain sectors—such as food, other manufacturing, and commercial and public services—played in driving emissions during the growth acceleration period, largely due to domestic demand level effect, it raises questions about the effectiveness of carbon taxes in reducing these emissions. A carbon tax on carbon-intensive goods and services could shift consumption towards less emission-intensive alternatives, thereby reducing emissions through the domestic demand mix effect. In this context, Arrieta and González (2018) demonstrate the substantial impact that reducing beef consumption could have on mitigating GHG emissions associated with the Argentine diet.

Mardones and Andaur (2024) also highlight that household demand for carbon-intensive goods in Argentina is sufficiently price-sensitive to induce significant changes in consumption through the implementation of a carbon tax. However, all their simulated scenarios reveal a trade-off between environmental and economic outcomes. While higher tax rates lead to greater reductions in CO₂ emissions, they also result in higher prices for consumers, potentially causing negative effects on production, employment, wages, poverty, and inequality. Given the socioeconomic conditions of developing countries like Argentina, implementing such policies poses considerable challenges. A future research agenda could explore how varying carbon tax levels impact GHG emissions and economic activity across different income groups.

2.5.3 Growth period: 2005-2010

During this period, a comparable pattern to the growth acceleration phase can be observed, with a significant contribution from final demand, amounting to 153 Mt. Domestic demand contributed 122,4 Mt, explained mainly by HFC, followed by GFCF and GFC, with shares of 59%, 19% and 17%, respectively (table 7).

Table 10: Sectoral structure of GHG emissions, 2005-2010 -growth period (Mt)

Table 16: Sectoral structure of GHG emissions, 2005-2010 - growth period (1A)								
Sector/Effect of	Final demand					Carbon intensity	Energy intensity	Technology
	Domestic demand			Total DD	Exports			
	DDL E	DDM E	DDD E					
Agriculture	4,8	0,1	-0,1	4,8 (4%)	3,4 (11%)	-1,6 (15%)	-7,5 (5%)	0 (-2%)
Mining and quarrying	1,2	0,1	0,0	1,3 (1%)	1,5 (5%)	-0,7 (6%)	-2,8 (2%)	0,2 (-10%)

Food	10,2	0,1	-0,8	9,5 (8%)	3,4 (11%)	-3,6 (32%)	-11,3 (8%)	0,1 (-5%)
Textiles	3,6	-0,1	-0,1	3,4 (3%)	0,7 (2%)	-0,5 (5%)	-4,3 (3%)	0,1 (-4%)
Wood and paper	3,1	0,0	0,0	3,1 (3%)	0,8 (3%)	-2,2 (20%)	-1,8 (1%)	-0,2 (12%)
Metal products	2,2	-0,2	0,6	2,6 (2%)	1,6 (5%)	0,5 (-5%)	-4,7 (3%)	-0,2 (11%)
Chemical and petrochemical	6,8	-0,1	0,3	7 (6%)	3,9 (13%)	16,3 (-	-28,4 (19%)	-0,1 (3%)
Transport equipment and machinery	5,2	0,0	0,2	5,4 (4%)	4,1 (13%)	-5,7 (52%)	-3,4 (2%)	-0,8 (45%)
Other Manufacturing	10,6	-0,2	1,1	11,5 (9%)	0,3 (1%)	-5,8 (52%)	-5,5 (4%)	-0,5 (27%)
Transport	6,2	0,0	-0,4	5,8 (5%)	2,1 (7%)	-1,4 (13%)	-7,3 (5%)	0 (2%)
Commercial and public services	65,7	0,2	-0,5	65,3 (53%)	8,2 (27%)	-3,4 (31%)	-73,6 (49%)	-0,4 (24%)
Electricity and gas	2,9	0,0	-0,2	2,7 (2%)	0,6 (2%)	-3 (27%)	-0,6 (0%)	0,1 (-3%)
Total	122,5	-0,1	0,0	122,4	30,8	-11,1	-151,2	-1,8

Source: Own elaboration from EORA MRIO database

Notably, exports also played a more substantial role in the change of emissions, representing 20% of the total emission change driven by final demand, with an absolute contribution of 31 Mt. This growth in exports was primarily propelled by the agriculture and food industry (3.4 Mt each), transport equipment and machinery (4.1 Mt), chemical and petrochemical (3.9 Mt), and commercial and public services (8.2 Mt). The evolution of emissions associated with exports aligns with favorable international prices and internal conditions (changes in relative prices), which stimulated increased exports in these productive sectors.

Emission intensity contributed moderately to emission reduction (-11 Mt). This reduction was observed across most sectors, which collectively offset the significant positive contribution of 16.3 Mt from the chemical and petrochemical industry. On the other hand, energy intensity experienced a significant reduction in emissions, amounting to -151 Mt, effectively counterbalancing the emissions increase attributable to final demand. This effect was driven mostly by the commercial and public services, and chemical and petrochemical sectors. Their negative contributions to emissions represented 49% and 19% of the total reduction driven by energy intensity, respectively. Similar to previous periods, the technological effect remained moderate, contributing to a 2 Mt reduction in emissions. In aggregate, the combined effects led to a net decrease of 11 Mt during this period.

Following the crisis of years 2001 and 2002, the energy policy shifted towards supplying the domestic market and maintaining local energy prices below international levels. This was

achieved through the imposition of export taxes to oil and gas, together with the prohibition of indexation in public service tariffs, subsidizing a portion of the energy generation costs for companies. At the same time, the economic recovery from 2003 onwards boosted local energy demand, initially driven by the agricultural and industrial sectors, followed by residential demand (Arceo et al., 2022).

During the initial two years of recovery, the upturn in the domestic market provided companies with robust demand, allowing them to meet it by reactivating their plants and leveraging the substantial existing idle capacity. However, as this capacity began to deplete across various sectors, the need for advancing new investments emerged. From 2005 onward, the majority of production was sustained through the establishment of new productive capacity (Herrera and Tavošnanska, 2011). Small and medium-sized enterprises (SMEs) constituted the business sector that achieved the most favorable relative performance in terms of investment, with disbursements growing at an annual average rate of 23%. This expansion was a result of an enhancement in their own financial reserves, driven by an increase in profitability, as highlighted by Kulfas (2009). Additionally, this process encouraged the establishment of new enterprises and the expansion of many pre-existing ones (Porta, 2015).

In this context, several significant factors influenced Argentina's GHG emissions trends between 2002 and 2010. On one hand, political measures aimed at fostering economic growth and reducing domestic energy prices resulted in heightened energy consumption and, consequently, increased emissions. Simultaneously, the introduction of new equipment and machines, linked to the surge in investments by local companies, led to a rise in embodied GHG emissions across all production stages, linked to GFCF component of final demand, particularly in metal products, chemical and petrochemical, transport equipment and machinery, the other manufacturing sector, and commercial and public sectors. However, it is noteworthy that these new investments also played a role in enhancing energy efficiency. In this regard, Dosi et al. (2024) highlight that the primary drivers of reduced emission intensity in developed countries have been productivity gains in the manufacturing sector, leading to more efficient production processes.

On the whole, these factors collectively contributed to a substantial increase in emissions driven by the scale effect, but this surge was effectively counterbalanced by the energy intensity effect, playing a significant role in mitigating emissions. While the rise in energy consumption linked to economic expansion increased the numerator of this driver, the total output of the economy experienced a much more substantial increase, resulting in the

energy intensity driver assuming notable negative values during this period, thereby contributing to emissions reduction.

These findings align with those of Lallana et al. (2021), who simulated various scenarios to explore pathways for deep decarbonization in Argentina alongside broader economic development goals. One key conclusion from their study is that the absolute level of primary energy supply remains similar across all scenarios, including both a business-as-usual trajectory and those involving profound structural change. This outcome arises from the counterbalancing effects of two key dynamics in the progressive structural change scenario. On the one hand, there is a significant increase in useful energy consumption per capita, driven by rising income levels and a substantial reduction in poverty, which leads to greater final demand and higher economic output. On the other hand, this increase is offset by substantial gains in average energy efficiency, attributed to the adoption of more efficient technologies and the electrification of energy uses. Together, these opposing trends result in a relatively stable primary energy demand across different scenarios.

2.5.4 Stagnation period: 2010-2016

In this period, a contribution to growing emissions from final demand (65 Mt) is observed, which results much more moderate than in the previous periods, especially because of the slowdown of the Argentinian economy. Domestic demand contributes with 80 Mt to emission change, triggered mostly by household consumption (51 Mt and 64% share), and government consumption (19 Mt), which increased considerably its participation in domestic demand emissions, reaching 24% in this period. GFCF decreased significantly its contribution to emission change, representing only 5% (4 Mt), as a consequence of the reduction in investment rates influenced by the negative economic context, marked by an increasing external restriction to economic growth (Porta, 2015). Exports determined a reduction of 15 Mt in emission change, due to the fact that as of 2010, in a context of increasing exchange rate appreciation, the competitiveness of the tradable sectors, especially those most sensitive to the level of the real exchange rate, was reduced, which affected the export performance of the manufactures. In this sense, the reduction of emissions from exports was driven mainly by food, metal products, transport equipment and machinery, together with commercial and public services.

Table 11: Sectoral structure of GHG emissions, 2010-2016 -stagnation period- (Mt)

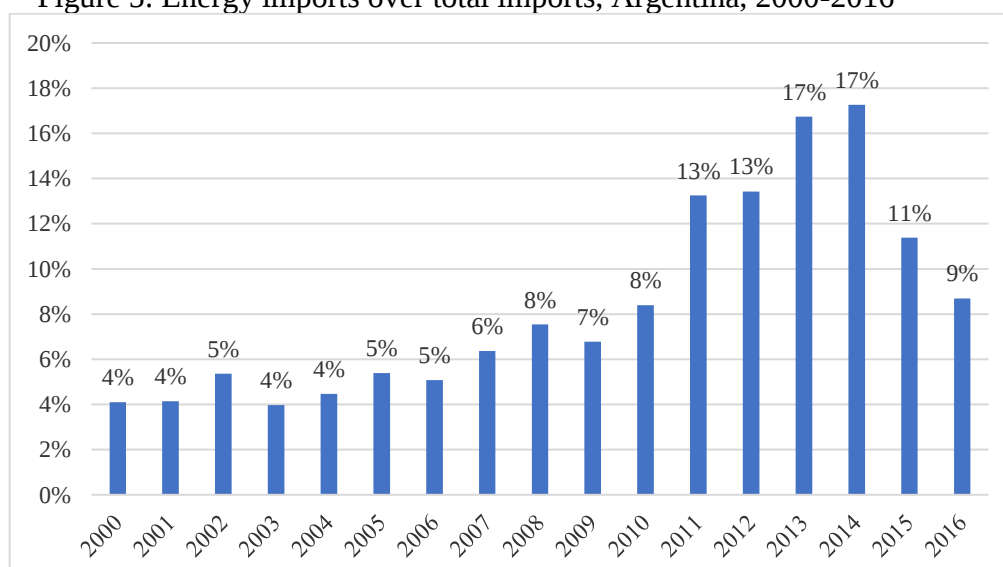
Sector/Effect of	Final demand			Carbon intensity	Energy intensity	Technology
	Domestic demand	Total DD	Exports			

	DDL E	DDM E	DDD E					
Agriculture	3,4	2,1	0,1	5,5 (7%)	-0,8 (5%)	-0,2 (0%)	-7,6 (-9%)	4,2 (77%)
Mining and quarrying	1,0	0,5	-0,1	1,4 (2%)	0,7 (-5%)	-2 (2%)	-4,1 (-5%)	4,3 (78%)
Food	6,8	1,9	0,0	8,8 (11%)	-1,7 (11%)	-39,8 (33%)	37,1 (46%)	-1,2 (-22%)
Textiles	2,3	-0,8	0,1	1,6 (2%)	-0,5 (3%)	-12,3 (10%)	12,2 (15%)	-0,1 (-2%)
Wood and paper	2,0	-0,2	-0,1	1,6 (2%)	-0,5 (3%)	-2,8 (2%)	3,1 (4%)	-0,7 (-13%)
Metal products	1,6	-0,2	-0,2	1,2 (2%)	-1,4 (9%)	-2,4 (2%)	2,8 (3%)	0,4 (7%)
Chemical and petrochemical	4,8	0,5	-0,1	5,2 (7%)	-3,1 (21%)	-19 (16%)	18,1 (22%)	0,6 (11%)
Transport equipment and machinery	3,4	-0,7	-0,9	1,8 (2%)	-2,7 (18%)	-36,2 (30%)	38,1 (47%)	0,1 (3%)
Other Manufacturing	6,6	0,0	-3,8	2,8 (4%)	-0,1 (1%)	8,7 (-7%)	-11 (-14%)	0,2 (3%)
Transport	4,1	0,3	-0,2	4,2 (5%)	-1,2 (8%)	-1,3 (1%)	-0,9 (-1%)	0,6 (11%)
Commercial and public services	42,5	-3,5	3,7	42,8 (54%)	-3,5 (23%)	-12,3 (10%)	-4,7 (-6%)	-4 (-74%)
Electricity and gas	1,9	0,9	0,0	2,7 (3%)	-0,3 (2%)	-0,1 (0%)	-2,7 (-3%)	1,1 (20%)
Total	80,3	0,9	-1,6	79,6	-15,1	-119,5	80,5	5,5

Source: Own elaboration from EORA MRIO database

Differently from the previous periods, energy intensity did not evolve in an inverse proportional way in relation to final demand. In this period, it contributed positively to emission change with 80 Mt. The driver that compensated the increase in emissions was the emission intensity effect, reducing 119 Mt, and keeping the total emission change during the period in 31 Mt. The technology effect contributed moderately to increasing emissions (5,5 Mt).

Figure 5: Energy imports over total imports, Argentina, 2000-2016



Source: own elaboration based on INDEC

The emission reduction derived from the emission intensity driver is mainly explained by the increasing amount of energy imports (which already started in the previous period), which resulted from a combination of rising energy demand and limited domestic production capacity. In this way, this period was marked by Argentina's struggle to balance its energy demand with domestic production capacity, resulting in a reliance on energy imports for a significant portion of its energy needs. Oil and, especially, natural gas were the primary components of Argentina's energy imports, while electricity imports with neighboring countries like Brazil played a smaller, more occasional role in meeting the country's energy needs. Crude oil and refined products were imported from Nigeria, Brazil, Trinidad and Tobago, Qatar, and the United States⁷, while significant volumes of natural gas were imported through pipelines with Bolivia, particularly after the two countries signed a long-term gas export agreement in the mid-2000s (Ministry of Energy and Mining of Argentina). Argentina also imported LNG from global suppliers to meet rising demand, particularly from Qatar, Nigeria and Norway (IEA). Figure 5 shows that energy imports began to increase significantly from 2010 onward, reaching their peak between 2011 and 2014.

Based on data extracted from IEA world energy balances, Argentina's energy imports exhibited dynamic fluctuations over the years. In 2000, these imports accounted for 7% of the country's total primary energy supply, but declined to 4% in 2002 due to the severe economic recession. However, by 2005, the total imports rebounded, reaching the same level as in 2000, and then experienced significant growth, doubling by 2010 and representing 11% of the total energy supply. The upward trend continued, and by 2016, energy imports more than doubled again, making up 20% of Argentina's total primary energy supply.

Consequently, energy imports played a significant role in reducing the emission intensity of domestic production activities and, consequently, the overall emission changes during the stagnation period. This reduction was achieved by minimizing emissions associated with energy-producing activities and substituting a larger proportion of carbon and oil with less carbon-intensive gas.

Abeles and Amar (2017) describe how, between 2002 and 2011, employment growth and wage expansion became the main drivers of private consumption in Argentina, which in turn accounted for nearly half of the increase in aggregate demand. However, they highlight that this positive feedback between rising employment and domestic demand led to a situation

⁷ <https://wits.worldbank.org/>

where real wage growth, consistently outpaced productivity gains throughout the period 2002-2015. This, combined with the higher share of wages in national income, resulted in an increase in unit labor costs. Starting in 2008, this cost increase coincided with a sharp rise in international commodity prices, fueling distributive struggles. As a consequence, inflation rose significantly, taking on an inertial nature and stabilizing at a much higher level than the regional average. From 2010 onwards, this led to a context of growing currency appreciation. As a result, the competitiveness of tradable sectors, especially those more sensitive to the real exchange rate, increasingly relied on energy consumption subsidies and various non-tariff protection mechanisms.

This situation was combined by a growing energy deficit, a marked trend toward dollarization of assets—resulting in approximately \$33 billion leaving the country for speculative purposes, equivalent to 3.4% of GDP in 2010-2011—and various political factors, all of which contributed to the reemergence of external constraints on economic growth.

This context, combined with the results of the SDA analysis of emissions for the 2010-2016 period—which indicate low emissions from GFCF, high emissions from domestic demand, and significant emissions related to energy intensity—highlights the need for environmental policies aimed at improving energy efficiency and increasing the share of renewable sources in total energy supply. These policies would not only contribute to reducing GHG emissions but also generate energy savings, which in turn would reduce energy imports, helping to alleviate external constraints on growth.

Moreover, as previously mentioned, investments in equipment and machinery to improve energy efficiency and increase renewable electricity generation have a positive impact on employment and output, making them particularly relevant as countercyclical policies in times of economic stagnation or recession. However, it is important to note that only a portion of the components for such equipment are produced domestically. In the case of solar photovoltaic electricity generation, Harari et al. (2022) point out that only 19% of the components are locally produced. As a result, the positive effects of increased demand in this sector on other sectors with which it is linked are limited compared to a scenario with higher national integration. Furthermore, an increase in demand for equipment with a high import content could place greater pressure on foreign exchange demand, exacerbating external constraint issues.

Thus, two opposing effects of environmental policies related to external constraints become evident. On one hand, increasing energy efficiency contributes to substituting energy

imports, which, as previously mentioned, were significant during this period. On the other hand, the demand for imported equipment and inputs puts additional pressure on foreign exchange demand.

In this context, an industrial policy aimed at increasing the local content of equipment for renewable energy and energy-efficient appliances becomes highly relevant. Such a policy could enhance the multiplier effects on output and employment while reducing the demand for imported inputs and components. At the same time, however, it may lead to higher equipment prices, potentially limiting broader adoption. This presents a trade-off between ensuring the faster and cheaper deployment of renewable energy and energy efficiency projects and fostering the development of a domestic industry, which tends to involve higher costs (Hochstetler, 2020). To mitigate these challenges, demand-side policies, such as consumer credit for purchasing equipment, tax exemptions, or even carbon taxes, could be implemented. While the impacts of such policies fall outside the scope of this study, they represent important areas for future research.

Ultimately, the points raised thus far emphasize the critical need for coordination between environmental, energy, and industrial policies aimed at promoting green economic growth. The alignment of policy instruments across diverse sectors—such as energy, science, technology, and industry—is therefore essential. These policies must be co-created to ensure coherence and effectiveness across the energy, environmental, and industrial domains (Lütkenhorst et al., 2014; Landini et al., 2020).

2.5.5 Structural indicators of emissions and energy use: Multipliers and linkages

To complement the Structural Decomposition Analysis and better characterize the structural determinants of GHG emissions in Argentina, we conducted an analysis of standard structural indicators commonly used in input-output studies, namely emissions and energy multipliers, as well as backward linkages across productive sectors. This approach allows us to gain a deeper understanding of the intersectoral relationships and the carbon and energy intensity embedded in the country's economic structure across the study period (2000–2016).

Emissions multipliers capture the total (direct and indirect) emissions generated throughout the economy for each monetary unit of final demand in a given sector. Consistently across all benchmark years (2000, 2005, 2010, and 2016), the highest emissions multipliers were observed in the Commercial and Public Services sector, followed by Chemical and Petrochemical, Metal Products, and Agriculture (tables 22–24 in Appendix E). These findings indicate that changes in the final demand for these sectors have disproportionately high

environmental impacts. Energy multipliers, in turn, indicate the total energy consumption (direct and indirect) required per unit of final demand. The Electricity and Gas sector exhibited the highest energy multipliers, as expected due to its role in supplying energy inputs to the entire economy, followed by the Transport sector. Sectors such as Metal Products and Other Manufacturing also presented high values, consistent with their typically energy-intensive production processes. Interestingly, in 2016, the Commercial and Public Services sector displayed one of the lowest energy multipliers while showing the highest emissions multiplier, pointing to a potential reliance on carbon-intensive energy sources rather than high energy consumption per se.

Backward linkages, which reflect the degree to which a sector depends on inputs from the rest of the economy, were consistently strongest in Food, Textiles, Metal Products, Wood and Paper, and Chemical and Petrochemical sectors—typical of manufacturing industries. The Construction sector was excluded from this analysis due to lack of disaggregated energy data, although its importance is likely significant.

The structural analysis reveals additional insights into the interplay between Argentina's productive structure and its environmental footprint. Notably, the Chemical and Petrochemical sector exhibited a simultaneous increase in both emissions multipliers and backward linkages, indicating that its growing role in the productive structure is accompanied by rising environmental pressure. Meanwhile, traditional sectors such as Agriculture and Food displayed relatively stable values in both emissions and energy multipliers, suggesting limited progress in improving environmental efficiency. Overall, these findings reinforce the importance of addressing sector-specific dynamics in designing effective decarbonization policies.

The structural indicators results reinforce—and nuance—the patterns uncovered by the SDA. For instance, the Commercial and Public Services sector consistently displayed the highest emissions multipliers, echoing its large positive contributions in every SDA sub-period. Yet its low energy multipliers show that the bulk of those emissions stem from carbon-intensive fuels rather than the total volume of energy consumed, clarifying why the sector's emissions rose even in episodes (2002-05 and 2005-10) when economy-wide energy intensity was falling. This insight strengthens the SDA-based recommendation that services decarbonization must pair demand-side measures (e.g. shifting consumption patterns) with a rapid switch to low-carbon power sources.

Likewise, the Chemical and Petrochemical and Metal Products industries emerge as two major emitters: SDA identified them as major contributors to both the rise (via exports or domestic demand) and fall (via energy-intensity improvements) of emissions, while the

multiplier–linkage analysis shows that their backward linkages—and thus their economy-wide spillover effects—have strengthened over time. Taken together, these results imply that technology-upgrading policies proposed in essay 1 should focus on greening the input chains of these sectors (e.g. substituting lower-carbon feedstocks and electrifying heat processes) so that the resulting emissions reductions spread throughout the rest of the economy.

Finally, the structural indicators shed light on the SDA’s finding that energy intensity drove emissions up during recession and stagnation periods (2000-02, 2010-16) but down in expansion years (2002-10). High energy multipliers in Electricity and Gas confirm that any downturn-induced fall in output leaves a large, relatively fixed block of energy use—and its associated emissions—intact. Conversely, in expansion periods new investment in more efficient capital stock (reflected in falling multipliers for several manufacturing branches) allows output to grow faster than energy use. This alignment of SDA and multiplier evidence underscores the importance of counter-cyclical energy-efficiency policies to avoid efficiency losses when demand contracts.

In short, combining SDA with multipliers and linkages gives a consistent overview: the same sectors that dominate the scale and intensity effects in the decomposition are also those with the largest economy-wide spillover effects. This convergence reinforces one of the key policy insights of this essay: targeted, sector-specific industrial and environmental measures—rather than uniform economy-wide instruments—offer the strongest means for decoupling Argentina’s growth from its emissions trajectory.

2.5.6 Decomposition model of the technology effect

As previously mentioned, this essay employs a decomposition model to further break down the effects of input changes across the different economic sectors and their impact on emissions across different periods.

As seen in Table 8 during the recession period, the sectors that had the most significant impact on reducing emissions were the food and chemical and petrochemical industries, jointly accounting for 51% of the total reduction in emissions. As this reduction was due to changes in the structure of intermediate inputs used by these sectors, these results suggest that in a recessionary context, these sectors shifted towards inputs with lower emission impacts.

Table 12: Decomposition of the technology driver

Sector/Period	2000-2002	2002-2005	2005-2010	2010-2016
Agriculture	-2 (10%)	1,3 (33%)	-0,5 (26%)	-0,1 (-1%)
Mining and quarrying	-0,7 (4%)	0,7 (18%)	-0,1 (5%)	1,6 (30%)
Food	-5,5 (28%)	2,2 (58%)	-0,1 (3%)	0,6 (11%)

Textiles	-1,4 (7%)	0,2 (6%)	0,1 (-4%)	0,7 (14%)
Wood and paper	-0,5 (3%)	-0,2 (-5%)	0 (-2%)	0,2 (3%)
Metal products	-1,4 (7%)	-0,1 (-2%)	-0,1 (7%)	0,6 (11%)
Chemical and petrochemical	-4,6 (23%)	0,4 (10%)	0,3 (-17%)	3,4 (62%)
Transport equipment and machinery	-3 (15%)	-0,8 (-21%)	0,3 (-19%)	1,4 (27%)
Other Manufacturing	-0,5 (3%)	-0,6 (-15%)	0,2 (-12%)	0,6 (11%)
Transport	-0,5 (3%)	0,2 (4%)	-0,2 (13%)	0,8 (15%)
Commercial and public services	0,8 (-4%)	0,7 (19%)	-1,7 (97%)	-4,2 (-77%)
Electricity and gas	-0,4 (2%)	-0,1 (-4%)	0 (2%)	-0,2 (-4%)
Total	-19,8	3,9	-1,8	5,5

Source: own elaboration from EORA MRIO database

In contrast, during the subsequent period of accelerated growth, the inputs used by the food sector had a positive impact on emissions related to the technology effect, accounting for 58% of the 3.9 Mt attributed to this determinant. Additionally, the agriculture, together with the mining and quarrying sectors also contributed to increased emissions, collectively representing 51% of the total emissions from technological factor. These findings imply that in a context of rapid economic growth, driven in part by favorable international conditions for exporting these products, the food and primary goods sectors increased their demand for more GHG inputs, primarily due to greater consumption of energy-intensive inputs.

During the 2005-2010 period, the technology effect showed a modest negative contribution of -1.8 Mt, largely attributed to the commercial and public services sector, whose negative contribution accounted for 97% of the total technological effect balance. In the stagnation period, there was a positive total balance of 5.5 Mt, with significant variation among sectors. On one hand, the commercial and public services sector contributed to a reduction of 4.2 Mt in emissions, explained by an increased use of imported energy inputs and a higher share of natural gas, as discussed in the previous subsection. On the other hand, the chemical and petrochemical sectors exhibited positive contributions to emissions, with 3.4 Mt representing 62% of emissions from the technology effect.

The analysis across different economic periods reveals that sectoral shifts in input composition influence emission patterns, especially in recession and stagnation periods. These findings underscore the importance of targeted policies that address sector-specific behaviors and promote sustainable practices, particularly in key industries like food, primary products, chemical and petrochemical, and commercial and public services.

2.6 Conclusions and policy implications

In this essay we have shown that the variation of GHG emissions in the years 2000-2016 has been driven mainly by the final demand level, in line with the findings of Lan et al.

(2016), Zhu et al. (2018) and Cansino et al. (2016), among others. In periods of economic growth, manufacturing and service sectors have had a strong impact on emissions linked to this effect, while, in the period of stagnation, their contribution was more moderate, to the time that, in the recessive period, they had a strong impact reducing emissions.

This increase in emissions driven by final demand has been related, as of the year 2002, to a set of redistributive policies aimed at strengthening mass consumption and the purchasing power of the most vulnerable socioeconomic sectors that suffered the most from the impacts of the Argentinian crisis of years 2001-2002. These measures generated a significant impact on emissions related to household final consumption, government final consumption and GFCF. The strong impact that domestic demand has on the level of emissions poses challenges to reduce its volume, since Argentina has heavy debts in terms of income distribution, so, in the event of an increase in income from lower levels, the impact on emissions could be very significant.

The effect of energy intensity on changes in emissions levels has been of considerable consequence, ranking alongside that of final demand. In this sense, it is noteworthy that in the years of economic growth, the strong increase in emissions generated by final demand was offset by a significant negative contribution from energy intensity, which may reflect an increase in productivity that has positively affected energy efficiency. In this sense, the results of this study highlight that increasing pressure on GHG emissions associated with a rise in the final demand for goods and services was offset by energy efficiency in periods of economic growth.

The findings indicated that the emission intensity effect exerted a moderate fluctuating impact on emissions during growth periods. However, during stagnation periods, it made notable contributions to reducing emissions, partially counterbalancing the increases attributed to energy intensity and final demand. Nevertheless, as previously stated, beginning in 2005, energy imports emerged as a critical factor in reducing the emission intensity of domestic production activities.

The change in the intermediate consumption structure of the economy, for its part, had a marginal impact in periods of growth and stagnation, while in the period of recession, it had a moderate impact. It should be noted that, although this effect is being considered as a proxy for the technological effect, it is imprecise, since part of the technical progress can be manifested through energy intensity (higher levels of productivity generate improvements in energy efficiency that contribute to lower emissions related to energy intensity effect).

These empirical patterns provide empirical grounding for essay 1's broader argument that a technological gap and commodity-biased development path trap the country in both a middle-income scenario and a carbon-intensive trajectory. Limited upgrading in energy-intensive manufacturing, a persistent fossil share in power generation and rigid service-sector equipment are precisely the channels through which that gap manifests itself in the SDA.

When examining the structural decomposition of GHG emission changes spanning the entire period from 2000 to 2016, several noteworthy facts emerge. The main drivers of changes in GHG emissions, alongside energy intensity, were variations in the level of final demand during most of the years. Our empirical results highlight that final consumption has a significant impact on emissions. This suggests that demand-side policies, which influence both the level and composition of final demand, could be instrumental in reducing emissions. However, such policies may be inconsistent with the social and economic needs of developing countries like Argentina, where economic growth is essential for generating wealth and income distribution.

Adjusting the product mix within final demand could offer a more socially and politically feasible policy approach. The government could promote the adoption of less emission-intensive consumption patterns by implementing economic instruments, such as higher taxes on carbon use and providing tax deductions or subsidies for energy-efficient products. These measures could incentivize a shift towards a greener composition of final demand. Another policy option is to introduce carbon taxes targeting more polluting products consumed by wealthier groups, in order to offset the increased emissions resulting from higher consumption levels among poorer households. This would lead to a shift in the product mix within final demand, making it a more socially viable approach. However, because the input-output tables employed here do not disaggregate final demand by income group, the analysis cannot reveal how shifts in purchasing power—or instruments such as carbon taxes aimed at higher-income consumers—would redistribute either emissions or welfare. Addressing that gap offers a clear agenda for future research. Extending the model to a Social Accounting Matrix or to an expenditure-weighted multiregional framework that links sectors to household deciles would allow emissions to be decomposed by income class and redistributive policy packages to be simulated: for example, testing how rising incomes among poorer groups alter the emissions profile, whether product-specific carbon taxes on richer households can offset that increase, and how progressive transfers might combine with efficiency retrofits. Such refinements would supply the empirical foundation needed to design equity-oriented demand-mix policies that lie beyond the scope of the present input-output model.

The results from the SDA analysis suggest an inverse relationship between the contributions of energy intensity and final demand to emission changes during periods of economic growth and recession. The data indicate that during periods of rapid economic growth, there were gains in energy efficiency, contradicting the assumption that growth necessarily leads to worsening energy efficiency. In contrast, the evidence suggests that during times of crisis, energy efficiency tends to deteriorate.

While we cannot establish a direct causal relationship between these variables based solely on this analysis, the data imply a potential decoupling between economic growth and energy consumption. This sheds light on a highly debated issue regarding the relationship between growth and emissions, suggesting that the rise in final demand did not undermine energy efficiency; instead, it appears to have improved it.

Moreover, the analysis identifies a handful of sectors responsible for the most substantial changes in emissions, with notable mentions being the commercial and public services, food, chemical and petrochemical industries, and other manufacturing sectors. Identifying the efficiency improvement potential within these specific sectors is of significant importance, as well as providing both financial and technical support to enhance improvements in their energy and emission efficiency. By targeting these critical areas, Argentina can make notable improvements in its efforts to mitigate climate change and foster sustainable development.

Considering the composition of Argentina's energy sources, a shift towards an energy mix characterized by a reduction in the use of oil and coal, and an increase in the utilization of natural gas as a primary energy source, can result in substantial emission reduction. This transformation was evident during the period from 2010 to 2016, where the increased imports of natural gas played a significant role in considerably lowering carbon emissions through the emission intensity driver. Additionally, Argentina possesses substantial shale gas reserves, which are notably cleaner than other conventional energy sources like oil and coal. Implementing initiatives to promote the integration of renewable energy sources into the overall fuel mix would be instrumental in reducing emission intensity and offsetting the impact of final demand on emission changes. Additionally, renewable energy investments, along with other initiatives aimed at promoting energy efficiency, have positive impacts not only in environmental terms by reducing GHG emissions, but also by fostering job creation and boosting economic output (Garrett-Peltier, 2017; IEA, 2020; Ungar et al., 2020; Harari et al., 2022; Romero et al., 2022).

This essay contributes to estimating the drivers of GHG emissions across different economic contexts. Combined with the policy analysis conducted, it can help inform the design of environmental policies that are tailored to specific economic contexts, in conjunction with industrial and technological policies. In this regard, policies based on carbon taxes, aimed at altering the demand mix, may be politically more feasible during periods of economic expansion. Policies focused on maximizing energy efficiency would also be useful in this context, as they would help prevent significant pressure on energy import demand, which could otherwise contribute to the emergence of an external constraint on growth.

Conversely, in periods of recession or economic stagnation, it would be more recommended to implement environmental policies that maximize positive economic impacts, such as job creation and production stimulation through supply chain linkages and potential rebound effects. Policies of this nature have been identified in studies like Romero et al. (2022) and Harari et al. (2022).

Finally, it is worth noting that the availability of comprehensive and reliable data is a key constraint to conduct the input-output studies for Argentina's economic, energy and emission issues. Enhancements in the data collection process and reporting on input-output matrices, as well as energy and emissions data in Argentina, are essential to facilitate in-depth research on energy and GHG emissions. Ensuring accurate and up-to-date data is crucial to enable timely assessments and analysis, ultimately supporting effective decision-making and policy formulation to address energy and environmental challenges in the country.

3 CARBON EMISSIONS AND VALUE-ADDED EMBODIED IN ARGENTINA'S TRADE: AN INPUT-OUTPUT ANALYSIS BETWEEN 2000-2016

3.1 Introduction

The impact of international trade on GHG emissions is a subject that has received considerable attention in both environmental and economic literature (Wang and Yang, 2020). Studies focusing on estimating CO₂ emissions embodied in exports and imports highlight the environmental costs associated with trade and contribute to understanding carbon transfers between countries (Huang, Lenzen and Malik, 2019; Wang and Zhou, 2019). The separation of consumers and producers through international trade allows for shifting environmental emissions associated with consumption to distant regions, facilitated by production fragmentation along GVCs (Davis and Caldeira, 2010; Peters et al., 2011). While exporters obtain an economic benefit for their production, they incur environmental costs related to their production processes and natural resource consumption, while importers benefit from avoiding

domestic environmental losses but forego potential economic benefits from domestic production (Prell et al., 2014; Duan and Jiang, 2017). Consequently, understanding the balance between economic gains and environmental losses from international trade becomes crucial.

International agreements and policies aim to mitigate the impacts of rising anthropogenic GHG emissions on global climate change, making it imperative to track emission performances and identify driving forces, particularly given that international trade has become a major driver of carbon transfers and emissions growth, contributing significantly to increasing global GHG emissions (Peters et al. 2011; Aichele and Felbermayr, 2015; Davis and Caldeira, 2010).

At the same time, climate change poses new challenges for developing economies, given their heavy reliance on commodity exports that are intensive in natural resources constituting a significant source of GHG emissions contributing to climate change. Additionally, developing countries dependent on commodities are profoundly affected by the direct consequences of climate change, such as heatwaves, floods, hurricanes, rising sea levels, and increased sea temperatures, all of which led to crop destruction or reduced yields and diminished fish production (UNCTAD 2019). Furthermore, a considerable proportion of developing nations depend on commodities as a crucial source of foreign exchange, a circumstance that engenders political and economic constraints to rapid GHG removal (Baiman, 2022).

In the context of this challenges faced by developing countries, we encounter the theory of Ecologically Unequal Exchange (EUE), which focuses on how the structure of international trade and global power relations leads to an unequal distribution of environmental problems and development. According to this approach, the most powerful and wealthy countries in the global north have greater access to natural resources and waste absorption capacity from countries in the global south (Givens, Huang, and Jorgenson, 2019). This theory is built upon various critical development perspectives, prominently including the theory of deteriorating terms of trade in developing countries, formulated by Prebisch (1950) and Singer (1975).

From this perspective, which later gave rise to the concept of Economically Unequal Exchange, there exists a dualistic international division of labor between the Core (developed countries or Global North) and the Periphery (developing countries or Global South). Products from the periphery are characterized by their use of natural resources and reliance on unskilled labor, while those from the Core are characterized as capital and knowledge intensive. The secular deterioration of the terms of trade for peripheral countries, as posited by Prebisch (1949), reflects the tendency of primary commodity prices to rise more rapidly than those of manufactured goods during periods of economic expansion, but to fall more sharply during

recessions. This asymmetry in economic cycles results in a long-term trend of declining terms of trade for the periphery, implying that an ever-increasing quantity of exports is needed to acquire the same amount of imported goods (for an empirical analysis of trends in commodity terms-of-trade of developing countries, see Ram, 2004). From an environmental standpoint, this implies that the pace of natural resource extraction by the periphery must intensify to maintain the same flow of export income (Pérez Rincón, 2006).

Several studies focus on carbon emissions embodied in trade between developed and developing countries, providing empirical evidence that the former undertake significant amount of GHG emissions to provide for the products consumed in the global north. In this sense, Jorgenson (2012) shows that for lower income nations, exports sent to higher income countries are related with higher GHG emissions, becoming increasingly ecologically unequal through time. Su and Ang (2014) find that developed countries are generally net importers of embodied carbon emissions, while developing countries are, in general, net exporters. Zhang, Zhu, and Hewings (2017) find evidence on net carbon flows from developing countries (mainly China and India), to developed nations (US and European Union and Japan, mainly). In general, empirical studies on GHG emission flows between periphery and core countries provide support for ecologically unequal exchange theory. Nevertheless, it is important to notice that trade between developing nations has increased significantly, more than doubling between 2004 and 2011 (Meng et al., 2018), leading to a surge in carbon emissions embodied in South-South trade (Kim, Suen, and Lin, 2019; Wang and Yang, 2020; Kim and Tromp, 2021; Yu, Feng, and Hubacek, 2014).

In light of growing trade between developing nations and the rise of South-South trade, the European Union's Carbon Border Adjustment Mechanism (CBAM) introduces an additional layer of complexity to global trade dynamics. CBAM aims to protect European industries by imposing tariffs on imports from countries with less stringent environmental standards. While the mechanism is designed to align trade with the European Union's climate goals, it may inadvertently shift trade patterns toward regions with fewer environmental restrictions, reinforcing global trade imbalances. Such dynamics risk creating additional economic disparities, particularly for developing nations that are already facing challenges in transitioning to greener technologies. These concerns highlight the need for a multilateral approach to climate and trade policies to ensure equitable solutions for all nations (Frankel and Aldy, 2008; Perdana and Vielle, 2022).

Building on the growing body of literature that explores the intersection of trade, environmental impacts, and economic value distribution, we estimate environmental harms,

quantified by GHG emissions, and economic benefits, quantified by value-added (VA), related to Argentina's trade with Brazil, China, European Union (EU) and the United States (US), analyzing its evolution during the 2000-2016 period. We have chosen Argentina because it is a peripheral country specialized in exports based in natural resources, with strong commercial flows with other peripheral countries (Brazil), core countries (EU and US), and with China, that exhibits both core and peripheral characteristics. Furthermore, this type of study has not been carried out so far for Argentina.

The method used to achieve this objective consists of a multi-regional input-output (MRIO) model of environmentally extended input-output matrices (which incorporate satellite accounts of GHG emissions), provided by EORA (<https://worldmrio.com>).

This essay is organized as follows. After this introduction, the second section is dedicated to a review and research progress on the ecologically unequal exchange theory and carbon emissions embodied in trade. Section 3 describes the essay's methodological aspects, presenting the main input-output foundations and the data used. Next, section 4 contains the results, and section 5 the discussions, followed by section 6, with conclusions and policy recommendations.

3.2 Literature review

This essay is closely linked to three related strands of literature: studies that test the theory of ecologically unequal exchange, those that examine the pollution haven hypothesis (PHH), and research that account for the emissions embodied in trade.

3.2.1 Ecologically unequal exchange

The theory of ecologically unequal exchange posits that developed countries (also called core countries, or Global North), rich in economic, technological and military power, obtain larger economic benefits and smaller environmental harms, because of their engagement in unequal trade patterns with less developed countries (also called peripheral countries, developing countries or Global South). Within this analytical framework, there are net transfers of resources (energy and materials) from peripheral to core countries (Dorninger et al., 2021; Prell and Feng, 2016; Jorgenson and Clark, 2009). Furthermore, there are significant differences in how products from different regions are compensated, with resources of less developed regions being compensated lower compared to those products of developed regions. The asymmetry that exists between the physical cost and productive potential of natural resources, on one hand, and its monetary value, on the other, facilitates unequal trade relations wherein core countries obtain undervalued resources produced in peripheral countries. These resources are crucial for building technological infrastructure and fostering economic development. In

exchange, peripheral countries receive direct foreign investment, external credit and high-value-added products and services (Hornborg, 1998; Pérez Rincón, 2006; Dorninger, et al. 2021; Prell and Feng, 2016). Givens, Huang, and Jorgenson (2019) offer a recent review of the extensive literature that theoretically explores the concept of ecologically unequal exchange.

The concept of EUE describes a self-perpetuating cycle in which peripheral countries are compelled to export a higher proportion of embodied resources and labor in exchange for less resource-intensive imports from high-income countries (Althouse et al., 2023). As a consequence of these unequal exchanges, peripheral nations incur greater environmental costs, including higher greenhouse gas (GHG) emissions (Burns, Davis, and Kick, 1997). In contrast, core countries manage to externalize their pollution-intensive production processes while reinvesting the resulting increased revenues in cleaner technologies for domestic productive activities (Timmons Roberts and Parks, 2007). This dynamic leaves peripheral countries facing both escalating environmental degradation and limited access to the material and financial resources necessary for their development (Rice, 2007).

According to the literature on EUE, high-income countries are able to maintain their domestic environmental quality by leveraging their ability to capture a larger share of global purchasing power. With this economic advantage, they exert greater control over global resources, allowing them to use low-income countries as waste sinks and sources of raw materials (Althouse et al., 2023).

Empirical studies have consistently shown that environmental impacts are disproportionately concentrated in peripheral regions (Givens and Huang, 2021). Among these impacts resulting from unequal exchange, Jorgenson (2006) examines deforestation, while Jorgenson (2012) and Prell and Sun (2015) focus on carbon emissions. Shandra et al. (2008) analyze water pollution, and Shandra et al. (2009) investigate biodiversity loss.

The multidimensional resource imbalances in international trade, which reflect ecological injustice, can be effectively captured through various dimensions such as labor time, energy, biodiversity, materials, and GHG emissions. These indicators can be reasonably well estimated using existing data, enabling a detailed mapping of the global social metabolism, its uneven geographic distribution, and the corresponding international ecological inequalities (Althouse et al., 2023).

In a study examining regions based on their relative share of global income, Dorninger et al. (2021) found that all regions classified as non-high-income between 1990 and 2015 acted as net suppliers of raw materials to global production. Additionally, the value-added per ton of exported goods was shown to be eleven times higher in high-income countries compared to

those with the lowest income. The authors quantified ecologically unequal exchange across four biophysical resources embodied in traded goods and services: raw materials, primary energy, land, and labor. Using environmentally extended multi-regional input-output analysis based on the EORA database, they generated consumption-based pressure indicators to capture the displacement effects of international trade.

Regarding the accounting used in the empirical EUE literature to analyze resource flows and environmental damage between core and peripheral regions, Althouse et al. (2023) argue that, all else being equal, increasing offshoring from core to peripheral countries would lead to a rise in EUE and an increase in the global environmental footprint. Conversely, reshoring would result in lower EUE and a reduced global environmental footprint. Similarly, a reduction in the use of environmental inputs and waste through improved environmental efficiency in peripheral countries, keeping everything else constant, would also decrease EUE and the global environmental footprint.

They also highlight that an increase in environmental efficiency in core countries, which helps reduce the use of environmental resources, could paradoxically increase EUE if only net trade outcomes are considered. For instance, all else being equal, improvements in domestic environmental efficiency in high-income countries lead to reduced ecological degradation embodied in exports, thereby increasing the ecological imbalance. Such improvements may appear as an increase in EUE, potentially misinterpreted as a greater displacement of environmental burdens.

In the same reasoning, Duan et al. (2021) point that focusing on net flows limits the capacity to distinguish between the effects of varying levels of efficiency and the impacts of progressive technological changes in the aggregate statistics accounting for embodied material and energy flows.

In this context, Althouse et al. (2023) argue that by analyzing the evolution of gross material flows, it becomes possible to technically differentiate between an increase in efficiency in core countries that reduces the resources embodied in their exports and a greater environmental load displacement toward the periphery. They emphasize that, to interpret changes in international ecological dynamics more accurately, it is essential to distinguish between increased environmental efficiency and heightened environmental load displacement. If a country improves its environmental efficiency by specializing in cleaner sectors, then the resulting increases in ecological imbalances correspond to an actual rise in environmental load displacement, as the country will need to import the more environmentally harmful products it previously produced domestically.

The authors conduct a clustering analysis on GVC insertion across multiple dimensions for 133 countries from 1995 to 2015, identifying three distinct patterns. The first pattern, mainly involving low-income countries, shows poor economic, social, and environmental outcomes due to minimal GVC integration. The second pattern includes developing countries like Argentina, Brazil, and China, with moderate GVC participation and value capture but suffering from above-average local ecological degradation, partly due to a negative external ecological balance. The third pattern, mostly comprising developed countries, shows strong benefits from GVCs through specialization in high-value, low-environmental impact segments, while offshoring environmental costs to peripheral nations.

While the EUE theory focuses on the identification and quantification of asymmetries in the biophysical flows embedded in global commerce, the concept of ecological debt, developed primarily within Latin American political ecology, brings with it a normative and historical focus. The concept of ecological debt relates to the fact that industrialized countries owe the Global South for centuries of environmental degradation, resource exploitation, and unequal consumption of the global ecological sinks such as the atmosphere or ocean (Martínez-Alier, 2002; Warlenius et al., 2015). The concept goes beyond physical indicators or the balance of trade to encompass moral and political calls for ecological justice, reparations, and differentiated responsibilities in issues of climate change and global sustainability. Ecological debt, in this sense, politicizes and reinforces the empirical evidence provided by EUE analysis in terms of historical responsibility and compensation. While EUE seeks to trace resource flows and environmental pressures (e.g., embodied emissions or material footprints), ecological debt frames these asymmetries as unjust and calls for structural correction, not only through recognition of differentiated responsibilities, but also through compensatory mechanisms and a fundamental rethinking of global trade relations to ensure ecological and distributive justice (Dillon, 2000).

3.2.2 Pollution haven hypothesis and emissions embodied in trade accounting

Recently, several studies differentiate between emissions generated within a country's borders and emissions resulting from that country's consumption activities, which are related to two different approaches for calculating GHG emissions. On one hand, the production-based accounting method consists of adding up all the emissions that are produced within a country's borders. However, this approach cannot take account for the fact that countries with strict emission controls, regulations or taxes might experience less environmental impacts, by the displacement of more polluting productive sectors to other parts of the world with more lax

environmental regulations. In this situation, the goods and services produced in the less restrictive countries might then be exported to the countries with tighter environmental regulations, resulting in a situation where decreasing emissions in one country are offset by increasing emissions in other country. This phenomenon has been called “pollution haven hypothesis” (Copeland and Taylor, 2004), being further enabled by the fragmentation of production facilitated by globalization, which has divided production processes into multiple stages spread across various regions along the GVC, and it has been object of strong debate among numerous studies in the last decades.

The replacement of production processes of carbon-intensive goods and services in response to environmental policies and production costs has been termed as carbon leakages, and they result in the reallocation of GHG emissions, deriving in a situation where the decrease in one country’s emissions is directly related to an increase in another (Franzen and Mader, 2018). In this sense, the consumption-based approach considers these issues, by subtracting from countries all emissions that are contained in exported products, and including the embodied emissions in the inventories of the importing countries (Peters et al., 2011), being useful to establish the carbon footprints of nations, complementing the territorial allocation of emissions as reported by the production-based accounting (Lenzen et al. 2012). Hence, the consumption-based approach can unveil situations in which high-emission countries produce carbon-intensive goods and services for the consumption of countries that would be considered as low emission, under the production-based framework (Franzen and Mader, 2018), which have led to discussions on the assignment of responsibilities for emissions between countries in the international policy arena, in a context where consumption and production are increasingly spatially separated across the world.

Over the past few years, several studies have applied the consumption-based accounting framework by using the MRIO model, highlighting the fact that a significant amount of carbon and energy footprints are embodied in international trade.

Arto and Dietzenbacher (2014) investigate the drivers of the growth in global GHG emissions from a multiregional perspective decomposing the change in global GHG emissions into the changes of consumption per capita, product mix of the consumption bundles, population size, technology, and trade structure, for 40 countries in the period 1995-2008. Xu and Dietzenbacher (2014) quantify the driving forces behind the growth of carbon dioxide emissions embodied in trade (EET), using a MRIO model to analyze drivers of EET changes in 40 countries, finding that in many developed countries, the growth of emissions embodied in

imports is significantly higher than the growth of emissions embodied in exports, shifting towards importing a larger share of products from emerging economies.

Peters et al. (2011) developed a trade-linked global database for CO₂ emissions, in order to quantify the growth in emission transfers via international trade, finding that most developed countries have increased their consumption-based emissions faster than their territorial emissions, and net emission transfers via international trade from developing to developed countries increased over the Kyoto Protocol emission reductions target, during 1990-2008. In this sense, they point out that international trade is a significant factor in explaining the change in emissions in many countries, both from a production and consumption perspective.

In addition to these studies that evaluate the pollution haven hypothesis, in recent years several studies have incorporated different measures to incorporate the economic dimension in the discussion about the EET, analyzing the degree of environmental losses relative to the economic gains that countries obtain from export production. In this sense, Prell et al. (2014) study the distributions of global shares of VA and pollutants for all products consumed in the United States, by creating a ratio that consists on the share of global pollutants (sulfur dioxide) emissions divided by each country's global share of VA from all production sectors along GVC for goods consumed in the United States.

Regarding the literature that investigates the balance of emissions embodied in trade, Antweiler (1996) and Straumann (2004) pointed out that this measure, captured by the difference between emissions embodied in exports and imports, is subject to trade imbalances, resulting in an unsuitable tool for long run analysis, as long as these imbalances may be reduced or even reversed over time. Instead, Antweiler (1996) proposed the pollution terms of trade (PTT) indicator, which consists on the ratio of the pollution directly generated per unit of exports and the pollution intensity of imports for one country, providing a measure of the relative intensity of pollution, hence being independent of balance of trade effect over years.

However, the PTT indicator as proposed by Antweiler (1996) has some limitations, arising from the increasing production fragmentation facilitated by GVC. On one hand, the double-counting problem in international trade implies that conventional trade data account for the gross value of goods every time they cross a border, overstating the domestic VA of exports (Johnson and Noguera 2012). On the other hand, global production networks involving multiple countries entails that intermediate product together with their embodied GHG emissions, may reach their ultimate destination through indirect pathways.

To account for the environmental consequences of global production chains, Grether and Mathys (2013) proposed a revised form of the PTT indicator. This indicator consists on the

ratio of the average pollution content (representing environmental costs) per dollar of VA (representing economic gains) in exports, divided by the average pollution content per VA in imports. In this sense, an increase in this indicator suggests an increase in the environmental costs to obtain the same number of economic benefits.

In recent years, there has been an increasing number of empirical studies that utilize similar methodologies to examine the environmental costs and economic benefits associated with international trade among various countries. Duan and Yan (2019) conducted an analysis on the evolution and driving forces behind pollution intensity in China's VA exports and imports. They found that China suffered larger environment losses per unit of VA through exports than almost all of its trading partners. However, the environmental losses suffered by China declined quicker than that of its bilateral trading partners over time. Regarding the pollution haven hypothesis, they found that developed economies have outsourced dirty intermediate production stages to emerging economies via trade in intermediate goods, leading to greater environmental losses in the latter. Furthermore, the researchers employed a SDA to assess the temporal changes in pollution intensity, allowing them to attribute its changes to five contributing factors: emission efficiency, input structure, trade in intermediate goods, composition effect of final demand (to capture consumer preference effect), and trade in final goods.

Duan and Jiang (2017) apply the PTT indicator proposed by Grether and Mathys (2013) to investigate China's environmental costs (measured by GHG emissions) against economic gains from international trade, distinguishing its trade partners by income level, for the 1995-2009 period. They perform an SDA, attributing the temporal changes in PTT indicator into four effects: technology effect, composition effect of final demand, final goods trade effect, and intermediate goods trade effect. Their empirical results pointed that substantial differences exist between China's PTTs with different trade partners in terms of temporal changes and underlying drivers.

Recent advances in material-flow accounting (MFA) have introduced complementary indicators that provide evidence on resource and emission transfers in ways a value-based metric such as the PTT cannot. On one hand, the physical trade balance (PTB) indicator consists on imports minus exports expressed in tonnes of raw-material equivalents (Weisz et al., 2006). On the other, the material footprint (MF) indicator allocates all raw-material equivalents embodied in a country's final consumption, including the upstream extraction that occurs abroad (Wiedmann et al., 2015). When PTB and MF are combined with embodied-carbon emissions, one can derive intensity ratios—often called “material-footprint-adjusted carbon”—

that relate the net physical flow of resources to the associated direct and upstream CO₂ emissions, thereby revealing how environmentally intensive processing is displaced along global value chains.

Pollution terms of trade, physical trade balance and material footprint pursue a similar question—whether a nation exchanges “cleaner” products for “dirtier” ones—but they rest on different informational bases. PTT is value-based: it compares the average pollution per dollar of domestic value-added in exports with that of imports and is therefore indifferent to the volume of trade. PTB and MF are based in volumes: PTB shows whether a country is a net physical exporter or importer of resources, while MF measures the total raw-material pressure embedded in its consumption, regardless of where extraction occurs. The divergence can be substantial: a country could have a favorable PTT (exports are less pollution-intensive per unit of economic value than its imports) yet still register a large positive PTB (and high MF-adjusted carbon intensity) if it exports low-value, high-tonnage primary goods and imports high-value manufactures; the reverse is equally possible. In a study conducted by Wang and Yang (2020), the authors examined the temporal changes and driving forces behind carbon emissions in China-India trade from 2000 to 2015. They analyzed the carbon and trade balances between these two countries, utilizing a modified version of the PTT indicator. Additionally, they performed an SDA to estimate the contribution of six different driving factors to the changes in carbon emissions embodied in trade. The findings of their research indicated that China acted as a net exporter in both VA and carbon, suggesting an increase in environmental costs alongside economic gains. Further analysis revealed that the primary factor driving the rise in embodied carbon emissions from China to India was final demand, while the carbon intensity coefficient played a significant role in curbing these emissions.

Kim and Tromp (2021) conducted a study with a similar focus, examining CO₂ emissions and VA embodied in China-Brazil trade from 2000 to 2014. The authors employed an SDA approach, investigating the same six driving factors as Wang and Yang (2020) for emission change. Their findings revealed significant increases in both CO₂ emissions and VA embodied in exports for China and Brazil throughout the studied period, strengthening China's position as a net exporter of CO₂ emissions and VA to Brazil. The SDA analysis highlighted that changing consumption patterns in Brazil and China, along with the evolving structure of intermediate exports from China to Brazil, played crucial roles in driving the rise of embodied CO₂ emissions.

Duan et al. (2021) employ an international input-output model to calculate the emission intensity in bilateral value-added trade. They decompose emission intensity into a composition

effect and a technical effect using SDA, and test the pollution haven hypothesis through panel data regressions. The authors argue that studies examining emissions embodied in trade appropriately account for trade in intermediate goods and allocate emissions to final consumers. However, they point out that these studies (Peters et al., 2011; Duan and Jiang, 2017; Duan and Yan, 2019; Wang and Yang, 2020) often assess the PHH by calculating net flows (emissions embodied in exports minus emissions embodied in imports). Typically, these studies find that low-income countries are net exporters of pollution while high-income countries are net importers, interpreting this as evidence supporting the PHH.

Nevertheless, Duan et al. (2021) argue that these results are a combined effect of trade composition and production technology, whereas the PHH focuses exclusively on trade composition. Given that low-income countries often lag behind high-income countries in green technology adoption (Duan and Jiang, 2017; Zhang et al., 2019; Duan et al., 2021), they may still emerge as net pollution exporters even if they specialize in producing cleaner goods. Therefore, it is crucial to disentangle the effects of trade composition and production technology to properly analyze the PHH.

Although EUE has been an effective empirical framework for understanding the physical imbalances in global trade, there have been theoretical issues of concern raised by several scholars. For Ajl (2023), much of EUE literature remains highly descriptive lacking a theory of imperialism, value transfers, and global trade, arguing that while EUE has succeeded in drawing attention to the uneven division of environmental harm between core and peripheral regions, it tends to downplay the inherent dynamics of capital accumulation and the power relations that structure global exchange. Specifically, Ajl (2023) contends that EUE approaches habitually conflate material flows and exploitation, overlooking the indispensable role of value theory for thinking through exploitation under capitalist relations. This can generate analytical paradoxes, such as interpreting unequal tonnage exchanges as inherently exploitative and environmentally degrading with no regard for the broader economic and ecological context in which these exchanges occur.

Similarly, Foster and Holleman (2014) highlight the challenge of establishing a coherent theoretical and empirical framework for EUE, given that most research relies on proxies like ecological footprint analysis, which even though helpful, does not tend to witness the material flows and their use-value transfers. They point to the fact that previous approaches have relied on data where the actually physical material of the goods is unknown and quantitative data is based prices instead of goods.

The PHH has also been criticized, as empirical studies offer contradictory evidence regarding this proposition (Eskeland and Harrison 2003). Critics argue that factors such as market size, labor costs, and political stability often weigh more heavily in investment decisions than environmental standards alone (Cole 2004). In this sense, Tobey (1990) points that, although environmental compliance costs may seem large in absolute terms, they are often marginal as a proportion of a firm's total costs.

In sum, while the EUE, PHH, and consumption-based accounting have all assisted in revealing how international trade can recreate ecological and economic asymmetries, they also possess theoretical and empirical limitations. EUE has been able to detail material imbalances in the core and peripheral countries but is generally deficient in having a precise theoretical framework when it comes to value transfers and the structural forces behind global trade. Likewise, the PHH is empirically contentious with evidence suggesting that environmental protection is merely one among numerous determinants of investment. Despite such constraints, such perceptions continue to be useful in empirically identifying patterns of ecological imbalance. On this basis, this paper provides empirical findings regarding the environmental asymmetries in world trade and formulates policy implications towards more balanced and sustainable trade relationships.

3.3 Methodology and data

3.3.1 Extended multi-regional input-output analysis (MRIO)

The MRIO model describes the interdependence between sectors of different countries and is commonly used to analyze GHG emissions embodied in international trade (Wiebe et al. 2012). Based on this model, this study estimates embodied GHG emissions, measured in CO₂ equivalent emissions, in both exports and imports for Argentina. Consequently, throughout the analysis, they will be denoted as CO₂ or GHG emissions. Additionally, this study assesses the VA embodied in exports between Argentina, on one side, and Brazil, China, the European Union, the United States, and an aggregate of all other countries named as “Rest of the World” (RoW), on the other. Starting from the basic equation of the input-output model with a matrix of technical coefficients A , a final demand vector f , and a sectoral output vector x , we have:

$$x = Ax + f \quad (25)$$

Considering that there are m countries in the model, we can express Equation (22) in matrix form as follows:

$$\begin{pmatrix} x^1 \\ x^2 \\ \vdots \\ x^m \end{pmatrix} = \begin{pmatrix} A^{11} & A^{12} & \dots & A^{1m} \\ A^{21} & A^{22} & \dots & A^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ A^{m1} & A^{m2} & \dots & A^{mm} \end{pmatrix} \begin{pmatrix} x^1 \\ x^2 \\ \vdots \\ x^m \end{pmatrix} + \begin{pmatrix} \sum_{j=1}^m f^{1j} \\ \sum_{j=1}^m f^{2j} \\ \vdots \\ \sum_{j=1}^m f^{mj} \end{pmatrix} \quad (26)$$

$$A^{ij} = x^{ij}/x^i \quad (27)$$

Where x^i represents the total output of country i , and x^{ij} is the vector of sectorial production in country i , that satisfies directly and indirectly the demand in country j . A^{ij} is the intercountry intermediate coefficient matrix, indicating the inputs of intermediate products from country i to country j needed to produce one unit of output by country j . f^{ij} represents the final demand of country j from country i , and $y^i = \sum_{j=1}^m f^{ij}$ is the final demand of country i . After some rearrangements, equation (26) can be expressed as follows:

$$\begin{pmatrix} x^1 \\ x^2 \\ \vdots \\ x^m \end{pmatrix} = \begin{pmatrix} I - A^{11} & I - A^{12} & \dots & I - A^{1m} \\ I - A^{21} & I - A^{22} & \dots & I - A^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ I - A^{m1} & I - A^{m2} & \dots & I - A^{mm} \end{pmatrix}^{-1} \begin{pmatrix} \sum_{j=1}^m f^{1j} \\ \sum_{j=1}^m f^{2j} \\ \vdots \\ \sum_{j=1}^m f^{mj} \end{pmatrix}$$

$$\begin{pmatrix} x^1 \\ x^2 \\ \vdots \\ x^m \end{pmatrix} = \begin{pmatrix} L^{11} & L^{12} & \dots & L^{1m} \\ L^{21} & L^{22} & \dots & L^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ L^{m1} & L^{m2} & \dots & L^{mm} \end{pmatrix} \begin{pmatrix} \sum_{j=1}^m f^{1j} \\ \sum_{j=1}^m f^{2j} \\ \vdots \\ \sum_{j=1}^m f^{mj} \end{pmatrix} \quad (28)$$

where I is an identity matrix and $L = (I - A)^{-1}$ is the Leontief inverse matrix in which L^{ij} is country i 's total (direct and indirect) output that is required for the final demand of country j . This paper focuses on CO₂ emissions and value-added flows embodied in Argentinian trade with Brazil, China, European Union, and United States, so countries other than these are considered as one country and labelled as RoW. Argentina, Brazil, China, European Union, United States and RoW are labelled as A, B, C, EU, US and R, respectively. Therefore, Equation (28) can be rewritten as follow:

$$\begin{pmatrix} X^A \\ X^B \\ X^C \\ X^{EU} \\ X^{US} \\ X^R \end{pmatrix} = \begin{pmatrix} L^{AA} & L^{AB} & L^{AC} & L^{AEU} & L^{AUS} & L^{AR} \\ L^{BA} & L^{BB} & L^{BC} & L^{BEU} & L^{BUS} & L^{BR} \\ L^{CA} & L^{CB} & L^{CC} & L^{CEU} & L^{CUS} & L^{CR} \\ L^{EUA} & L^{EUB} & L^{EUC} & L^{EUEU} & L^{EUUS} & L^{EUR} \\ L^{USA} & L^{USB} & L^{USC} & L^{USEU} & L^{USUS} & L^{USR} \\ L^{RA} & L^{RB} & L^{RC} & L^{REU} & L^{RUS} & L^{RR} \end{pmatrix} \begin{pmatrix} F^{AA} + F^{AB} + F^{AC} + F^{AEU} + F^{AUS} + F^{AR} \\ F^{BA} + F^{BB} + F^{BC} + F^{BEU} + F^{BUS} + F^{BR} \\ F^{CA} + F^{CB} + F^{CC} + F^{CEU} + F^{CUS} + F^{CR} \\ F^{EUA} + F^{EUB} + F^{EUC} + F^{EUEU} + F^{EUUS} + F^{EUR} \\ F^{USA} + F^{USB} + F^{USC} + F^{USEU} + F^{USUS} + F^{USR} \\ F^{RA} + F^{RB} + F^{RC} + F^{REU} + F^{RUS} + F^{RR} \end{pmatrix} \quad (29)$$

The exports of each country are driven by foreign final demand and domestic supply conditions. Therefore, in order to estimate Argentina's exports to Brazil, for example, all F^{**} are 0, except for F^{*B} , and all L^{**} are 0, except L^{A*} (Wang and Yang, 2020). In this sense, Argentina's exports to Brazil, EX^{AB} , and Brazil's exports to Argentina, EX^{BA} , are calculated as shown in equations (30) and (31):

$$EX^{AB} = \begin{bmatrix} L^{AA} & L^{AB} & L^{AC} & L^{AEU} & L^{AUS} & L^{AR} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 + F^{AB} + 0 + 0 + 0 + 0 \\ 0 + F^{BB} + 0 + 0 + 0 + 0 \\ 0 + F^{CB} + 0 + 0 + 0 + 0 \\ 0 + F^{EUB} + 0 + 0 + 0 + 0 \\ 0 + F^{USB} + 0 + 0 + 0 + 0 \\ 0 + F^{RB} + 0 + 0 + 0 + 0 \end{bmatrix} \quad (30)$$

$$= L^{AA}F^{AB} + L^{AB}F^{BB} + L^{AC}F^{CB} + L^{AEU}F^{EUB} + L^{AUS}F^{USB} + L^{AR}F^{RB}$$

$$EX^{BA} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ L^{BA} & L^{BB} & L^{BC} & L^{BEU} & L^{BUS} & L^{BR} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} F^{AA} + 0 + 0 + 0 + 0 + 0 \\ F^{BA} + 0 + 0 + 0 + 0 + 0 \\ F^{CA} + 0 + 0 + 0 + 0 + 0 \\ F^{EUA} + 0 + 0 + 0 + 0 + 0 \\ F^{USA} + 0 + 0 + 0 + 0 + 0 \\ F^{RA} + 0 + 0 + 0 + 0 + 0 \end{bmatrix} \quad (31)$$

$$= L^{BA}F^{AA} + L^{BB}F^{BA} + L^{BC}F^{CA} + L^{BEU}F^{EUA} + L^{BUS}F^{USA} + L^{BR}F^{RA}$$

Taking equation (30) as an example, the first part, $L^{AA}F^{AB}$, is Argentina's direct exports of final products to Brazil; the second part, $L^{AB}F^{BB}$, is Argentina's direct exports of

intermediate products to Brazil that are eventually consumed in the same country; the third part, $L^{AC}F^{CB}$, is Argentina's indirect exports of intermediate products to Brazil, which are first exported to China and then ultimately exported to Brazil; the fourth part, $L^{AEU}F^{EUB}$, is Argentina's indirect exports of intermediate products to Brazil, which are first exported to European Union and then ultimately exported to Brazil through these countries' trade, the fifth part, $L^{AUS}F^{USB}$, is Argentina's indirect exports of intermediate products to Brazil, which are first exported to United States and then exported to Brazil; and the last part, $L^{AR}F^{RB}$, is Argentina's indirect exports of intermediate products to Brazil, which are first exported to other countries and then ultimately exported to Brazil. In a similar way, EX^{BA} measures both final and intermediate products exported from Brazil to Argentina.

Considering emission intensity δ^m , which represents each country's GHG sectoral emissions per unit of output, we can combine this vector with equations (30) and (31), in order to calculate CO₂ emissions embodied in Argentina's exports to Brazil (EC^{AB}), and Brazil's exports to Argentina (EC^{BA}), in the following way:

$$\begin{aligned}
 EC^{AB} = & \\
 & [\delta^A \quad 0 \quad 0 \quad 0 \quad 0 \quad 0] \begin{bmatrix} L^{AA} & L^{AB} & L^{AC} & L^{AEU} & L^{AUS} & L^{AR} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 + F^{AB} + 0 + 0 + 0 + 0 \\ 0 + F^{BB} + 0 + 0 + 0 + 0 \\ 0 + F^{CB} + 0 + 0 + 0 + 0 \\ 0 + F^{EUB} + 0 + 0 + 0 + 0 \\ 0 + F^{USB} + 0 + 0 + 0 + 0 \\ 0 + F^{RB} + 0 + 0 + 0 + 0 \end{bmatrix} \\
 (32) \quad & = \delta^A L^{AA} F^{AB} + \delta^A L^{AB} F^{BB} + \delta^A L^{AC} F^{CB} + \delta^A L^{AEU} F^{EUB} + \delta^A L^{AUS} F^{USB} + \delta^A L^{AR} F^{RB}
 \end{aligned}$$

In equation (32), the first term, $\delta^A L^{AA} F^{AB}$, is embodied CO₂ emissions in Argentina's direct exports of final products to Brazil; the second term, $\delta^A L^{AB} F^{BB}$, represents embodied CO₂ emissions in Argentina's exports of intermediate products to Brazil; the following terms represent embodied CO₂ emissions in Argentina's indirect exports of intermediate products to Brazil, which are first exported to other countries (China, European Union, United States and the Rest of the World) and then ultimately exported to Brazil. In order to calculate Brazil's embodied CO₂ emissions in exports to Argentina, we proceed the same way, multiplying the CO₂ emission coefficient for Brazilian sectors, with equation (31).

In the same way, we can calculate the value-added flows embodied in Argentina's exports to Brazil, by multiplying the value-added coefficients for Argentinian economic sectors (γ^A), with equation (30). In the same way we can calculate value-added flows for other

countries, using γ^M , a vector representing each country's sectoral VA per unit of output. This study uses value-added flows in trade, as opposed to gross trade, to avoid the double counting problem in international trade (Johnson and Noguera, 2012). Value-added coefficients represent each country's VA per unit of output. In this order, Argentina's value-added exports to Brazil (EV^{AB}) are calculated as:

$$\begin{aligned}
 EV^{AB} = & \\
 & [\gamma^A \quad 0 \quad 0 \quad 0 \quad 0 \quad 0] \begin{bmatrix} L^{AA} & L^{AB} & L^{AC} & L^{AEU} & L^{AUS} & L^{AR} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 + F^{AB} + 0 + 0 + 0 + 0 \\ 0 + F^{BB} + 0 + 0 + 0 + 0 \\ 0 + F^{CB} + 0 + 0 + 0 + 0 \\ 0 + F^{EUB} + 0 + 0 + 0 + 0 \\ 0 + F^{USB} + 0 + 0 + 0 + 0 \\ 0 + F^{RB} + 0 + 0 + 0 + 0 \end{bmatrix} \\
 (33) \quad & = \gamma^A L^{AA} F^{AB} + \gamma^A L^{AB} F^{BB} + \gamma^A L^{AC} F^{CB} + \gamma^A L^{AEU} F^{EUB} + \gamma^A L^{AUS} F^{USB} + \gamma^A L^{AR} F^{RB}
 \end{aligned}$$

In equation (33), the first term, $\gamma^A L^{AA} F^{AB}$, is valued added embodied in Argentina's direct exports of final products to Brazil; the second term, $\gamma^A L^{AB} F^{BB}$, represents valued added embodied in Argentina's exports of intermediate products to Brazil; the following terms represent valued added embodied in Argentina's exports of intermediate products to Brazil, which are first exported to other countries (China, European Union, United States and the Rest of the World) and then ultimately exported to Brazil. These same calculations will be conducted for exports to China, the EU, the US, and RoW, as well as for imports from these countries or regions. Additionally, we will extend the analysis to differentiate between the Global North and Global South, using the World Bank income classification to categorize countries.

With embodied CO₂ emissions and value-added flows in Argentina's trade with its different trading partners, we can obtain net embodied CO₂ emissions exports (NC) and net value-added exports (NVA), following Wang and Yang (2020).

$$NC^{AB} = EC^{AB} - EC^{BA} \quad (34)$$

$$NV^{AB} = EV^{AB} - EV^{BA} \quad (35)$$

The NC and NVA indicators represent the costs and benefits of Argentina-Brazil trade from environmental and economic perspectives. In this order, there are four possible outcomes from Equations (34) and (35). If $NC^{AB} > 0$ and $NV^{AB} > 0$, Argentina has an emissions surplus

and value-added surplus with Brazil, incurring environmental costs but gaining economic benefits. If $NC^{AB} > 0$ and $NV^{AB} < 0$, Argentina has an emissions surplus and value-added deficit with Brazil, incurring in both environmental and economic costs. On the opposite side, if $NC^{AB} < 0$ and $NV^{AB} > 0$, then Argentina has an emissions deficit and value-added surplus with Brazil, gaining both environmental and economic benefits. Finally, if $NC^{AB} < 0$ and $NV^{AB} < 0$, Argentina has an emissions deficit and value-added deficit with Brazil, gaining environmental benefits but incurring economic costs. The same applies to the values of NC and NV with the other trading partners of Argentina.

Building on the issues raised by Althouse et al. (2023) regarding the limitations related to the use of net flows and the importance of analyzing the evolution of gross material flows, we extend our analysis of emissions embodied in Argentina's exports and imports with its trading partners to include other dimensions related to unequal exchange. Specifically, we incorporate total cropland area (hectares), water (mm^3/year), and raw material⁸ (tons) footprints of exports and imports. This approach broadens the scope by accounting for multiple resource imbalances and the environmental load displacement associated with trade (Dorninger et al., 2021).

To calculate these footprints, we follow the same procedure used for GHG emissions and Value-added. Specifically, we pre-multiply a vector containing the coefficients for water, raw materials, and cropland area per unit of gross output by the Leontief inverse and the final demand matrix. In this way, we adopt the multi-resource physical trade balance approach, as it captures the absolute physical imbalances central to ecologically unequal exchange.

3.3.2 Data source

The world input-output tables used for this empirical study are based on data from the EORA database (Lenzen et al. 2013). This database has global multi-regional input-output tables for 189 countries (including Argentina) with a division of 26 sectors. This paper aggregates these sectors into seven categories, following Wang and Yang (2020), with details in table 25 in appendix F. Satellite accounts include information, among others, on direct environmental pressures (including CO₂ emissions) and socio-economic accounts (including gross VA), with data available from year 1990 to 2016, on an annual basis. For these reasons, this paper uses this database, which is frequently used for this kind of empiric studies (Lan et

⁸ The raw material footprint indicator will only be calculated up to 2008, as the EORA Database provides updated data only until that year. Water and cropland area, however, are updated through 2016, in line with the GHG emissions data.

al. 2016; Duan and Yan 2019; Wang and Yang 2020; Kim and Tromp 2021, Dorninger et al. 2021, among others).

Additionally, the construction of input-output tables at constant prices is a necessary step prior to any type of analysis, to eliminate the price impact over time. In this order, this paper converts the data from EORA, which is expressed in current US dollars, into constant 2010 US dollars, by using the World Bank's GDP deflator (Wang and Yang, 2020).

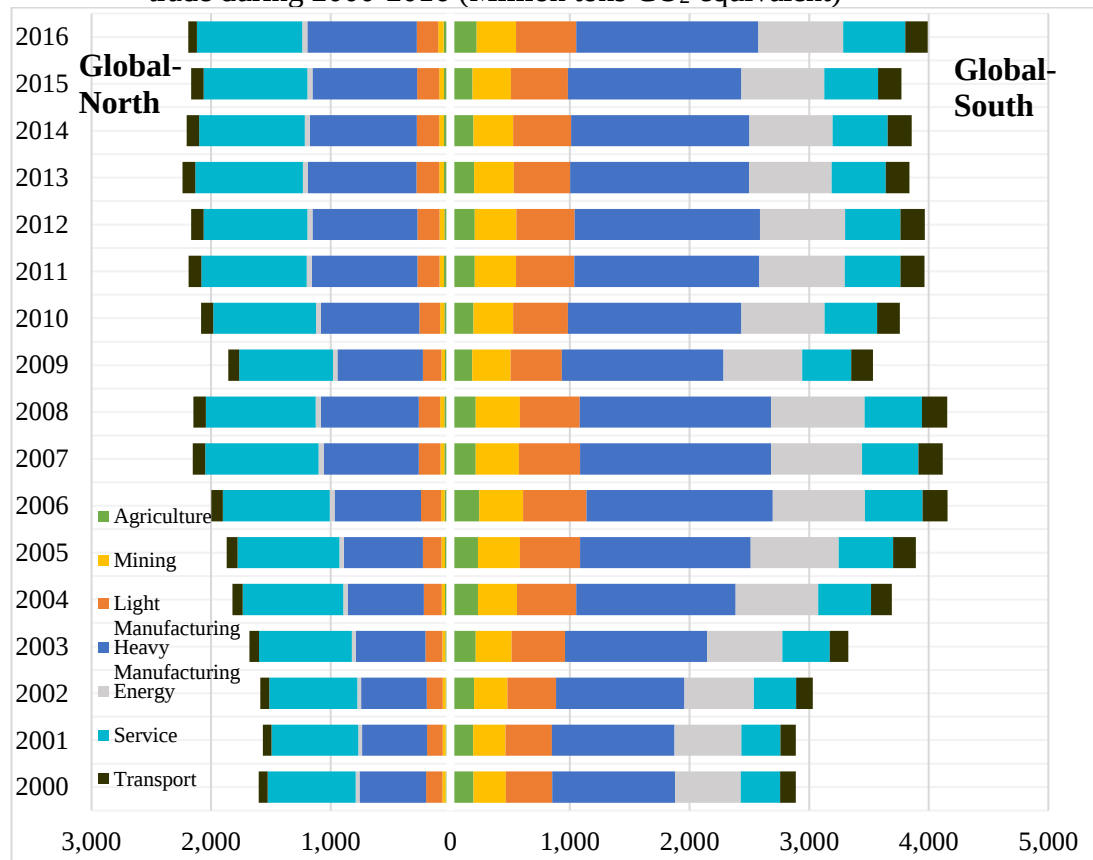
Finally, the data used for GHG emissions in EORA comes from the PRIMAP-HIST database. This database aligns with the categories established by the Intergovernmental Panel on Climate Change (IPCC). It is important to note that PRIMAP-HIST does not include emissions from changes in land use, due to the significant fluctuations in these emissions between periods, which would lead to abrupt changes in the time series (Gütschow et al. 2016).

3.4 Results

In this section, we will analyze the emissions, value added, and other material resources embodied in Argentina's exports and imports with different trading partners. However, before delving into this analysis, Figure 6 presents the results of emissions and VA embodied in bilateral trade between the Global North and South, using the World Bank income classification to categorize countries⁹. The globalization-driven shift of production toward emerging markets has led to an increase in emissions embodied in imports from developing countries to advanced economies (Peters et al., 2011; Xu and Dietzenbacher, 2014; Riccio et al., 2024). As production relocates to countries with less stringent environmental regulations, advanced countries benefit from lower domestic emissions, while developing nations bear the environmental costs of increased resource extraction and energy use. This transfer of emissions underscores the environmental challenges posed by globalized trade.

⁹ Global North countries: Canada, United States, Germany, Austria, Belgium, Denmark, Spain, Finland, France, Ireland, Iceland, Italy, Luxembourg, Norway, Netherlands, Portugal, United Kingdom, Sweden, Switzerland, Slovenia, Estonia, Latvia, Lithuania, Czech Republic, Slovakia, Poland, Hungary, Australia, New Zealand, Japan, South Korea, Taiwan, Israel.

Figure 6: Sectoral structure of embodied GHG exports in Global-South and North bilateral trade during 2000-2016 (Million tons CO₂ equivalent)

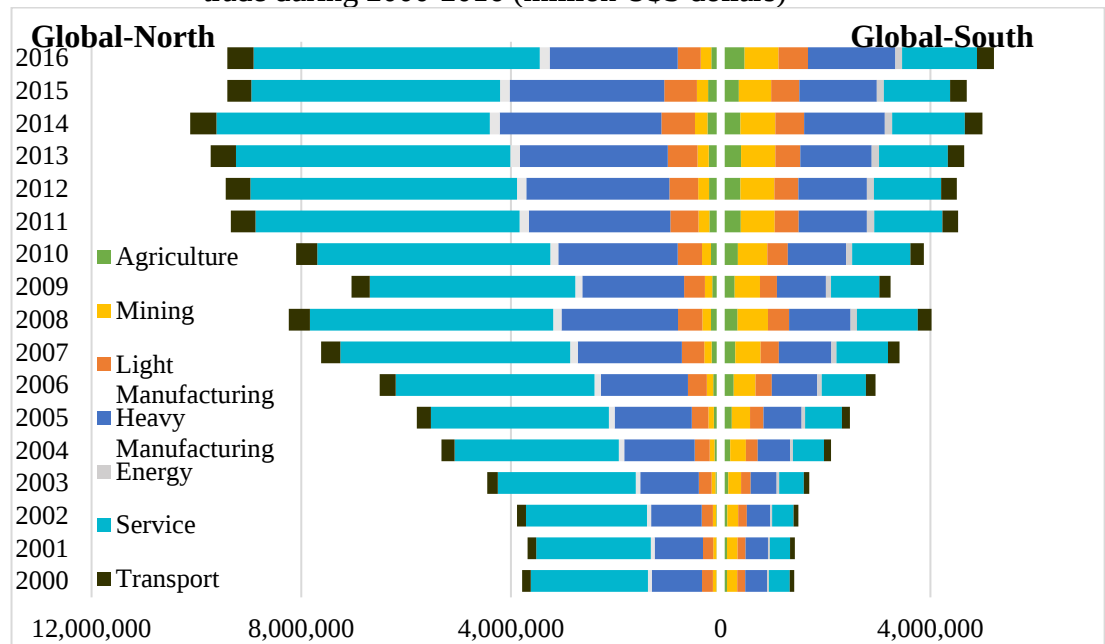


Source: Own elaboration from EORA database

Figure 6 shows that emissions embodied in exports from the Global South are approximately twice those from the Global North. This discrepancy is particularly significant when considering the population sizes: Global South is home to around 6.5 billion people, while the Global North has a population of about 1.2 billion (World Bank).

Considering these population differences, the Global North's lower export-related emissions further underline the inequity in global carbon distribution. Despite having much larger carbon footprints per capita in domestic consumption, the Global North manages to externalize a significant portion of emissions to the Global South, amplifying the unequal environmental burden shared between regions.

Figure 7: Sectoral structure of embodied VA exports in Global-North and South bilateral trade during 2000-2016 (million U\$S dollars)



Source: Own elaboration from EORA database

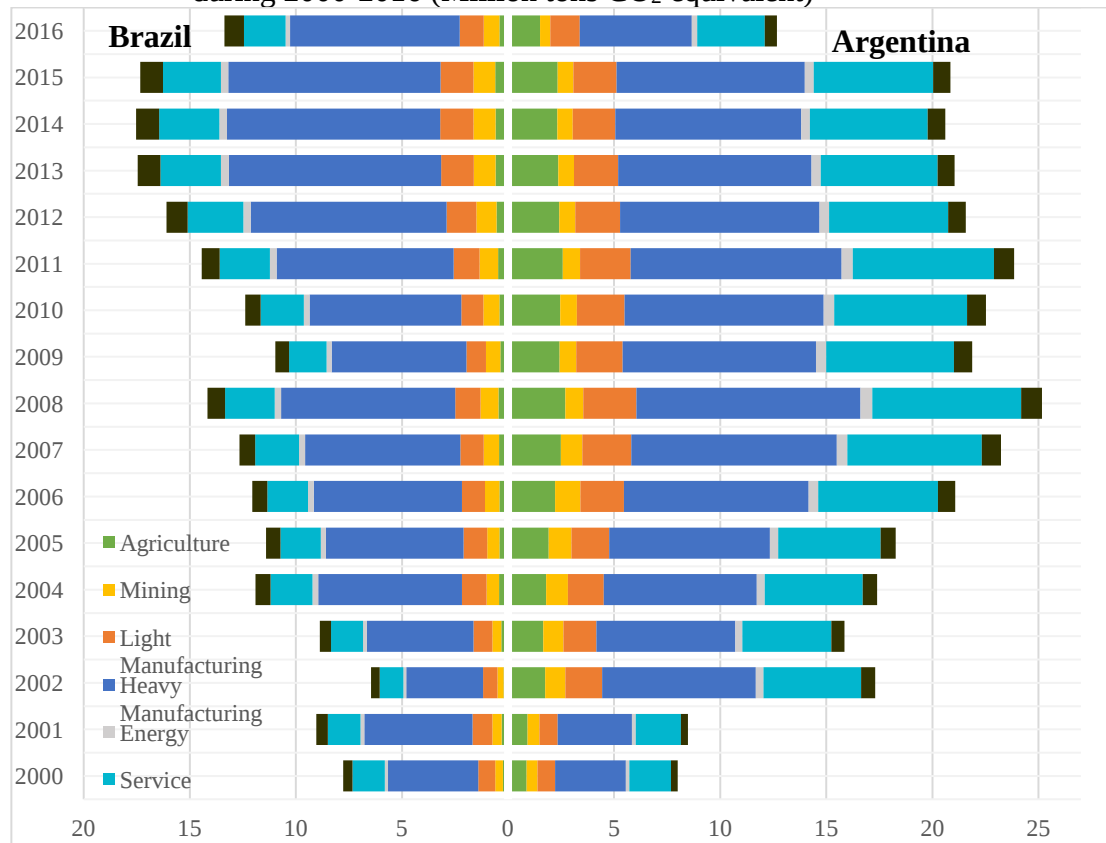
When analyzing the value-added (VA) embodied in bilateral exports between the Global North and Global South, it becomes clear that the former receives roughly double the volume of VA for its exports compared to the Global South. Although the gap has narrowed over time—declining from 2.7 times greater VA in the Global North in 2000 to 1.8 times greater in 2016—the data still align with the theory of EUE (Prell et al., 2014; Dorninger et al., 2021; Althouse et al., 2023).

3.4.1 Embodied emissions and VA in Argentina-Brazil bilateral trade

According to World Integrated Trade Solution data (WITS), in 2021, Brazil was Argentina's main export destination, accounting for 15% of its share, significantly ahead of China, which held 8%. Similarly, Brazil ranked second as Argentina's import origin, with a 19.6% share, slightly behind China, which accounted for 21.4%. Based on these figures, Brazil can be considered Argentina's primary trading partner, as it consistently ranked as the top destination for both exports and imports in the early 2000s, prior to China's increasing penetration in Latin American markets, and by year 2021 it was its main export destination. Argentina and Brazil, alongside Uruguay and Paraguay, are members of the Southern Common Market (Mercosur), a South American free trade area with significant trade volumes.

Appendix G, exhibits figures related to Argentina's exports and imports based on their technological intensity, following Lall's (2000) classification, with data sourced from Comtrade. It is important to note that this classification excludes services and does not encompass all traded goods, but rather provides an approximation to identify the type of goods exchanged between Argentina and its trade partners. Notably, there is significant trade in medium-technology manufactures, particularly due to the exchange of vehicles and capital goods, sectors that have been notably stimulated by MERCOSUR. To a lesser extent, the trade in resource-based manufactures, linked to raw materials and intermediate goods, is also noteworthy, both in exports and imports.

Figure 8: Sectoral structure of embodied GHG exports in Argentina and Brazil bilateral trade during 2000-2016 (Million tons CO₂ equivalent)



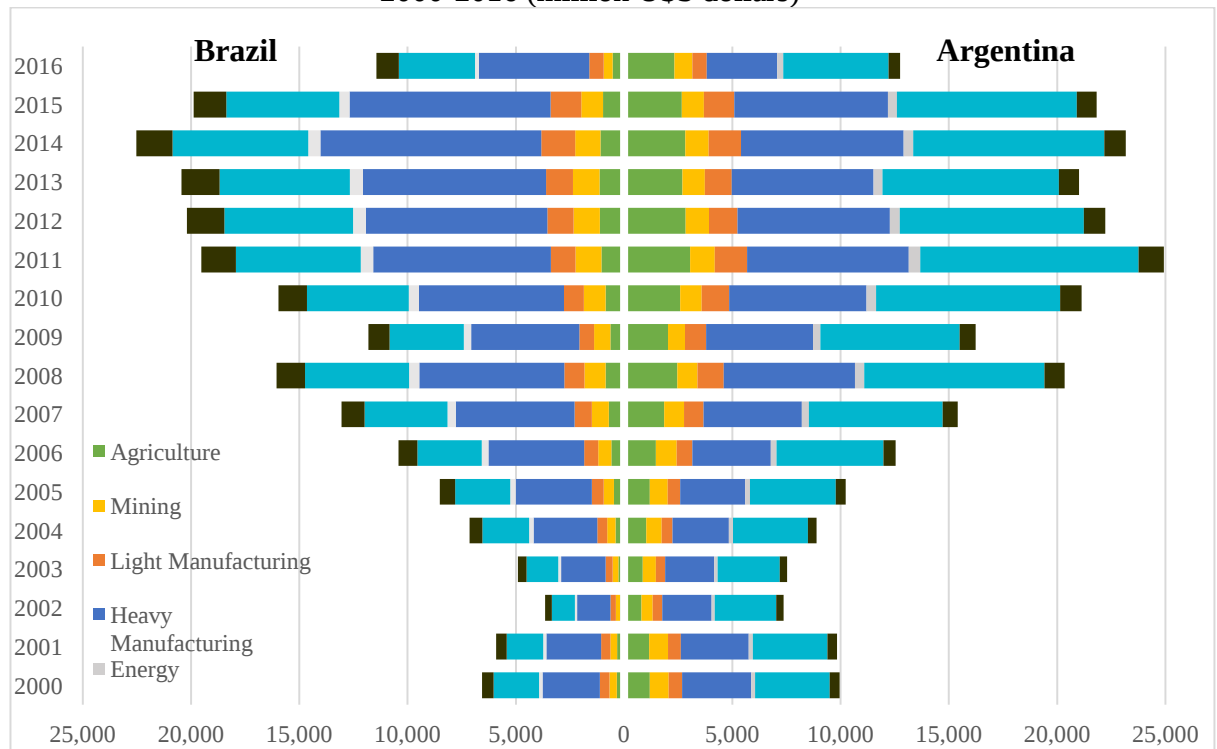
Source: Own elaboration from EORA database

The total emissions stemming from Argentine exports nearly tripled from 8 million tons of CO₂ equivalent (Mt) in 2000 to 25.2 Mt in 2008, when they reached their peak, followed by a subsequent gradual reduction to 20.8 Mt in 2015, and a significant reduction to 12.7 Mt in 2016. Notably, each sector in Argentina experienced a substantial decline of approximately 40-50% in its emissions embodied in exports from 2010 to 2016. Conversely, Brazil demonstrated a more consistent progression, with emissions steadily increasing in each period, rising from

7.8 Mt in 2000 to 17.5 Mt in 2014, when they reached the peak, representing a 126% increase over this period, and then reducing notably in 2016 when they reached 13.4 Mt.

The findings presented in Figure 8 reveal that the predominant source of EET in both countries stemmed from heavy manufacturing, constituting approximately 42% of emissions from Argentine exports and 57% of total EET on average for all periods in Brazil. Following heavy manufacturing, the Service sector accounted for an average of 27% of total EET during 2000-2016 in Argentina, whereas in Brazil, it represented an average of 17% of total EET. Light manufacturing contributed, on average, 10% of Argentina's EET and 9% in the case of Brazil. Thus, both countries exhibited similarities in the industrial composition of EET.

Figure 9: Sectoral structure of embodied VA exports in Argentina and Brazil trade during 2000-2016 (million U\$S dollars)



Source: Own elaboration from EORA database

In terms of Argentina's VA embodied in exports to Brazil, it predominantly originated from service industries, heavy manufacturing, and agriculture. The proportion of VA exports from these sectors to the total VA embodied in exports remained stable over the whole period. On average, during 2000-2016, these three sectors accounted for approximately 39%, 30%, and 12% of the total VA embodied in exports, respectively. However, despite the service sector contributing significantly to embodied VA exports, its share of EET only amounted to approximately 27%, contrasting with heavy manufacturing, which accounted for 42% of total EET.

In contrast, heavy manufacturing in Brazil contributed 42% of the total VA embodied in exports during 2000-2016, while representing an average of 57% of EET. Similarly to Argentina, service industries in Brazil significantly contributed to VA embodied in exports, with a stable share averaging 29% during the whole period, yet the share of Brazilian service industries in total EET showed a decreasing trend, reducing from 20% in 2000 to 15% in 2016.

The total VA exported and imported with Brazil, representing Argentina's primary trading partner throughout the entire period, underwent a substantial expansion between 2000 and 2014, attributed to the robust economic growth witnessed by both economies. However, both the VA exported and imported from Brazil experienced a significant contraction in the year 2016. This decline in Argentina's exports can be attributed to the recessionary environment experienced by Brazil, stemming from its political crisis, and a loss of competitiveness in Argentine exports due to increasing exchange rate appreciation. The notable reduction in VA imported from Brazil can be explained by the stagnation of the Argentine economy as of 2010, and a growing rationing of imports, within a context of increasing external restrictions.

This is particularly significant in the case of VA exports of Heavy and Light Manufacturing from Argentina, which experienced a 54% reduction between 2015 and 2016, while services experienced a 41% reduction. Conversely, the industries in which Argentina has its greatest comparative advantage, such as Agriculture and Mining, experienced milder reductions, at 13% and 17%, respectively, compared to the sectors.

Table 13: Sectoral flows of NC and NVA embodied in Argentina-Brazil trade (Mt and million US\$)

	2000		2005		2010		2016	
	Net CO ₂	Net VA	Net CO ₂	Net VA	Net CO ₂	Net VA	Net CO ₂	Net VA
Argentina-Brazil								
Agriculture	0,63	858	1,52	718	2,05	1.736	1,10	1.793
Mining	0,16	529	0,49	344	0,03	-8	-0,25	419
Light Manufacturing	0,03	172	0,67	48	1,20	337	0,25	-1
Heavy manufacturing	-0,93	535	1,09	-522	2,24	-353	-2,71	-1.854
Energy	0,02	23	0,14	-38	0,23	-23	0,04	112
Service	0,45	1.351	2,93	1.434	4,22	3.806	1,22	1.340
Transport	-0,13	-76	0,03	-254	0,17	-336	-0,36	-508
Total	0,22	3.392	6,86	1.730	10,14	5.159	-0,70	1.302

Source: Own elaboration from EORA database

The results of the indicators for NC and NVA with Brazil yield diverse outcomes. Firstly, it is noteworthy that in only five instances, the scenario where NC is negative and NVA is positive, is observed, indicating a situation where Argentina gains both environmental and economic benefits from trading with Brazil. This scenario occurred in the heavy manufacturing sector in the years 2000 and 2001, in the mining sector in 2015 and 2016, and in the light manufacturing industry, in 2001. However, the trend of these sectors over the entire period contradicts these values. In the case of heavy manufacturing, from 2004 to 2012, it exhibits $NC > 0$ and $NVA < 0$, that is, a situation in which Argentina incurred both economic and environmental losses, transitioning to an intermediate scenario from 2013 to 2016, with a carbon deficit indicating a reduction in environmental costs, accompanied by a significant deficit in VA, which indicates net economic losses.

As for Mining, except for the years 2015 and 2016, which showed the most favorable scenario, the sub-period 2000-2007 exhibited a scenario where Argentina acted as a pollution haven for Brazil, switching to the inverse situation from 2010 to 2014. The Agriculture and Services industries represent pollution havens scenarios in all periods, with strong positive balances in both emissions and VA for Argentina. In both cases, there is an increasing trend in CO₂ and VA flows between 2000 and 2011. By 2016, the agriculture sector showed a VA stagnation and a reduction in the net CO₂ balance, while the Services sector experienced a significant decrease in both emissions and VA balances. The light manufacturing sector maintains positive emissions balances throughout the analyzed period, with the VA balance turning slightly negative from 2014 onwards.

In the case of the energy industry, the period between 2004 and 2015 witnessed the worst scenario, characterized by slightly positive NC and deficits in NVA. A similar situation occurred in the transportation industry from 2003 to 2011, subsequently extending to the scenario where both NC and NVA were negative for Argentina until 2016. During this period, there were increasing values for negative NVA, peaking in 2013.

When we extend the analysis to include materials footprints with Brazil (figures 22-24 in Appendix H), Argentina showed a resource-intensive trade pattern, acting as a net provider of land and water resources, and to a lesser extent, raw materials. Additionally, the value-added per unit of raw material in trade with Brazil was, on average, 20% higher for the latter. This suggests that while Argentina contributed significant natural resources, there were no large discrepancies in the monetary compensation for materials embedded in the goods exchanged between the two countries, underscoring the key role of intra-industry trade in shaping this relationship. This type of trade, where countries exchange similar types of goods,

suggests a more balanced trade relationship, reflecting the fact that these countries operate on relatively equal terms in key sectors such as manufacturing and agriculture.

The Mercosur agreement promotes such economic integration, aiming to reduce barriers and promote fair competition. This equitable trade dynamic reinforces a relationship of "equals" in terms of economic partnership, as both Argentina and Brazil have comparable technological and industrial bases in several sectors. Consequently, the value-added per unit of material is more evenly distributed than in North-South trade relations, where resource-rich nations often receive lower compensation for raw materials (Dorninger et al., 2021).

In this context, the integration provided by Mercosur encourages deeper value-chain linkages, where Argentina and Brazil not only trade resources but also co-develop industries, further narrowing the compensation gaps in material trade. This mutual exchange benefits both economies, enhancing competitiveness and fostering a more integrated regional market. Such dynamics also contribute to regional economic resilience by fostering greater interdependence and reducing reliance on external markets.

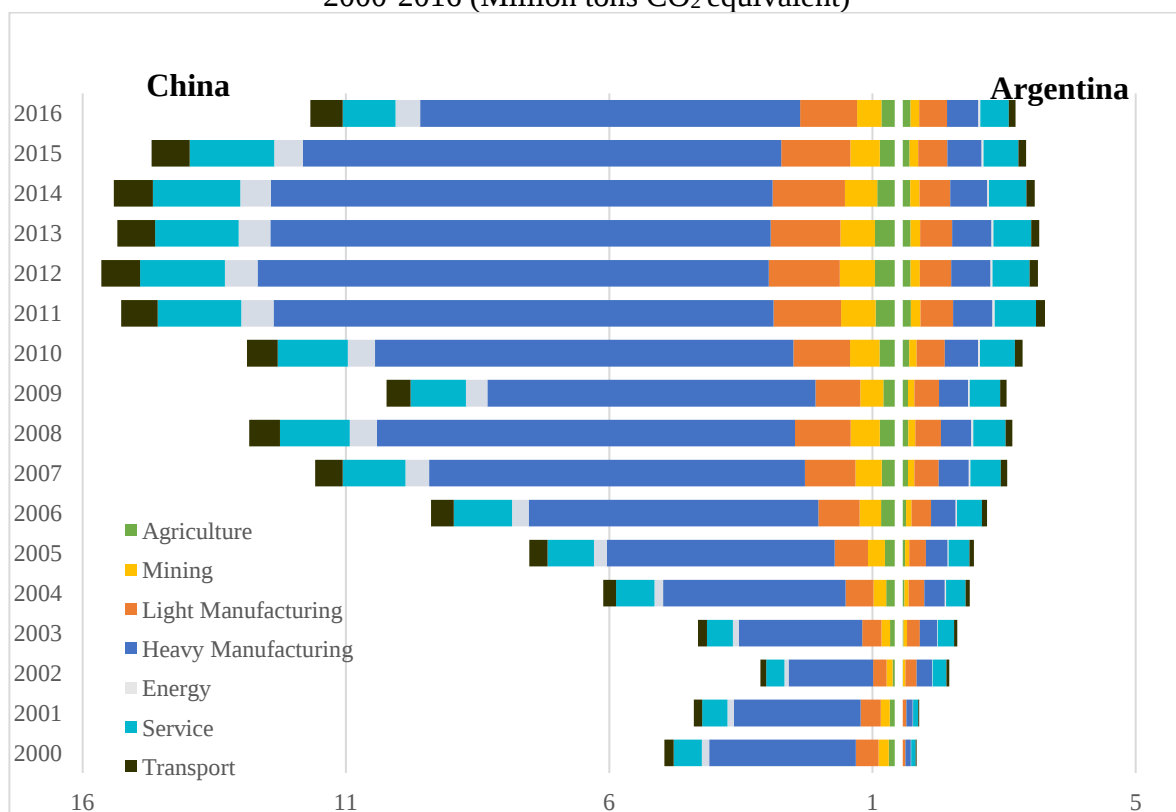
3.4.2 Embodied emissions and VA in Argentina-China bilateral trade

China is Argentina's second-largest export destination, accounting for 7.9% of its exports, and the main supplier of imports, with a 21.4% share in 2021. Since 2000, Argentina's exports of primary products, particularly soybean derivatives, have grown significantly, peaking in 2010. This increase is tied to China's economic rise and a commodity price boom that substantially improved Argentina's terms of trade (Erten and Ocampo, 2013). Exports of other goods from Argentina remain marginal compared to primary products.

On the other hand, Argentina's imports from China are concentrated in medium- and high-technology manufactures, including capital goods, intermediate goods, chemicals, machinery, and electronics. To a lesser extent, imports also include low-technology goods (consumer products) and resource-based manufactures, with a steady rise in these imports from 2000 to 2021. These trends align with the growing commercial influence of China across the South American continent.

One notable aspect of Argentina's trade with China is the pattern of Ricardian trade specialization, where each country focuses on products in which they hold comparative advantages—Argentina in primary products and China in labor- and technology-intensive manufactured goods. This dynamic underscores the complementary nature of their trading relationship.

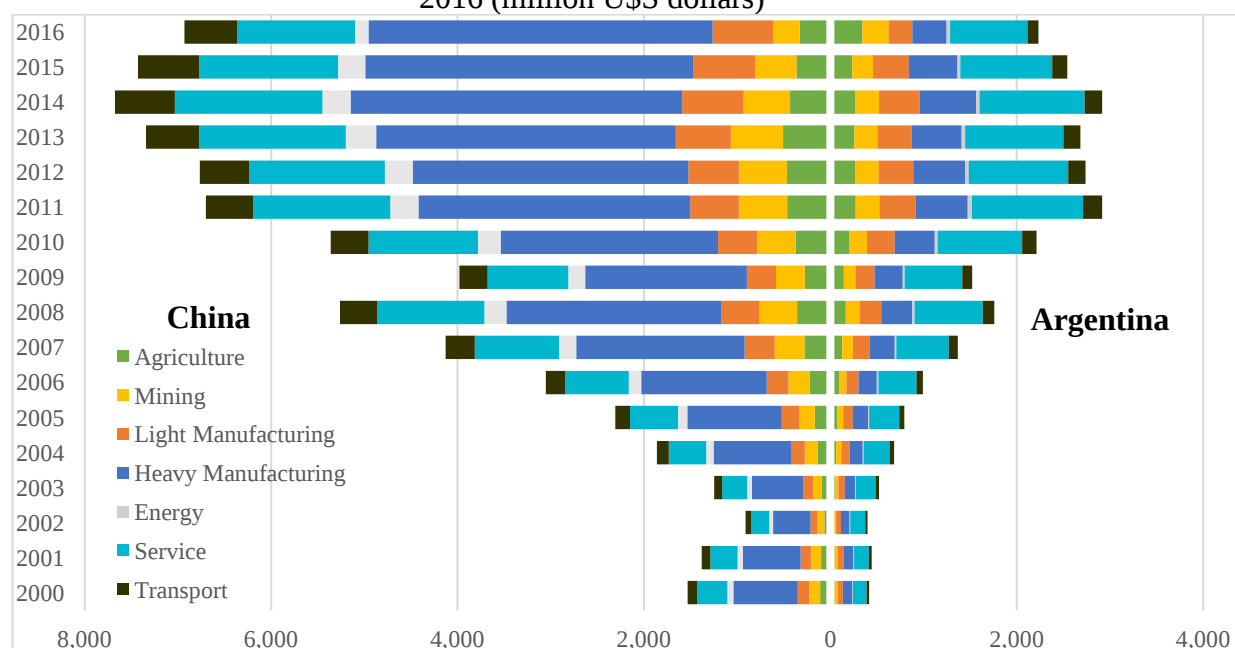
Figure 10: Sectoral structure of embodied GHG exports in Argentina-China trade during 2000-2016 (Million tons CO₂ equivalent)



Source: Own elaboration from EORA database

Argentina's EET increased significantly from 0.3 Mt in 2000 to 2.2 Mt in 2016 (551%), reaching a peak of 2.8 Mt in 2011. China's CO₂ emissions embodied in exports to Argentina increased consistently from 2000 to 2012, from 4.4 Mt to 15.1 Mt (240%), and then dropped to 11.2 Mt in 2016. Regarding Argentina's exports to China, EET are distributed across the sectors of light manufacturing, heavy manufacturing, and services, with average shares of 23%, 28%, and 27%, respectively. The agriculture sector contributes an average of 9% of the emissions during the analyzed period. In the case of China's EET, the findings demonstrate that the majority can be attributed to heavy manufacturing, accounting for 63%, on average, of the total carbon emissions embodied in trade during the analyzed period.

Figure 11: Sectoral structure of embodied VA exports in Argentina-China trade during 2000-2016 (million US\$ dollars)



Source: Own elaboration from EORA database

VA embodied in exports from Argentina also exhibited a notable increase, from US\$415 million (M) in 2000 to US\$2233 M in 2016 (438%), with a peak of US\$2917 M in 2014. China's VA embodied in exports to Argentina also rose significantly between 2000 and 2016, from US\$1,530 M to US\$6,931 M (353%), reaching its peak in 2014, with US\$7,676 M. From an industry perspective, the main contributor to Argentinian VA exports was the service industry, with an average participation of 40% on total VA between during the 2000-2016, increasing notably from US\$147 M to US\$831 M (463%), followed by light and heavy manufacturing, rising jointly in a consistent way, from US\$156 M in 2000 to the peak of US\$1040 M in 2014 (566%). The agriculture and mining industries averaged a joint participation of 18% in VA exports, on average, from 2000 to 2015, rising significantly to 28% in 2016.

Regarding China, heavy manufacturing accounted, on average, for 45% of the total VA during the analyzed period, followed by the service sector, with a share of 21%. The dominance of heavy manufacturing in both VA and EET aligns with China's consolidating role as the "world's factory" in global supply chains (Yu et al., 2014), and its increasing significance as a supplier of industrial products to Argentina. Notably, the VA generated by China for light and heavy manufacturing products exported to Argentina experienced substantial growth, increasing from US\$812 M in 2000 to US\$4344 M by 2016 (435% growth).

The service sector, as mentioned before, played a significant role in the VA generated by China, with a growth rate of 292% across the whole period. In this sector, it is notable that, while the VA flows from Chinese exports to Argentina are significantly higher than those of Argentine exports to China, being 119% higher in 2000 and 52% in 2016, carbon flows are even greater, being 541% higher in 2000 and 84% in 2016, compared to those of Argentina. The same relation holds for all the other Chinese industries, especially for Light and Heavy Manufacturing, and Energy sectors. This suggests that carbon emissions in China's industries notably surpass those of Argentina. This can be attributed to China's heavy reliance on coal for electricity generation (Kim and Tromp 2021), which significantly impacts the embodied emissions in its exports. In contrast, Argentina's energy matrix, although heavily reliant on fossil fuels, sees a notable reduction in carbon emissions from its exports when compared to China, due to the intensive use of natural gas, which, among fossil fuel sources, has the lowest potential for GHG emissions.

Table 14: Sectoral flows of NC and NVA embodied in Argentina-China trade (Mt and million US\$)

	2000		2005		2010		2016	
	Net CO ₂	Net VA	Net CO ₂	Net VA	Net CO ₂	Net VA	Net CO ₂	Net VA
Argentina-China								
Agriculture	-0,2	-64	-0,1	-95	-0,2	-164	-0,1	13
Mining	-0,2	-85	-0,2	-105	-0,4	-230	-0,3	1
Light Manufacturing	-0,4	-65	-0,3	-81	-0,5	-120	-0,6	-398
Heavy Manufacturing	-2,7	-590	-3,9	-850	-7,3	-1.906	-6,6	-3.328
Energy	-0,1	-60	-0,2	-89	-0,5	-209	-0,4	-103
Service	-0,5	-175	-0,5	-190	-0,7	-269	-0,5	-433
Transport	-0,2	-75	-0,3	-105	-0,4	-252	-0,5	-451
Total	-4,11	-1.115	-5,59	-1.515	-10,03	-3.150	-8,95	-4.699

Source: Own elaboration from EORA database

Between 2000 and 2016, Argentina experienced negative NC and NVA flows across all sectors, except for Agriculture and Mining in 2016, where a modest positive NVA was observed, being the only sectors that could reverse the increasingly negative NVA trend over the years. China's high carbon exports in the heavy manufacturing industry is a major contributor to the transfer of carbon emissions from Argentina. Nevertheless, the substantial environmental costs linked to this sector are accompanied by significant economic gains for China. As a result, it

contributes significantly to China's overall NVA surplus, accounting for a considerable share ranging from 53% to 71% during the whole period.

In summary, Argentina became an NC and NVA importer in its trade relations with China. This shift occurred because the growth in CO₂ emissions and VA embodied in exports from China's industries notably surpassed those from Argentina's industries, except for the Agriculture and Mining sectors in the last period. These sectors saw a consistent increase in their absolute VA exports over time, narrowing the gap in net flows with China starting from 2013, and reversing the trend in 2016. Although Argentina's service sector also experienced a notable increase in exported VA over the years, it couldn't offset the VA deficit, which continued to grow throughout the period.

In terms of material flows and natural resources in trade with China (Appendix H), Argentina consistently exported more water and land-embodied resources than it imported, with the exports being on average three and four times greater, respectively, over the period analyzed. However, the land footprint in trade with China steadily increased throughout the entire timeframe. Starting from a neutral balance in 2000, in 2016 China imported six times more land-embodied resources through trade with Argentina.

These results align with the findings of Weinzettel et al. (2013), which highlight that China has been a leading global player in both the export and import of land footprints. This reflects China's dual role in the global economy: on the one hand, it is a massive importer of raw materials and agricultural products, which require significant land use in exporting countries like Argentina. On the other hand, China re-exports finished goods that embody not only domestic but also imported land resources. This contributes to a complex ecological exchange, where both countries are deeply interconnected through their resource-intensive trade relations, but with different economic and environmental implications.

Notably, China is the only trading partner where Argentina recorded a deficit in raw materials, importing four times more embodied raw materials on average than it exported. This substantial flow of embodied raw materials, mainly in the form of manufactured goods from China, resulted in a relatively low disparity in value-added per unit of raw material, with Argentina earning 42% more value-added on average for its exports compared to its imports—an unusual case where Argentina yielded higher monetary compensation for its exported materials.

Nonetheless, trade with China follows a Ricardian, intersectoral pattern based on traditional comparative advantages. Argentina specializes in natural resource exports, while China's competitive edge lies in its large-scale, labor-intensive manufacturing sector. This type

of exchange often leads to the overexploitation of natural resources, including current and potential deforestation in Argentina, exacerbating environmental concerns. As China's demand continues to grow in sectors where Argentina already holds a strong position, this pattern of trade specialization deepens rather than diversifies. Consequently, Argentina remains trapped in a cycle of dependency on low value-added, environmentally intensive exports, limiting its prospects for more sustainable, diversified economic development.

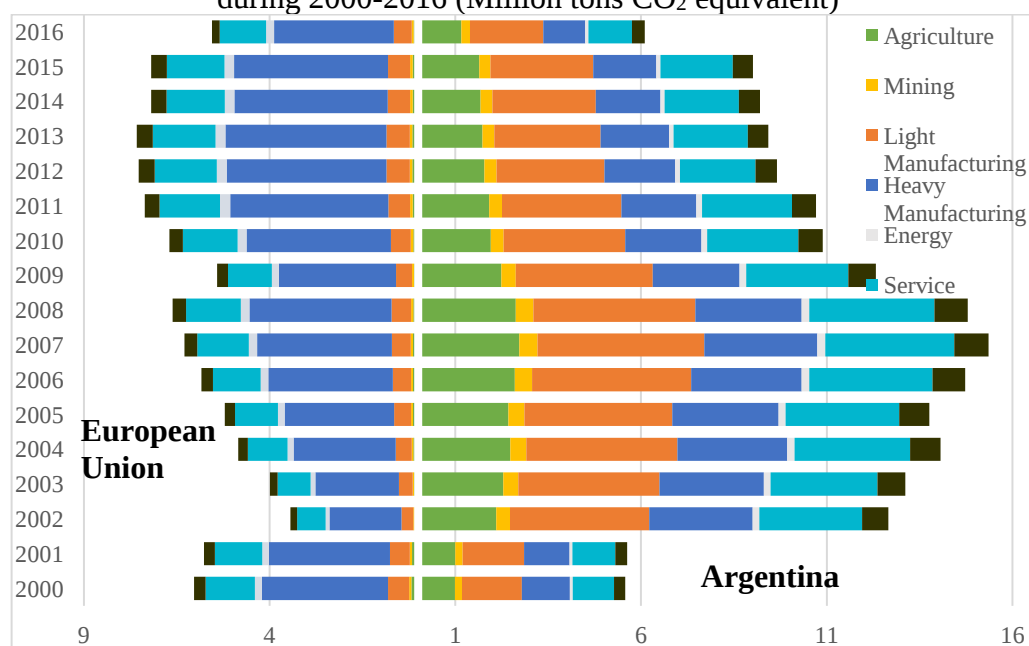
Even though Argentina's trade with China shows significant deficits in value-added and emissions over the period analyzed, it does not align with the pattern of ecologically unequal exchange. China's exports, despite being more emission- and raw material-intensive, are matched by a greater share of economic value-added for the latter, meaning China gains economically at the expense of higher local emissions.

3.4.3 Embodied emissions and VA in Argentina-European Union bilateral trade

The European Union has been one of Argentina's main export destinations, accounting for approximately 12% of the country's total exports. The EU also played a significant role as a supplier of goods, covering around 16% of Argentina's total imports.

Argentinian exports to the EU are predominantly concentrated in primary products. The most exported goods include agricultural and agro-industrial products such as soybeans, oils, corn, beef, and fish. In contrast, Argentina primarily imports industrial products from the EU, including machinery, vehicles, chemicals, and pharmaceuticals. Argentina typically registers a trade deficit with the EU, as it imports higher value-added products while exporting mainly raw or minimally processed goods.

Figure 12: Sectoral structure of embodied GHG exports in Argentina-European Union trade during 2000-2016 (Million tons CO₂ equivalent)

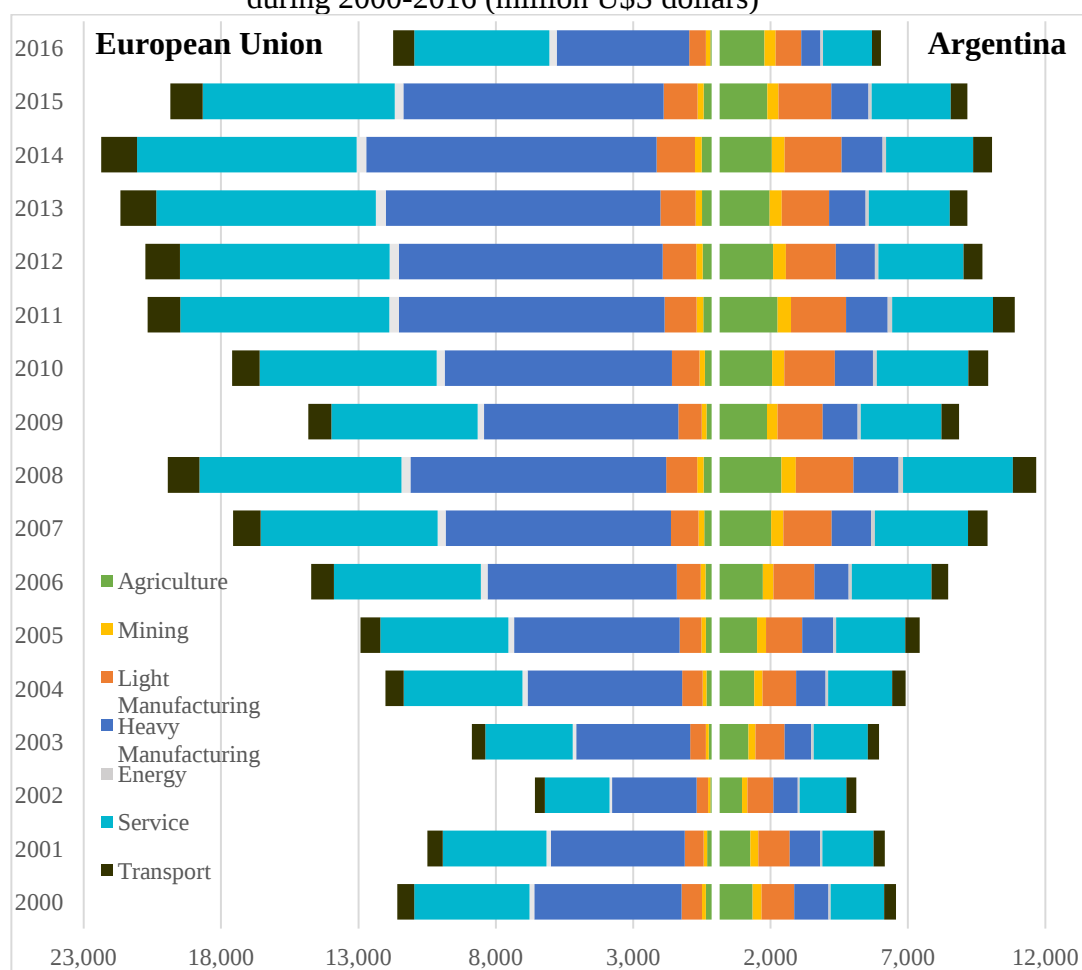


Source: Own elaboration from EORA database.

Between 2000 and 2007, Argentina experienced a steady increase every year in its CO₂ emissions embodied in exports to the European Union, rising from 5.6 Mt to 15.4 Mt, representing a total increase of 176%. However, from 2007 to 2016, there was a notable decrease in emissions embodied in exports, dropping to 6.1 Mt (-60%). Conversely, the CO₂ emissions embodied in exports from the European Union to Argentina showed a more stable pattern, declining from 6 Mt to 5.6 Mt (-8%), from 2000 to 2016, exhibiting a maximum value of 7.6 Mt in 2013.

The distribution of Argentinian EET to the European Union varies across different sectors. On average, light manufacturing accounts for 30% of these emissions, followed by the service sector at 22%, heavy manufacturing at 20%, and agriculture at 18%. Regarding the European Union's EET to Argentina, they are primarily concentrated in the heavy manufacturing industry, contributing an average of 57% over the period, while the service sector contributes 22%.

Figure 13: Sectoral structure of embodied VA exports in Argentina-European Union trade during 2000-2016 (million US\$ dollars)



Source: Own elaboration from EORA database.

The VA embodied in exports from Argentina to the EU experienced fluctuations over the whole period. In 2000, the VA amounted to US\$6570 million, which increased to US\$11664 million (78%) in 2008, when it reached its peak. In the subsequent years, VA exports fluctuated in the range of US\$9000-11000 million, however, there was a significant drop to US\$6015 million in 2016. Among the sectors contributing to Argentinian VA exports, the service sector had the highest average participation at 33%. The agriculture sector also played a significant role, maintaining a consistent participation rate of 21% from 2000 to 2015, with a notable increase to 30% by 2016, followed by light manufacturing with an average share of 18% on VA generation.

On the other hand, the EU's VA embodied in exports to Argentina began at US\$11,585 in 2000 and, despite a decline in the years 2002 and 2003 due to the Argentinian crises, it increased steadily over the period, reaching a peak of US\$22,259 in 2014. However, VA declined significantly to US\$11,738 in 2016, representing a 41% drop compared to the previous year. The heavy manufacturing sector was the main driver behind the VA embodied in

European exports to Argentina, contributing an average of 46% in value generation. The service sector followed closely with a 37% share.

Table 15: sectoral flows of NC and NVA embodied in Argentina-European Union trade (million tons and million US\$)

	2000		2005		2010		2016	
	Net CO ₂	Net VA	Net CO ₂	Net VA	Net CO ₂	Net VA	Net CO ₂	Net VA
Argentina-European Union								
Agriculture	0,8	988	2,3	1.152	1,8	1.673	1,0	1.581
Mining	0,1	189	0,4	172	0,3	231	0,2	249
Light Manufacturing	1,0	442	3,5	508	2,7	840	1,5	322
Heavy Manufacturing	-2,1	-4.113	-0,1	-4.884	-1,8	-6.888	-2,1	-4.126
Energy	-0,1	-87	0,0	-99	-0,1	-147	-0,1	-164
Service	-0,2	-2.248	1,9	-2.152	1,0	-3.103	-0,1	-3.131
Transport	0,0	-186	0,5	-199	0,3	-286	0,1	-454
Total	-0,46	-5.015	8,55	-5.502	4,19	-7.682	0,54	-5.723

Source: own elaboration from EORA database.

When examining NVA and NC between Argentina and the EU, the data reveals that Argentina's Agriculture, Mining, and Light manufacturing sectors consistently exhibited positive values throughout the analyzed period. This indicates that Argentina derived economic advantages from primary exports and basic manufacturing, albeit at the expense of environmental consequences. Additionally, it is noteworthy that the light manufacturing industry yielded lower economic benefits but incurred greater environmental costs compared to Agriculture. This is evident in each period, as the NC associated with Light manufacturing exceeded those of Agriculture, while NVA displayed smaller figures.

Contrarily, in the Heavy Manufacturing and Energy industries, Argentina experienced negative NC and NVA flows throughout the years, implying the saving of environmental costs but at the expense of a significant deficit in VA flows. In the case of the service and transport sectors, Argentina experienced positive NC and negative NVA flows throughout most years, implying both environmental and economic losses. The absolute value of NVA flows in the Service and Heavy Manufacturing industries was particularly significant. It is important to highlight that in bilateral trade with the European Union, the VA deficit in these industries fluctuated between three to six times the surplus generated by primary products and light manufacturing. It is noteworthy that this occurred within a context of significant improvement in the terms of trade, driven by an increase in export prices of primary products since the early 2000s up to 2013, after which the terms of trade embarked on another cycle of deterioration.

In terms of the overall NC and NVA embodied in trade with the EU, it is worth noting the significant VA deficits Argentina experienced in every period, in the range of US\$5,000-12,500 million. Despite these deficits, Argentina incurred minimal environmental savings in 2000 (-0.46 Mt deficit), with significant CO₂ surpluses in the rest of the years, especially in the subperiod 2002-2010. Except for 2000 and 2001, the rest of the years represented the worst-case scenarios, characterized by substantial economic and environmental losses, facing VA deficits coupled with CO₂ surpluses. These results demonstrate the existence of ecologically unequal exchange between Argentina and the EU, as the former incurs environmental losses to produce its exportable goods yet fails to generate sufficient monetary resources to finance its imports from the EU, resulting in significant value-added deficits that must be financed through VA embodied in exports to other destinations where trade results in a surplus, such as Brazil.

The asymmetries between the EU and Argentina become even more pronounced when focusing on the flows of natural resources between the two. In every case—land, water, and raw materials—there were net transfers from Argentina to the EU. Argentina exported, on average, 17.5 times more land than it imported from the EU, while for water, Argentina exported 35 times more than it imported, making the EU the primary appropriator of this Argentine resource. In terms of raw materials, Argentina exported seven times more than it imported from the EU, only surpassed by the US (another high-income nation), where the export-to-import ratio reached nine times.

Additionally, the EU captured 11 times more value-added per unit of raw material compared to Argentina, which reflects the region's significant economic advantage in this trade relationship. Thus, it can be concluded that the EU achieves a net appropriation of materials, land and water, while simultaneously generating a monetary surplus from these appropriations. These findings align with Dorninger et al. (2021) regarding the imbalances in exchanges between high-income regions and other countries. Furthermore, this high resource consumption is facilitated by globally extended supply chains (Prell et al., 2014), in which EU and other high-income nations benefit the most in terms of value capture, socioeconomic outcomes and productive development relative to lower income countries, while suffering less from ecological degradation (Althouse et al., 2023). These dynamic highlights the uneven nature of trade relationships, where wealthier regions benefit disproportionately from the resources of lower-income countries, deepening ecological and economic inequalities.

This imbalance is further intensified by the implementation of the CBAM, a climate policy from the European Union aimed at preventing carbon leakage and aligning the prices of imported goods with European environmental standards. In practice, however, CBAM may act

as a mechanism that perpetuates ecological and economic inequalities, by shifting the costs onto exporting countries like Argentina.

CBAM is part of a broader set of policy measures to support the EU's goal of reducing emissions by 55% from 1990 levels by 2030 and achieving carbon neutrality by 2050. It complements the phase-out of free allowances under the EU Emissions Trading System (ETS) (Munro, 2018) and aims to level the playing field through carbon-based tariffs on certain goods imported into the EU. Initially, CBAM is limited to sectors covered by the ETS, which primarily includes energy-intensive industries. The most recent EU legislative proposals target the power sector as well as sectors like cement, steel, aluminum, and fertilizers to be included in the mechanism (Perdana and Vielle, 2022).

The introduction of the EU's CBAM is likely to come at a high cost for countries with significant export shares to the EU, including Argentina. As the mechanism is applied, it will likely reduce exports from these countries unless they adopt effective mitigation strategies and integrate environmental sustainability into their national development plans. Without such strategies, the economic consequences could be considerable. Notably, the CBAM does not provide exemptions for Least Developed Countries (LDCs), and its revenues are not earmarked to help developing countries fund their decarbonization efforts (Eicke et al., 2021).

For Argentine producers, this poses a dual challenge. First, they must absorb the costs of implementing traceability and environmental certification systems. Second, they will face the CBAM tax, which will make their products more expensive compared to European goods. European producers, already operating within a regulatory framework that supports decarbonization, benefit from subsidies and support, creating a competitive imbalance. This asymmetry favors European producers, who receive financial backing to improve their competitiveness and reduce their carbon footprint, while Argentine producers bear the additional costs without equivalent support. Essentially, while European industries benefit from a decarbonization strategy partially funded by CBAM revenues, Argentine and other developing economies producers are left with higher costs and less market access.

In this sense, the implementation of CBAM could have adverse distributive effects. Revenues generated by this mechanism are intended to finance the EU's own decarbonization efforts, further deepening global inequality. Instead of being used to support the transition to sustainable practices in developing countries, these funds are channeled toward strengthening the competitiveness of European industries and their green transition. Tariffs and policies imposed by industrialized nations tend to worsen the terms of trade for developing countries,

effectively shifting the responsibility for emission reduction onto them and deepening existing income inequalities (Böhringer et al., 2012).

To address these concerns, the CBAM could consider redistributing some of the revenues it generates to support affected lower-income countries. Many countries have expressed concerns about potential trade distortions and the need for special treatment, making revenue redistribution a potential solution (Perdana and Vielle, 2022). Rather than directing funds solely toward the EU's budgetary objectives, part of the revenue could be used to create a fund aimed at accelerating the adoption of cleaner production technologies in developing nations (Pirlot, 2021).

Furthermore, the tariffs could create a trade distortion effect that not only reshapes commercial flows between Europe and its partners but could also have far-reaching implications for other regions. For instance, China might realign its supply chains in response to the EU's stricter regulations. If Europe imposes additional costs on imports with higher carbon footprints, China may opt to reduce imports from Europe, favoring suppliers from regions not subject to these regulations or offering more competitive prices. Rather than encouraging global adoption of higher environmental standards, the CBAM could unintentionally incentivize a shift in trade toward countries with less stringent environmental practices, thus sustaining or even amplifying global carbon footprints.

The implications of the CBAM for carbon leakage remain a highly debated issue in the literature. By introducing carbon tariffs on imports, the CBAM seeks to disincentivize imports from countries with weaker environmental regulations, effectively leveling the playing field for EU-based industries. However, there are concerns about its actual effectiveness in reducing carbon leakage. Critics highlight that it could inadvertently trigger trade diversion, where importers shift their sourcing to less-regulated producers, potentially increasing overall global emissions (Schroeder and Stracca, 2023).

This situation underscores the need for a multilateral framework to guide the implementation of such measures, which would involve collaboration with both developed and developing nations. Climate change, being a global externality, cannot be effectively addressed by any single country acting alone (Frankel and Aldy, 2008). Without a global cooperative approach, such mechanisms may risk exacerbating international inequalities and fail to address the broader issue of climate change in a balanced and sustainable way.

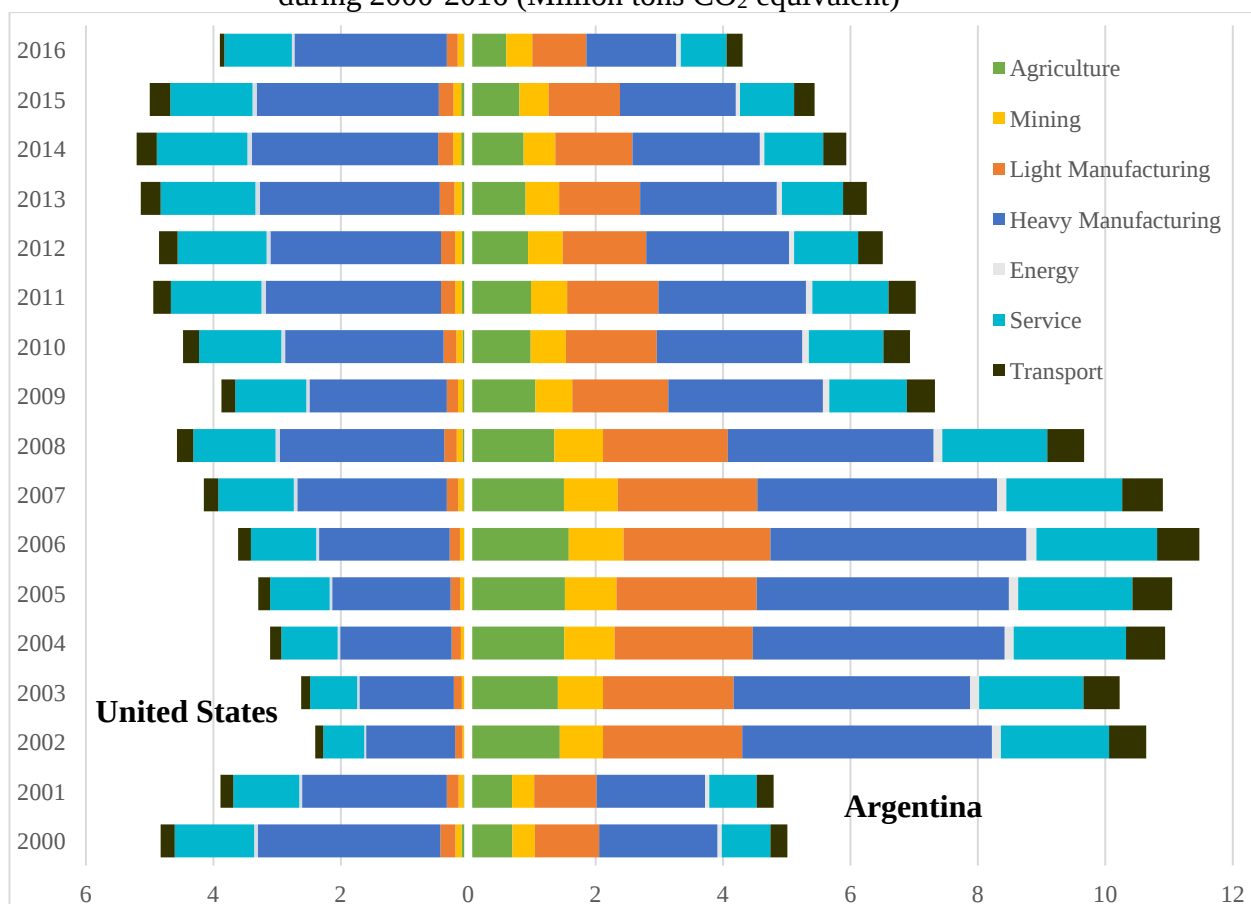
While this essay does not aim to fully analyze the impacts of CBAM, it is essential to consider its potential effects when discussing concepts such as Ecologically Unequal Exchange and the Pollution Haven Hypothesis. For further in-depth discussions on CBAM, see Atkinson

et al. (2011), Böhringer et al. (2012), Sato et al. (2015), Sakai and Barrett (2016), Naegele and Zaklan (2019), Perdana and Vielle (2022), among others.

3.4.4 Embodied emissions and VA in Argentina-United States bilateral trade

The United States serves as an important destination for Argentine exports, accounting for approximately 6.4% of the total export market. Conversely, the U.S. is also a significant source of imports for Argentina, holding a share of around 9.4%. Argentina imports a range of high-technology manufactured goods from the U.S., including capital goods, machinery, and electronics, as well as medium-technology products such as chemicals and various intermediate and consumer goods. Additionally, there is a substantial import of resource-based manufactured goods, particularly fuels and raw materials. In contrast, Argentine exports are primarily focused on raw materials, fuels, and other miscellaneous products.

Figure 14: Sectoral structure of embodied GHG exports in Argentina-United States trade during 2000-2016 (Million tons CO₂ equivalent)



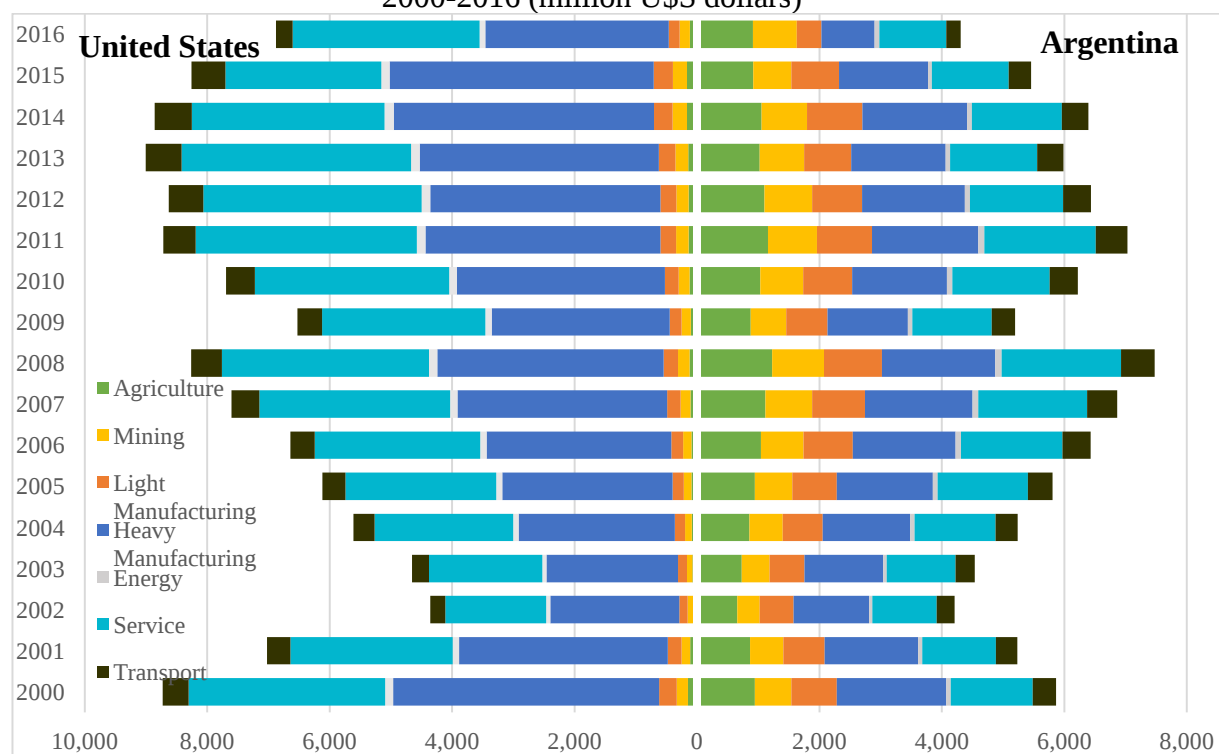
Source: Own elaboration from EORA database.

Between 2000 and 2006, Argentina experienced a substantial increase in its CO₂ emissions embodied in exports to the United States, increasing from 5 Mt to 11.5 Mt, marking a 129% increase. However, from 2006 onwards, there was a notable decrease in CO₂ emissions

embodied in exports, declining steadily each year, reaching 4.3 Mt in 2016 (-62%). Conversely, the CO₂ emissions embodied in exports from the United States to Argentina showed a more stable pattern, increasing from 4.8 Mt to 5.2 Mt (+8%), from 2000 to 2014, when it reached its peak, and then reducing to 3.9 Mt in 2016.

The distribution of Argentinian EET to the US varies across the different sectors. The distribution is like that of the European Union, with heavy manufacturing having a higher participation rate (35%), followed by light manufacturing (20%), the service sector (16%), and agriculture (14%). In the case of CO₂ emissions embedded in exports from the United States, they are concentrated in heavy manufacturing (57%) and the service sector (28%).

Figure 15: Sectoral structure of embodied VA exports in Argentina-United States trade during 2000-2016 (million US\$ dollars)



Source: Own elaboration from EORA database.

The VA embodied in exports from Argentina to the US experienced fluctuations over the whole period. In 2000, the VA exports amounted to US\$5863 M, which decreased to US\$5239 M in 2004 (-11%), before experiencing slight increases until 2008, reaching its peak at US\$7475 M. Subsequently, VA exports fluctuated in the range of US\$5000-7000 M, with a drop to US\$4305 M in 2016. Among the sectors contributing to Argentinian VA exports, heavy manufacturing industry had the highest average share with 26% over the whole period, although its share decreased significantly in 2016, to 20%. The service sector was the second contributor

to VA generation, with an average share of 25%, followed by agriculture, with 17%. Interestingly, the mining and energy sectors were the only industries that did not experience a decrease in absolute VA exports in 2016. Instead, they showed growth (15% and 21%, respectively).

The total VA embodied in exports from the US to Argentina decreased from US\$8,727 M to US\$6,877 M, representing a decline of 21% over the period from 2000 to 2016. The range fluctuated between US\$4000-9000 M during the same period. Regarding the sectoral composition of VA, it shares similar characteristics with those from the European Union, with a substantial average participation from the heavy manufacturing sector (46%) and the service industry (40%).

Table 16: sectoral flows of NC and NVA embodied in Argentina-United States trade (million tons and million US\$)

	2000		2005		2010		2016	
	Net CO ₂	Net VA	Net CO ₂	Net VA	Net CO ₂	Net VA	Net CO ₂	Net VA
Argentina-United States								
Agriculture	0,6	796	1,5	853	0,9	914	0,5	799
Mining	0,3	412	0,7	491	0,5	523	0,3	548
Light Manufacturing	0,8	457	2,0	537	1,2	573	0,7	226
Heavy Manufacturing	-1,0	-2.557	2,1	-1.211	-0,2	-1.848	-1,0	-2.130
Energy	0,0	-56	0,1	-17	0,0	-39	0,0	-14
Service	-0,5	-1.871	0,9	-993	-0,1	-1.586	-0,3	-1.963
Transport	0,0	-45	0,4	32	0,2	-12	0,2	-38
Total	0,2	-2.864	7,8	-308	2,5	-1.474	0,4	-2.572

Source: own elaboration from EORA database.

When comparing the NVA and NC between Argentina and the US, the data indicates that Argentina's agriculture, mining, and light manufacturing sectors consistently showed positive values throughout the analyzed period, like the trade patterns with the European Union. This suggests that Argentina gained economic benefits from primary exports and basic manufacturing but at the expense of significant environmental impacts in terms of GHG emissions. Additionally, as with the EU, the light manufacturing industry generated lower economic benefits while incurring higher environmental costs compared to the agriculture and mining industries.

In the heavy manufacturing and service industries, Argentina experienced significant negative NVA flows over the years, with NC flows fluctuating from slightly negative to

positive. This implies a very limited saving of environmental costs at the expense of a significant deficit in NVA. Like bilateral trade with the EU, the NVA deficit in these industries with the US notably surpassed the surplus generated by primary products and light manufacturing.

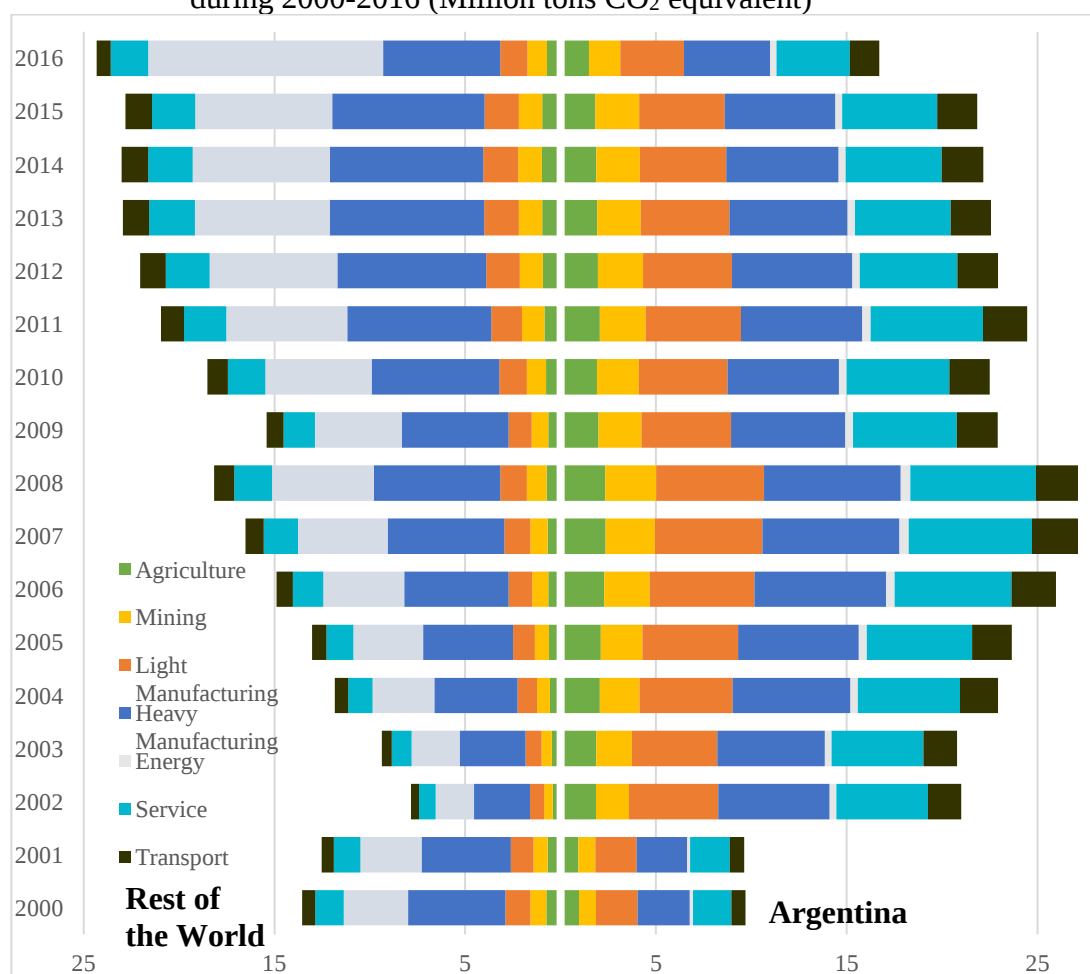
Regarding the overall NC and NVA embodied in trade with the US, there were consistent NVA deficits and NC surpluses in every period. NVA deficits ranged from 120 to 3000 M U\$, typically exceeding 1500 M U\$ in most years. Meanwhile, NC surpluses exhibited lower values during periods with the highest NVA deficits and significant values in years with lower NVA deficits. These results demonstrate the existence of ecologically unequal exchange between Argentina and the US, like the case with the EU.

The asymmetries between the US and Argentina become even more striking when examining the flow of natural resources between the two countries. In all categories—land, water, and raw materials—Argentina was a net exporter to the US. On average, Argentina exported 12 times more land, 16 times more water, and 9 times more raw materials than it imported from the US. Moreover, the US extracted 10 times more value-added per unit of raw material compared to Argentina. As with the trade dynamics between Argentina and the EU, this indicates that the US engages in a net appropriation of Argentina's resources—land, water, and raw materials—while simultaneously generating a financial surplus from these transfers. These patterns highlight the unequal exchange that underpins the trade relationship and reflect broader trends in global resource flows, where wealthier nations capture greater value from resource-rich countries without providing equitable benefits in return.

3.4.5 Embodied emissions and VA in Argentina-Rest of the World bilateral trade

In the case of CO₂ emissions contained in Argentine exports to the Rest of the World, it is worth noting the significant increase in total emissions between the years 2000 and 2008, rising from 9.7 Mt to 27.4 Mt (183%), and then declining consistently through the years, reaching 21.8 Mt in 2015, and dropping to 16.7 Mt in 2016. They are distributed among the sectors of heavy manufacturing and light manufacturing, with average shares of 27% and 21% respectively, and the services sector, with an average share of 23%.

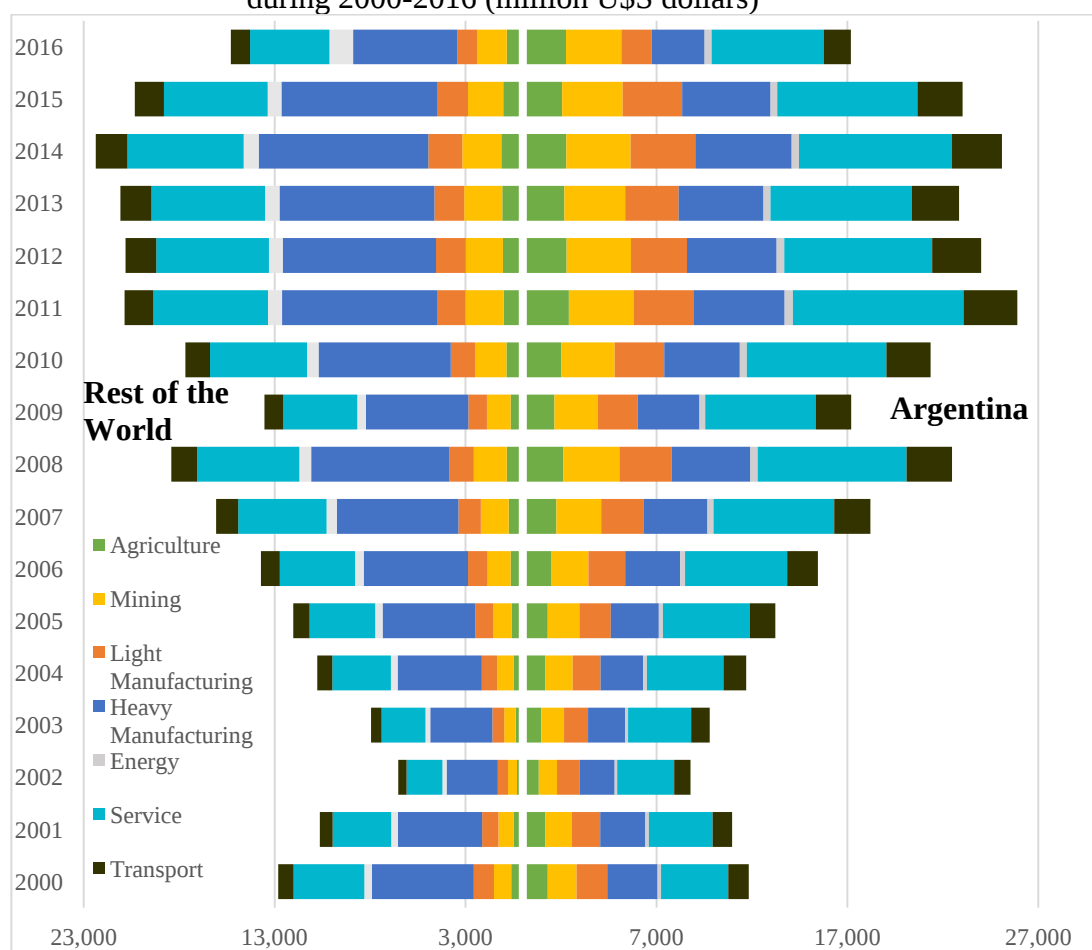
Figure 16: Sectoral structure of embodied GHG exports in Argentina-Rest of the World trade during 2000-2016 (Million tons CO₂ equivalent)



Source: Own elaboration from EORA database.

Regarding the CO₂ content in exports from RoW to Argentina, they have increased an 80% throughout the whole period, from 13.6 Mt in 2000 to 24.3 Mt in 2016, when they reached their highest value. The high participation of the heavy manufacturing sector stands out, averaging 36%. This sector has seen an absolute increase of 20%, from 5.1 Mt in the year 2000 to 6.1 Mt in 2016. An interesting aspect is the consistent evolution of the energy sector, which went from representing 25% of CO₂ emissions embodied in RoW exports to Argentina, to a 31% share in 2015, jumping to 51% in 2016, with an absolute value of 12.3 Mt. This sector experienced a continuous growth in absolute EET throughout the period, but it is worth noting the significant jump of 71% between 2015 and 2016.

Figure 17: Sectoral structure of embodied VA exports in Argentina-Rest of the World trade during 2000-2016 (million US\$ dollars)



Source: Own elaboration from EORA database

Concerning the VA embodied in exports from Argentina to RoW, it is noteworthy that the total value showed a growth trend until the year 2011, reaching a peak of US\$25,897 M, after which it remained in the range of US\$22.000-25.000 M, dropping to a value of US\$17,185 M in 2016. The services sector stood out with an average contribution of 33%. The light and heavy manufacturing industries contributed with an average share of 12% and 19%, respectively, in both cases with notable reductions in 2016. An interesting finding is that from 2009 to 2014, all industries exhibited growing VA, the opposite trend compared with the EU and US, showing a redirection of exports from Argentina to other regions, apart from these core countries.

On the other hand, the VA of RoW was concentrated in the sectors of heavy manufacturing and services, with average shares of 40% and 28%, respectively. The total VA exhibited a rising trend until reaching its peak in 2014, followed by a decline towards the year 2016, except for the energy sector. Another notable aspect is the 72% leap in the exported VA of the energy sector between 2015 and 2016.

Table 17: sectoral flows of NC and NV embodied in Argentina-Rest of the World trade (million tons and million US\$)

	2000		2005		2010		2016	
	Net CO ₂	Net VA	Net CO ₂	Net VA	Net CO ₂	Net VA	Net CO ₂	Net VA
Argentina-RoW								
Agriculture	0,2	704	1,5	741	1,2	1.162	0,8	1.434
Mining	0,1	587	1,4	651	1,2	1.154	0,6	1.320
Light Manufacturing	0,9	572	3,9	736	3,2	1.323	1,9	556
Heavy Manufacturing	-2,4	-2.702	1,6	-2.345	-0,8	-2.969	-1,6	-2.678
Energy	-3,2	-217	-3,3	-174	-5,2	-244	-12,0	-863
Service	0,5	-187	4,1	1.114	3,4	2.236	1,9	1.710
Transport	0,1	273	1,3	487	1,0	1.015	0,8	409
Total	-3,9	-970	10,6	1.210	4,0	3.677	-7,6	1.889

Source: own elaboration from EORA database.

When analyzing the NVA and NC between Argentina and RoW, a notable feature is the prevalence of positive indicators in primary sectors and light manufacturing across all periods, echoing patterns observed in bilateral trade with the United States and the European Union. However, the heavy manufacturing sector consistently displayed a significant negative total NVA annually. Between 2002 and 2009, the negative NVA was accompanied by a positive NC for Argentina, resulting in a scenario with both net environmental and economic costs. The energy sector exhibited significant negative NC values, along with slightly negative NVA, indicating a trade-off where Argentina saved high environmental costs at the expense of moderate economic losses in terms of VA generation. Notably, in trade with RoW, the service and transport sectors consistently showed positive NVA balance in all periods (excluding 2000 for services). Particularly in the service sector, this balance entailed significant NVA amounts accompanied by corresponding NC values, portraying a scenario where Argentina achieved economic gains at the cost of heightened environmental impacts.

Finally, the total value of NVA, starting from the year 2000, showed positive values for Argentina, reaching its peak in 2011. Subsequently, there is a persistent decline leading up to 2016, culminating in a scenario characterized by emissions deficit and VA surplus. Overall, trade with the Rest of the World yielded economic benefits for Argentina, with surplus NVA balances. However, it also entailed environmental costs, with pronounced NC surpluses between 2002 and 2009, followed by moderate surpluses, and ultimately transitioning to a deficit from 2013 onwards, which became particularly significant by 2016.

Regarding natural resource flows between Argentina and RoW, Argentina exported, on average, 4.5 times more land, 6 times more water, and 3 times more raw materials than it imported. Moreover, RoW captured 2.5 times more value-added per unit of raw material compared to Argentina. However, since this aggregate includes all countries not covered in the previous analysis, it is not possible to draw conclusions about the existence of trade patterns that align with the theory of EUE or PHH. This high level of aggregation includes countries across varying income levels, which limits the capacity to assess consistent trade imbalances. Nevertheless, what can be conclusively confirmed is Argentina's specialization as a net exporter of natural resources. This pattern reinforces concerns about the country's reliance on resource extraction and exportation, which often leads to significant ecological and economic asymmetries, especially given the value-added disparity between Argentina and its trading partners. This evidence suggests the need for more nuanced analysis that considers the different categories of countries involved and their respective developmental stages.

3.5 Discussion

Overall, Argentina exhibited a net positive balance in EET and VA in trade with Brazil across most periods, except for 2001 and 2016 when the net EET slightly turned negative. This suggests that Argentina derives significant economic benefits from bilateral trade with Brazil in sectors such as agriculture, mining, light manufacturing, and services, albeit at an increased local environmental cost. Even in cases where the NVA balance is negative, such as in the heavy manufacturing sector from 2004 to 2016, the substantial total VA in Argentina's exports indicate high export activity. The sectoral structure similarity between Argentina and Brazil in terms of embodied carbon and VA exports underscores the importance of intra-industry trade within the Mercosur.

The evidence from Argentina's trade with Brazil reveals no pattern of ecologically or economically unequal exchange. The predominance of intra-industry trade, characterized by similar products being both exported and imported, implies that variations in export prices correspondingly influence the value of imports. This dynamic mitigates the impact of price fluctuations on the trade balance, which is sensitive to shifts in the economic conjuncture of each country. Additionally, special regimes within Mercosur, such as those promoting the automotive sector, have a favorable impact on the export of higher VA products for both countries.

Conversely, trade with China showed a clear comparative advantage for China's manufacturing, service, and transport industries, which significantly contributed to the widening imbalance in VA and carbon emissions embodied in trade with Argentina among the

years. These findings indicate that Argentina has saved environmental costs at the expense of significant economic gains in bilateral trade with China. This trend aligns with the findings of Huang, Lenzen, and Malik (2019) and Kim and Tromp (2021), who observed an increasing trajectory in CO₂ emissions embodied in China's exports to developing countries until 2015.

Even though Argentina's trade dynamics with Brazil and China differ, there was a remarkable balance in the VA per unit of raw material traded with both countries. For instance, Brazil received about 20% more monetary compensation per unit of raw material, while Argentina received 40% more than China. These findings highlight the significance of South-South trade, where value-added per unit of material was more equitably distributed, in contrast to trade with more developed economies.

In trade with Brazil and China, the country with a positive net emissions surplus also consistently exhibited a favorable balance in terms of value-added. This suggests that greater environmental degradation, through higher GHG emissions and increased domestic raw material extraction, was at least accompanied by increased volumes of VA, partially compensating for the environmental costs. In contrast, this compensation is not present in the typical South-North trade pattern, where lower-income countries often bear more severe environmental consequences while reaping fewer economic benefits. As shown in Figures 1 and 2, South-North trade dynamics tend to disproportionately place the environmental burden on developing countries, leaving them with minimal VA gains in return. This disparity underscores the inequities in global trade, where developing economies absorb the environmental damage without receiving proportional economic returns, further reinforcing the need for more equitable trade frameworks.

In trade with the EU, Argentina experienced a combination of economic losses stemming from the low monetary value of goods exported concerning the high monetary values of imports, and on the other hand, ecological deterioration due to a higher level of GHG emissions associated with the production of goods which incorporate a higher quantity of energy and materials. These findings align with Pérez Rincón (2006), who described an ecological trap for commodity-exporting countries. When prices are low, an intense effect is generated through the intensified exploitation of natural resources to generate sufficient export volumes. Conversely, when prices are high, an extensive effect is generated by the expansion of the agricultural frontier. Furthermore, there is a specialization effect, related to the increased production of goods with the greatest comparative advantages, which in the case of peripheral countries like Argentina, are intensive in natural resources.

Empirical studies, such as that by Samaniego, Vallejo, and Martínez-Alier (2017), support these findings, showing a significant physical trade deficit during the commodity boom until 2012/13, where exports, measured in tones, far exceeded imports in peripheral countries like Argentina and other countries in South America. Additionally, they highlight that in contexts of monetary trade deficits, peripheral countries face increased biophysical effort, as larger volumes of natural resource exports are required to acquire monetary assets for importing goods and services, as well as meeting financial commitments.

In trade with the US, Argentina's agriculture, mining, and light manufacturing sectors consistently showed positive values, indicating economic benefits derived from primary and basic manufacturing exports, albeit at the expense of net environmental losses. However, the heavy manufacturing and service sectors exhibited significant VA deficits, combined with positive values of NC between 2002 and 2009, configuring the worst scenario with both net environmental and economic losses. From 2002 to 2008, the transport sector showed a slight positive NC and NVA balance, which shifted to positive NC and negative NVA subsequently.

Argentina consistently maintained a positive NC balance in bilateral trade with the US, while the NVA remained negative, resulting in net economic and environmental losses for Argentina every year, configuring a pattern of unequal trade in both economic and environmental dimensions, as in trade with the EU. This conclusion is reinforced when analyzing other material flows. During the 2000-2016 period, both the EU and the US imported, on average, significantly more resources from Argentina than they exported: 18 and 12 times more land, 35 and 16 times more water, and 7 and 9 times more raw materials, respectively. This clearly demonstrates that the EU and US not only generate higher value-added but also leverage this increased income to appropriate resources, perpetuating unequal exchange with lower-income nations like Argentina.

This configuration aligns with the existing literature on ecologically unequal exchange, which posits that peripheral countries, such as Argentina, often export natural resource-intensive goods with lower economic value while importing high-value added manufactured goods from core countries. Dorninger et al. (2021) underscore how significant disparities in the monetary compensation of materials, energy, land, and labor embedded in traded goods are often determined by a country's income level. Lower income countries find themselves positioned in global supply chains in such a way that results in lower compensation for the resources they export, while high-income nations, through the export of high value-added goods, accrue higher gross national income. This dynamic enables high-income nations to maintain their elevated dependencies on imported inputs, all while generating a monetary surplus from

the appropriation of resources. Studies by authors like Huang, Lenzen, and Malik (2019) and Kim and Tromp (2021) have highlighted similar patterns in other developing countries, where trade relationships with more industrialized nations result in significant environmental costs due to increased resource extraction and pollution.

In this context, Argentina's trade with the United States and European Union exemplifies the core-periphery dynamics raised by the approach of ecologically unequal exchange, wherein the peripheral country bears the brunt of environmental harm while gaining relatively little economic benefit. This underscores the need for policy interventions aimed at achieving more equitable and sustainable trade practices, both economically and environmentally.

A growing body of literature examines these impacts, highlighting how global environmental inequalities emerge from the uneven geography of value capture. In this context, GVCs serve as mechanisms for both value-added and CO₂ transmission (Dosi et al., 2024). Increasing evidence shows that without strategic management, GVCs can undermine development prospects for countries. The "smile curve" literature, for instance, underscores power dynamics in GVCs that favor advanced economies. These nations retain high-value activities like R&D and management while outsourcing lower-value, resource-intensive tasks, such as fabrication, to developing countries (Meng et al., 2020).

Althouse et al. (2023) distinguish between various trajectories within GVCs. They reveal that some developing countries, including Argentina, Brazil, and China, are experiencing an "ecologically perverse upgrading" trajectory. This situation is characterized by advancements in productive capacities and improved socio-economic indicators, but accompanied by a worsening environmental balance due to the overexploitation of domestic natural resources. However, they argue that most developing nations face "GVC marginalization," characterized by ecological degradation without corresponding socio-economic benefits.

The evidence presented in this essay suggests that Argentina's participation in GVCs can be categorized simultaneously into these two trajectories, depending on the trade partner. Trade with other countries in the Global South, such as Brazil and China, aligns with "ecologically perverse upgrading," while trade with the Global North, such as with the EU and US, follows a "GVC marginalization" pattern, leading to productive downgrading, social downgrading (lower wages), and environmental downgrading (increased ecological burden from low-end activities), consistent with findings by Dosi et al. (2024).

Regarding trade with the Rest of the World, Argentina consistently exhibited NVA surpluses in almost every period, except for 2000. These surpluses were accompanied by

positive NC values, indicating a scenario where Argentina achieved economic gains at the cost of heightened environmental impacts, like the case with Brazil. However, given the diverse composition of this aggregate, which includes both peripheral and core countries, it is challenging to determine a consistent pattern of ecologically unequal exchange. Detailed analyses of bilateral trade with each corresponding country would be necessary to draw more precise conclusions. Nonetheless, the economic gains observed suggest that the exchange is not entirely unequal in the economic sphere. This partial conclusion highlights the complexity and variability of trade relationships and the importance of considering both economic and environmental dimensions in assessing the impacts of international trade.

In scenarios where trade yields net economic benefits alongside environmental costs, such as in the case of Brazil, the surplus of VA offers an increased pool of financial resources that could potentially aid in financing the transition towards production processes with reduced environmental impact, thereby mitigating environmental losses. However, this transition is not automatic but rather requires active policies and consensus-building efforts to effectively channel the necessary resources for it.

The increasing exports of minerals to EU, driven, among other things, by the growing demand for the manufacturing of electric vehicles and consumer electronics, among other products, represent a contradiction for Argentina, as it incurs net environmental economic losses exporting materials that contribute to the energy transition in the EU, benefiting the latter both economically and environmentally. This observation aligns with the conclusions drawn by Muradian and Martínez-Alier (2001), which suggested that the relative dematerialization experienced by certain core countries was directly linked to the exploitation of natural resources in numerous peripheral countries.

Furthermore, the increased revenues derived by core countries, such as the EU and the US, from trade with peripheral countries, afford them the possibility to finance green industrial policies. These policies are directed towards fostering cleaner technologies for the productive activities that persist within their borders, as highlighted by Roberts and Parks (2007).

While reducing GHG emissions is a globally beneficial objective, the unequal distribution of economic and environmental benefits resulting from trade between developed and developing countries must be discussed. To make increased trade economically beneficial and environmentally friendly for Argentina as well as other peripheral countries, the need for transmission tools and financing of green technologies is emphasized, along with increased monitoring of natural resource exploitation and resolution of emerging socio-environmental conflicts. The environmental scenario becomes more complicated if Argentina faces balance of

payment restrictions, limiting its capacity to sustain economic growth and finance active policies for energy transition, climate change mitigation and adaptation.

Trade with the EU and US, in this regard, hinders Argentina's green transition in two ways. Firstly, the study clearly shows the environmental disadvantages of this trade relationships for Argentina. Secondly, significant deficits in VA during time lead to balance of payment restrictions that result in a constraint on economic growth. This severely limits the capacity to design and implement environmental policies while forcing the country to increase its specialization in primary products to meet financial commitments, increasing the depletion of natural resources, environmental pollution, and exacerbating socio-environmental conflicts (Samaniego, Vallejo, and Martínez-Alier, 2017).

3.6 Conclusions and Policy Implications

Based on the results of this study, it can be concluded that international trade has different economic and environmental outcomes for Argentina, depending on the trading partner involved. In the case of trade with Brazil, Argentina's main trading partner during the period 2000-2016 and a fellow member of the Mercosur regional organization, Argentina benefited economically throughout the analyzed period, with strong NVA surpluses. However, these economic benefits were accompanied by environmental costs stemming from the net positive balance of emissions embodied in trade with Brazil. A similar situation was observed in trade with the Rest of the World. NVA flows were strongly positive in every period analyzed, except for the year 2000. NC flows were significantly positive for most of the period, although they turned slightly negative from 2013 to 2016. Regarding trade with China, the findings reveal a notable upward trend in CO₂ emissions embodied in Chinese exports to Argentina, coupled with negative NVA flows for the latter. This suggests that Argentina has saved environmental costs at the expense of significant economic gains in bilateral trade with China.

Regarding trade with the European Union and the United States, Argentina demonstrates a pronounced specialization in natural resources and simple manufacturing. Sectors with higher VA, such as heavy manufacturing and services, consistently exhibited negative NVA throughout the entire period analyzed. This imbalance suggests that Argentina was exporting goods with lower VA while importing goods with higher VA, leading to unfavorable trade dynamics. Furthermore, the environmental impact of this trade relationship was substantial, with Argentina bearing considerable net environmental costs. This combination of economic disadvantages and environmental burdens clearly indicates a scenario of ecologically unequal exchange. Consequently, Argentina's trade with these core countries

not only undermines its economic development but also exacerbates its environmental degradation, highlighting the urgent need for policies aimed at diversifying exports and promoting sustainable development.

Negative NVA values in the energy sector with the RoW, as well as in the heavy manufacturing industry with China, provide evidence that Argentina experienced shifts in carbon emissions to other regions in these sectors. These shifts allowed Argentina to reduce domestically generated GHG emissions by externalizing them to supplier countries. By importing energy or energy-intensive products, such as those from the heavy manufacturing sector, Argentina saved on domestic emissions and their associated environmental costs. For manufactured products, the savings occurred because energy resources were not consumed to produce these goods locally. In the case of energy imports, although domestic consumption generates emissions locally, there is also a saving of emissions related to the extraction and production processes of various energy sources. This highlights the importance of increasing clean energy sources in Argentina, enabling the country to produce clean energy locally without relying on external sources and their consequent emission shifts.

Similarly, in the case of emissions shifts associated with heavy manufacturing imports from China, it is noteworthy that China is considered the world's largest energy consumer. Consequently, China is heavily dependent on coal, is the second-largest consumer of oil, and the fourth-largest consumer of natural gas, making it the largest absolute emitter of GHG (Oliveira et al. 2020). These characteristics position the Chinese economy as a major global polluter. Therefore, advancing the inclusion of clean energy sources in China will have significant effects on reducing global GHG emissions.

The increasing importance of trade with Brazil in value capture underscores the need for regional strategies that promote industrialization and economic diversification, reducing reliance on raw material exports. By shifting away from an extractive economic model, these strategies could help mitigate environmental issues like deforestation and land degradation, which are often linked to current trade patterns in developing economies. Encouraging the development of higher-value industries and integrating cleaner technologies would not only enhance economic resilience but may also support a sustainable development trajectory. This approach enables countries to generate value added domestically while minimizing ecological damage, ensuring that economic growth does not come at the expense of environmental sustainability.

Considering this, it is important to highlight the existence of a globalized production and trade structure that facilitates the transfer and externalization of GHG emissions between

countries, which negatively impacts global efforts to reduce global warming. Therefore, it is essential to consider not only production-based emissions when formulating policies aimed at reducing GHG emissions, but also consumption-based emissions for a more effective approach to addressing climate change.

It is also necessary to address the negative distributive impacts of mechanisms like CBAM or similar unilateral climate policies. Revenues generated from these mechanisms should prioritize supporting the transition to sustainable practices in developing countries, rather than reinforcing the competitiveness of European industries and facilitating their green transitions. Tariffs and policies imposed by industrialized nations often worsen the terms of trade for developing economies, placing an undue burden on them to reduce emissions and exacerbating existing income inequalities. Such dynamics effectively transfer the responsibility for climate action to countries with fewer resources, further entrenching global disparities (Böhringer et al., 2012).

Furthermore, environmental policies must consider not only the CO₂ and value added embodied in trade but also the natural resources involved, such as land and water. Peripheral countries often engage in large-scale extraction of these resources to produce export crops or raw materials, resulting in significant environmental degradation. This can occur even in the absence of carbon leakage, underscoring that environmental impacts extend beyond carbon emissions alone. Countries may deplete water resources or degrade land without gaining sufficient economic benefits, contributing to a net loss in both environmental and economic terms, particularly when trading with higher-income nations.

A global effort to combat climate change must support peripheral countries in their green transition by providing the necessary resources to finance green industrial policies. This financing should involve both direct resource transfers to facilitate an energy transition that reduces emissions from energy consumption and initiatives to increase the demand for higher VA products from peripheral countries. Such measures will enable these countries to diversify their export baskets and reduce their reliance on natural resource-based specialization. This, in turn, will mitigate the negative environmental impacts associated with commodity production and provide additional resources for further advancing the green transition.

Finally, it is crucial to recognize that while this study focuses on the effects of international trade on GHG emissions, numerous other dimensions of trade and natural resource-based specialization significantly impact sustainability. These include biodiversity losses, water pollution, soil degradation, and deforestation, all of which have far-reaching environmental, social, and economic consequences. A comprehensive approach to

sustainability must consider these interconnected issues, ensuring that policies aimed at reducing GHG emissions also address broader ecological impacts. By doing so, we can promote a more holistic and effective strategy for achieving long-term environmental sustainability.

CONCLUDING REMARKS

Throughout the three essays presented in this thesis, we have examined the specific challenges Argentina faces in advancing the green transition within a global context that demands urgent action on climate change. As a middle-income developing economy with a heterogeneous productive structure, high levels of informality, a trade pattern specialized on resource-based commodities, and persistent balance of payments constraints that hinder sustained economic growth—alongside rising poverty and other structural issues—the challenges are significant. However, opportunities also exist. This thesis has analyzed these dynamics from different theoretical and empirical perspectives, leading to key conclusions that will be briefly discussed in this final section.

A convergence was identified between the technological trap discussed in the evolutionary approach—stemming from challenges in learning and technology diffusion—and the vicious cycles analyzed within the structuralist tradition. These cycles are linked to a heterogeneous productive structure, marked by a strong dependence on low-technology sectors and an international trade specialization on natural resources. This combination constrains the capacity to generate and diffuse innovation, limiting participation in the most dynamic global markets. As a result, economic performance remains weak, restricting development prospects and exacerbating environmental challenges. While neo-Schumpeterian literature has extensively examined technology gaps, it has placed less emphasis on sustainability. Although the GWO framework addresses this intersection, structuralist perspectives offer valuable insights that further our understanding of the complex relationship between technological gaps and sustainable development.

The domestic-emission evidence in essay 2 reinforces this theoretical claim. The sectors that the SDA identifies as the largest contributors to Argentina's energy-intensity rise—commercial services, food, and resource-based manufacturing—are precisely those that dominate the low-technology pole of the productive structure described in essay 1. Their rigidity in recessions and rapid expansion in booms illustrate, in numerical form, the vicious circle whereby structural heterogeneity, weak learning, and environmental stress reinforce one another.

Building on the previous discussion, we have observed how Argentina's technological gap is reflected in a productive structure heavily concentrated in low-technology sectors with relatively lower productivity. This exacerbates structural heterogeneity, limiting energy efficiency and affecting negatively the adoption and diffusion of green and digital technologies—factors that contribute to higher GHG emissions. Thus, the interplay between technology diffusion (as emphasized in the evolutionary tradition) and the productive structure (a key concern of the structuralist tradition) reveals an environmental dimension linked to energy efficiency and green technology adoption. Furthermore, this dynamic shapes Argentina's trade specialization, which remains focused on primary products and resource-based manufacturing. This pattern places significant pressure on the environment, driving deforestation due to the expansion of the agricultural frontier and increasing pollution levels associated with raw material extraction.

The theoretical and qualitative case analysis presented in the first essay offered several policy implications, showing convergence along the theoretical approaches explored—Latin American structuralism, neo-Schumpeterian and the evolutionary perspectives, uncovering points of synergy and mutual reinforcement. A central element shared by these approaches is the recognition of the critical role of the state and institutions in steering the shift toward an environmentally sustainable economy.

According to the neo-Schumpeterian approach on GWO, the rapidly evolving technological landscape offers opportunities for developing countries to introduce new or improved products and services with reduced carbon footprints. This could assist these countries in narrowing development gaps, while mitigating climate change, and strengthening their position in GVCs. However, seizing these opportunities requires latecomer countries to increase innovation and digital capabilities, and establish or strengthen the required infrastructure and institutions, while overcoming financial obstacles. Moreover, success is highly dependent on preexisting conditions and capabilities, leading to a path-dependent outcome, as highlighted by the evolutionary approach. In this context, a country with an established capacity to manufacture medium and high technology products is better positioned to exploit these green opportunities. Conversely, nations mainly specialized in primary products face more limited starting points.

Structuralist approaches emphasize the relevance of broader macroeconomic policies, including trade, monetary, fiscal, and competition policies in shaping the effectiveness of STI policies. Adverse macroeconomic conditions—such as high inflation, significant external debt, elevated interest rates and more generally, volatile economic cycles—severely constrain long-

term investments in both physical and intellectual capital, which are essential for industrial and technological development. These challenges highlight the need for a more integrated policy approach between the different frameworks, aligning STI policies with macroeconomic strategies to overcome barriers to technological upgrading, productive transformation, and the green transition in developing countries.

Additionally, this essay examined the opportunities and challenges associated with Argentina's abundant unconventional gas reserves. These resources could serve to finance green industrial policies in Argentina, provided that risks of carbon lock-in and state capture are carefully managed. Moreover, gas exports could help ease Argentina's balance of payments constraint, contributing to economic stability. Coordinated actions across STI and energy policies are essential to achieving these objectives. Additionally, exporting gas to neighboring countries, and LNG to broader market could contribute to reducing global emissions, as long as the gas is used to displace higher emission fossil fuels such as oil and coal, which still dominate the global energy mix.

When analyzing the structural decomposition of GHG emission changes in Argentina across the period 2000-2016, as examined in the second essay, several key findings emerged. Alongside energy intensity, variations in domestic final demand were among the main drivers of emission changes throughout most of the period. Our empirical results highlight the significant impact of final consumption on emissions, suggesting that demand-side policies—those that shape both the level and composition of final demand—could play a crucial role in reducing emissions. However, such policies may conflict with the social and economic priorities of developing countries like Argentina, where economic growth remains essential for wealth generation and income distribution.

Notably, the effect of changes in the domestic demand mix on emissions was neutral over the period, making this a potentially more socially and politically viable alternative for policy intervention. The government could promote less energy-intensive consumption patterns through economic instruments such as higher carbon taxes and tax deductions or subsidies for energy-efficient products. Another policy option would be the introduction of carbon taxes specifically targeting more polluting goods consumed primarily by wealthier groups, thereby offsetting the emissions increase resulting from higher consumption levels among lower-income households. This approach would lead to a shift in the composition of final demand in a way that is more socially equitable. A future research agenda could further explore the economic, distributive, and environmental implications of imposing differentiated carbon taxes across products and services consumed by various income groups.

Moreover, the results of the SDA analysis suggested an inverse relationship between the contributions of energy intensity and final demand to emission changes during periods of economic growth and recession. The data indicate that during times of rapid economic expansion, energy efficiency improved, challenging the assumption that growth necessarily leads to worsening energy performance. Conversely, the evidence suggests that during economic downturns, energy efficiency tends to deteriorate. While this analysis did not establish a direct causal relationship between these variables, the findings imply a potential decoupling between economic growth and energy consumption. This contributes to the ongoing debate on the relationship between growth and emissions, suggesting that the increase in final demand did not undermine energy efficiency; rather, it appears to have enhanced it.

Furthermore, the analysis identified a few key sectors as the main contributors to emission changes, including commercial and public services, the food industry, the chemical and petrochemical industries, and other manufacturing sectors. Promoting energy efficiency within these sectors is critical to facilitate improvements in their energy use and emissions performance.

The analysis of Argentina's emissions and value-added embodied in trade performed in the third essay, revealed no clear pattern of ecologically or economically unequal exchange with Brazil and China. The predominance of intra-industry trade with Brazil promoted by Mercosur—where similar products are both exported and imported—was highlighted. In contrast, trade with China exhibits a marked comparative advantage in China's manufacturing, service, and transport industries, which has significantly contributed to the widening imbalance in value-added and carbon emissions embodied in bilateral trade over the years. These findings suggest that while Argentina has reduced its local environmental impacts through trade with China, it has done so at the expense of substantial economic losses. This trend aligns with the findings of Huang, Lenzen, and Malik (2019) and Kim and Tromp (2021), who observed a rise in GHG emissions embodied in China's exports to developing countries until 2015.

Despite the distinct trade dynamics with Brazil and China, a notable balance was observed in VA per unit of raw material traded with both countries. For instance, Brazil received about 20% more monetary compensation per unit of raw material than Argentina, while Argentina, in turn, obtained 40% more than China. These findings highlight the relative equity in value-added distribution within South-South trade, in contrast to the more asymmetric patterns typically seen in trade with developed economies.

Furthermore, in trade with both Brazil and China, the country with a net emissions surplus also consistently exhibited a favorable VA balance. This suggests that greater

environmental degradation—through higher GHG emissions and increased domestic raw material extraction—was at least partially offset by increased economic gains. In contrast, this form of compensation is absent in the typical South-North trade pattern, where lower-income countries endure greater environmental damage while receiving disproportionately lower economic returns.

Argentina's trade with the European Union and the United States exemplifies this unequal dynamic. Argentina faced economic disadvantages due to the low monetary value of its exports relative to the high value of its imports, coupled with significant environmental degradation. During the 2000–2016 period, both the EU and the US imported substantially more resources from Argentina than they exported: 18 and 12 times more land, 35 and 16 times more water, and 7 and 9 times more raw materials, respectively. This pattern underscores how developed economies generate higher VA while they appropriate resources from the Global South, perpetuating ecologically unequal exchange.

Argentina's trade with the US and EU reflects the core-periphery dynamics central to the theory of ecologically unequal exchange, where peripheral countries endure greater environmental deterioration while receiving disproportionately fewer economic benefits. Addressing these disparities requires policy interventions that foster more equitable and sustainable trade. As noted earlier, cooperation mechanisms, financing, and trade standards tailored to national contexts are essential. It is also necessary to address the negative distributive impacts of mechanisms like CBAM or similar unilateral climate policies. Core economies can play a key role by increasing demand for high-value and green products from peripheral countries through enhanced trade agreements. This is especially relevant for lithium and other critical minerals vital to the energy transition, which Argentina and other South American nations primarily export as raw materials. A regional industrialization strategy that adds value to these resources—supported by demand from developed economies—could contribute to the green transition in peripheral countries, improve trade balances, and sustain higher growth rates within external constraints, thereby advancing economic development.

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APPENDICES

Appendix A: allocating sectorial energy consumption from IEA energy balances

The energy balances are presented in tabular format: columns for the various sources of energy and rows for the different origins and uses (IEA). They present, in the first rows, the data related to the total primary energy supply, that is, the production of coal, crude oil, petroleum derivatives, natural gas, nuclear energy, hydroelectricity, biofuels, and other renewable sources. As can be seen in the first rows of table 20, the primary supply of energy is given mainly by local production, added to imports, less exports. The total of these elements constitutes the total primary energy supply, made up of primary energy sources, such as coal, crude oil, natural gas, together with biofuels and renewable energy sources. Petroleum derivative products, as well as electricity from thermal sources, come mainly from imports, since they are secondary sources, and their transformation process is detailed in the following rows of the energy balance.

In the following rows, from Transfers to Losses, it is presented the transformation of energy from primary sources (coal, crude oil and natural gas) to secondary sources (oil derivatives, electricity). Here it is shown the use of primary and secondary fuels for the production of electricity as negative entries. In this sense, total gross electricity produced appears as a positive quantity in the electricity column and in the Electricity plants row, while transformation losses appear in the total column as a negative number. In the same way, the row Oil refineries shows the use of primary energy for the manufacture of finished petroleum products and the corresponding output (positive value in the column Oil Products). Thus, the total reflects transformation losses (IEA, 2016). For illustrative reasons, we added the row Total Energy Transformation, where we sum up all the intermediate consumption and output of primary and secondary sources of energy. As it can be seen, the total column yields a negative value, which reflects the consumption of energy in the energy transformation process. Adding this value to the Total primary energy supply, equals the total final consumption (TFC), which is the sum of energy (in both primary and secondary forms) consumption by the different end-use sectors (consumption by industrial sectors, agriculture, transport, etc.).

Table 18: Energy Balance, Argentina, 2016 (thousand tons of oil equivalent)

Supply and consumption	Coal	Crude oil	Oil products	Natural gas	Nuclear	Hydro	Biofuels/waste	Electricity	Total
Production	14	29546		35963	2159	3207	4826		75764

Imports	819	790	6476	8740				847	1767
Exports	-36	-2332	-1542	-51			-1448	-28	-5437
Total primary energy supply	824	28068	3096	44652	2159	3207	3378	819	8625
Transfers		927	-354						573
Statistical differences	28	784	29	-487			10	0	364
Electricity Plants	-		-4886	-	-2159	-	-576	12616	-
	643			15579		3207			1448
Blast furnaces	-								-
	192								192
coke/pat.fuel/BKP/ PB plants	204		-557						-353
Oil refineries		-30329	29703						-626
Petrochemical plants		640							640
Other transformation							-144		-144
Energy industry own use		-90	-1409	-6235				-333	-8067
Losses				-213				-1757	-1970
Total energy transformation	-	-28068	22526	-	-2159	-	-710	10526	-
	603			22514		3207			2425
Total final consumption	220	0	25623	22137	0	0	2668	11344	6199
									2

Source: Own elaboration from IEA Energy Balance.

The energy consumption reported in the balance was assigned to the different sectors of the input-output matrix, using the sectoral correspondence table 21 in appendix B. Most of the sectors included in the input-output matrix can be grouped into the different sectors that are part of the Total Final Consumption aggregate in the energy balance. However, for the energy consumption of the Electricity and Gas sector, data from the energy transformation section of the energy balance were extracted. Likewise, although the Petrochemical sector is reflected in the Total Final Consumption aggregate, in order to reflect the energy consumption of the processes of transformation of crude oil into petroleum derivatives, this information was supplemented with data from the energy transformation section.

In this way, the totals of the Electricity Plants rows, and other rows related to the Electricity and Gas transformation processes, were attributed to this sectoral aggregate. In the same way, the totals of the rows of Petrochemical Plants, Liquefaction Plants, and other rows and cells related to the own consumption of coal and oil, were assigned to the Petrochemical aggregate.

Appendix B: reconciliation of sector aggregation from different data sources

Table 19: reconciliation of EORA input-output matrix and energy balance sectors.

EORA Sectors	Abbreviation	Energy balance sectors
Agriculture	Agriculture	Agriculture
Fishing		
Mining and Quarrying	Mining and Quarrying	Non metallic minerals
		Mining and Quarrying
Food & Beverages	Food	Food and tobacco
Textiles and Wearing Apparel	Textiles	Textile and leather
Wood and Paper	Wood and Paper	Paper pulp and printing
		Wood and wood products
Metal Products	Metal Products	Iron and steel
		Non ferrous metals
Petroleum, Chemical and Non-Metallic Mineral Products	Chemical and petrochemical	Chemical and petrochemical + Data from transformation matrix
Electrical and Machinery	Transport Equipment and machinery	Transport equipment
Transport Equipment		Machinery
Other Manufacturing	Other Manufacturing	Construction
Construction		Non specified
Transport	Transport	Transport
Recycling	Commercial and public services	Commercial and public services
Maintenance and Repair		
Wholesale Trade		
Retail Trade		
Hotels and Restaurants		
Post and Telecommunications		
Financial Intermediation and Business Activities		
Public Administration		
Education, Health and Other Services		
Private Households		
Others		
Electricity, Gas and Water	Electricity and gas	Data from transformation matrix

Appendix C: deflation procedures of current-price IO tables

The construction of input-output tables at constant prices is a necessary step prior to any type of SDA analysis. In the process of converting domestic currencies to a common currency at constant prices, a series of deflators and currency conversion rates must be chosen.

In this regard, according to Lan et al (2016), there are two main methods generally used in empirical studies to carry out this deflation procedure:

1. Convert, first of all, the values of the national currencies to a common currency (usually US dollars), using converters (official exchange rates and exchange rates adapted to purchasing power parity are the most used), and then apply deflators (price indices) from the United States, which account for the variability of price levels, to express the data in constant prices.
2. First deflate the values of domestic currencies using the corresponding deflators, which account for the temporal variability in local price levels, and then convert these data into a common currency (for example, United States dollars) using the appropriate converters.

For the procedure of deflation of the values of the matrices, there are 3 types of alternative methodologies. The simplest consists of using a general deflator of the gross product, either at the sectoral or general level, which accounts for the variation in the general level of prices, and apply it to the entire matrix, for all the years in which prices are to be converted into constants. However, this method, by applying a single deflator, assumes that all sectors experience the same price evolution, both at the producer level and for the different components of final demand.

Alternatively, specific deflators could be used for each sector, either for intermediate consumption or for final demand, which give a more detailed account of the evolution of prices in each of the branches according to the type of demander, which increases significantly the data requirement.

Finally, specific deflators can be used for each cell of the input-output matrix. Although this type of deflator is more precise than the previous ones, since it accounts for the fact that the same product can be sold at different prices for the different demanding sectors, it is not always feasible, due to the high data requirements that entails. To carry out this methodology, it is necessary to have input-output matrices at constant prices and current prices, for each year.

Thus, by comparing the current and constant values for each year, a specific deflator can be calculated for each cell of the input-output matrix.

On the other hand, in order for the input-output matrix to remain balanced at constant prices, the double deflation method can be used, which is upon the most widely used in empirical studies. Using this method, the gross product, together with the intermediate consumption and final products of each sector, are deflated using a price index, under the assumption that each sector produces only one homogeneous good. In this way, the value added of each sector is obtained from the difference between the deflated sectoral output, and intermediate consumption together with imports at constant prices.

It is worth noting the study by Dietzenbacher and Temurshoev (2012), which evaluates whether the results of input-output impact analyses differ significantly depending on the type of deflator used. Specifically, the study compares the outcomes when data from the matrices are deflated using three different types of deflators. This analysis was conducted using Denmark's input-output matrices for the years 2001-2007, with the aim of predicting vectors of gross outputs and employment based on an exogenous final demand.

This study concludes that the results of the input-output impact analyses are very similar between the different methodologies, as long as one of the 3 types of deflators mentioned above is used. Based on this, the method that uses the gross product deflator is recommended, due to its simplicity and the fact that it does not require the availability of input-output matrices at constant values. Whenever input-output matrix data at constant values are available, it is recommended to deflate the final demand vector from current to constant values, and then use that vector to estimate output values using the constant-value matrices.

Appendix D: Empirical results for the period 2000-2005 and 2000-2016

Table 20: Sectoral structure of GHG emissions, 2000-2005

Sector/Effect of	Final demand					Exports	Carbon intensity	Energy intensity	Technology
	Domestic demand			Total DD					
	DDL E	DDM E	DDD E						
Agriculture	-8,6	-0,3	-0,2	-9,2 (4%)	0,5 (8%)	-3 (-20%)	16,1 (7%)	-1,9 (15%)	
Mining and quarrying	-2,3	-0,1	0,0	-2,4 (1%)	0,7 (9%)	0 (0%)	4,9 (2%)	-1,7 (13%)	
Food	-18,0	-0,4	-0,3	-18,7 (9%)	0,8 (11%)	3,2 (21%)	19,1 (8%)	-1,2 (10%)	
Textiles	-6,1	0,2	-0,1	-6,1 (3%)	0,1 (2%)	-0,2 (-2%)	7,6 (3%)	-0,4 (3%)	
Wood and paper	-5,2	0,0	0,0	-5,2 (3%)	0,2 (2%)	1,3 (8%)	4,9 (2%)	-0,1 (1%)	

Metal products	-3,9	0,2	-0,2	-3,9 (2%)	0,6 (9%)	0,5 (3%)	5,4 (2%)	-1,5 (12%)
Chemical and petrochemical	-11,9	0,0	-0,3	-12,2 (6%)	0,7 (9%)	22,7 (150%)	-5,2 (-2%)	-2 (16%)
Transport equipment and machinery	-8,9	0,0	0,4	-8,5 (4%)	0,5 (6%)	10,1 (67%)	1,8 (1%)	-0,3 (2%)
Other Manufacturing	-17,1	0,2	1,6	-15,2 (7%)	-0,4 (-5%)	0,8 (5%)	16,1 (7%)	0,3 (-2%)
Transport	-11,0	-0,1	0,0	-11,1 (5%)	0,8 (11%)	2,4 (16%)	10,8 (5%)	-1,2 (9%)
Commercial and public services	111,6	0,3	-0,9	-112,2 (54%)	2,6 (36%)	-21,7 (-144%)	142,1 (62%)	-2,3 (18%)
Electricity and gas	-5,0	0,0	0,0	-5,1 (2%)	0,2 (2%)	-0,9 (-6%)	6,5 (3%)	-0,3 (3%)
Total	209,7	-0,1	0,1	-209,7	7,2	15,1	230,1	-12,7

Source: own elaboration from EORA MRIO database

Table 21: Sectoral structure of GHG emissions, 2000-2016

Sector/Effect of	Final demand							
	Domestic demand			Total DD	Exports	Carbon intensity	Energy intensity	Technology
	DDL E	DDM E	DDDE					
Agriculture	0.2	2.0	-0.3	1.9 (43%)	1.7 (15%)	-4.8 (4%)	1.7 (1%)	2.5 (-33%)
Mining and quarrying	0.1	0.5	-0.1	0.5 (11%)	1.8 (16%)	-2.6 (2%)	-1.2 (-1%)	2.8 (-37%)
Food	0.4	1.8	-1.2	1.1 (24%)	1.2 (11%)	-39.9 (37%)	44.2 (29%)	-2.1 (28%)
Textiles	0.1	-0.6	-0.2	-0.7 (-17%)	0.2 (1%)	-13.5 (12%)	15.8 (11%)	-0.4 (5%)
Wood and paper	0.1	-0.2	-0.1	-0.2 (-4%)	0.2 (2%)	-3.6 (3%)	6 (4%)	-1 (13%)
Metal products	0.1	-0.3	0.3	0.1 (3%)	0.4 (3%)	-1.2 (1%)	3.4 (2%)	-1.2 (16%)
Chemical and petrochemical	0.3	0.4	0.0	0.7 (16%)	0.4 (3%)	20.5 (-19%)	-15.8 (-11%)	-1.2 (16%)
Transport equipment and machinery	0.2	-0.8	-0.3	-0.9 (-20%)	0.8 (7%)	-24.3 (22%)	29.5 (20%)	-0.9 (12%)
Other Manufacturing	0.4	0.0	-1.1	-0.7 (-16%)	-0.1 (-1%)	3.4 (-3%)	-0.3 (0%)	-0.1 (1%)
Transport	0.3	0.2	-0.7	-0.2 (-4%)	0.9 (8%)	-0.1 (0%)	2.3 (2%)	-0.5 (6%)
Commercial and public services	2.7	-3.1	2.5	2.1 (47%)	3.9 (34%)	-39 (36%)	62 (41%)	-6.2 (82%)
Electricity and gas	0.1	0.8	-0.2	0.7 (16%)	0.3 (2%)	-4.3 (4%)	3.4 (2%)	0.8 (-10%)
Total	5.1	0.8	-1.5	4.4	11.7	-109.4	150.9	-7.6

Source: own elaboration from EORA MRIO database

Appendix E: Emissions and energy multipliers, and linkages

Table 22: Emissions multipliers, 2000-2016

Sector/ Year	2000	2005	2010	2016
Agriculture	0.0008	0.0015	0.0009	0.0007

Mining and quarrying	0.0007	0.0012	0.0008	0.0005
Food	0.0005	0.0011	0.0006	0.0006
Textiles	0.0006	0.0013	0.0008	0.0008
Wood and paper	0.0006	0.0013	0.0008	0.0008
Metal products	0.0008	0.0015	0.0009	0.0010
Chemical and petrochemical	0.0008	0.0016	0.0010	0.0010
Transport equipment and machinery	0.0006	0.0012	0.0007	0.0008
Other Manufacturing	0.0005	0.0009	0.0006	0.0005
Transport	0.0007	0.0014	0.0008	0.0008
Commercial and public services	0.0015	0.0029	0.0018	0.0016
Electricity and gas	0.0006	0.0013	0.0008	0.0006

Source: own elaboration from EORA MRIO database

Table 23: Energy multipliers, 2000-2016

Sector/ Year	2000	2005	2010	2016
Agriculture	0.0001	0.0003	0.0002	0.0002
Mining and quarrying	0.0001	0.0002	0.0001	0.0001
Food	0.0000	0.0000	0.0000	0.0001
Textiles	0.0000	0.0000	0.0000	0.0000
Wood and paper	0.0000	0.0001	0.0000	0.0001
Metal products	0.0002	0.0004	0.0002	0.0003
Chemical and petrochemical	0.0002	0.0002	0.0001	0.0001
Transport equipment and machinery	0.0000	0.0000	0.0000	0.0000
Other Manufacturing	0.0002	0.0003	0.0002	0.0002
Transport	0.0007	0.0011	0.0007	0.0007
Commercial and public services	0.0000	0.0001	0.0000	0.0000
Electricity and gas	0.0011	0.0024	0.0022	0.0017

Source: own elaboration from EORA MRIO database

Table 24: Backward linkages, 2000-2016

Sector/ Year	2000	2005	2010	2016
Agriculture	1.6147	1.5756	1.5488	1.5747
Mining and quarrying	1.4085	1.4129	1.3989	1.6362
Food	2.1551	2.0513	2.0391	2.0997
Textiles	2.0600	1.9274	1.9306	2.0670
Wood and paper	1.8467	1.7265	1.7301	1.7816
Metal products	1.9610	1.7517	1.7300	1.8533
Chemical and petrochemical	1.7677	1.6081	1.6165	1.8361
Transport equipment and machinery	1.7279	1.4732	1.4911	1.6159
Other Manufacturing	1.7320	1.6421	1.6495	1.7254
Transport	1.4652	1.4337	1.4210	1.4803
Commercial and public services	1.3437	1.3414	1.3302	1.3100
Electricity and gas	1.7409	1.6664	1.6567	1.6625

Source: own elaboration from EORA MRIO database

Appendix F: Database aggregation for Essay 3

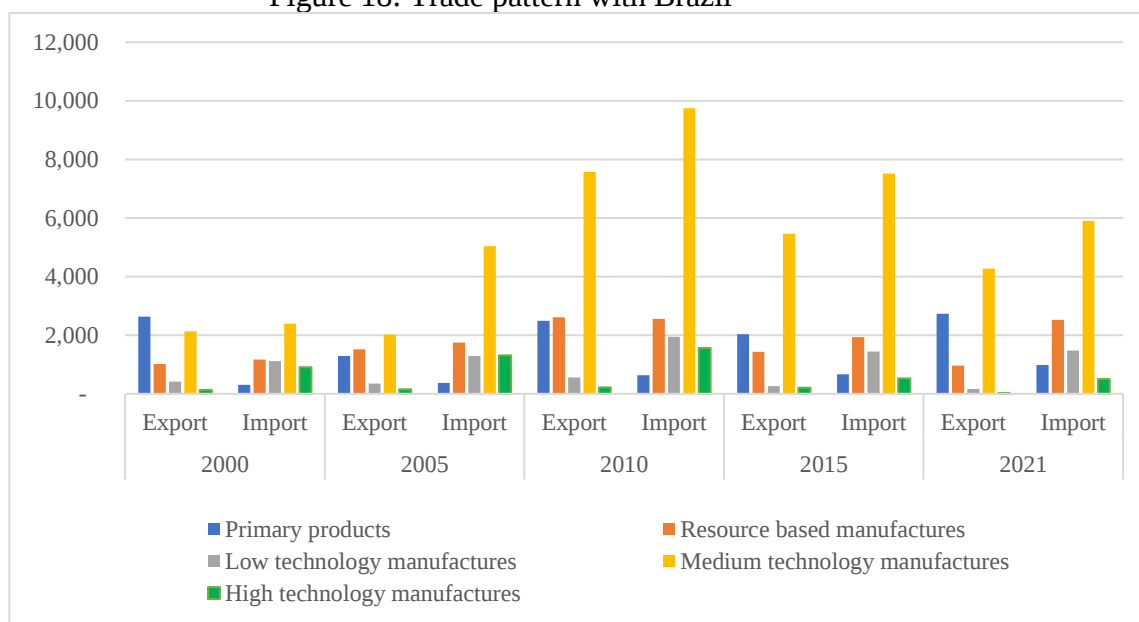
Table 25: EORA sector aggregation

EORA Sectors	Abbreviations
Agriculture	Agriculture
Fishing	Agriculture
Mining and Quarrying	Mining
Food & Beverages	Light Manufacturing
Textiles and Wearing Apparel	Light Manufacturing
Wood and Paper	Light Manufacturing
Petroleum, Chemical and Non-Metallic Mineral Products	Heavy Manufacturing
Metal Products	Heavy Manufacturing
Electrical and Machinery	Heavy Manufacturing
Transport Equipment	Heavy Manufacturing
Other Manufacturing	Heavy Manufacturing
Recycling	Light Manufacturing
Electricity, Gas and Water	Energy
Construction	Heavy Manufacturing
Maintenance and Repair	Service
Wholesale Trade	Service
Retail Trade	Service
Hotels and Restaurants	Service
Transport	Transport
Post and Telecommunications	Service
Financial Intermediation and Business Activities	Service
Public Administration	Service
Education, Health and Other Services	Service
Private Households	Service
Others	Service
Re-export & Re-import	Service

Source: own elaboration in base of Wang and Yang (2020).

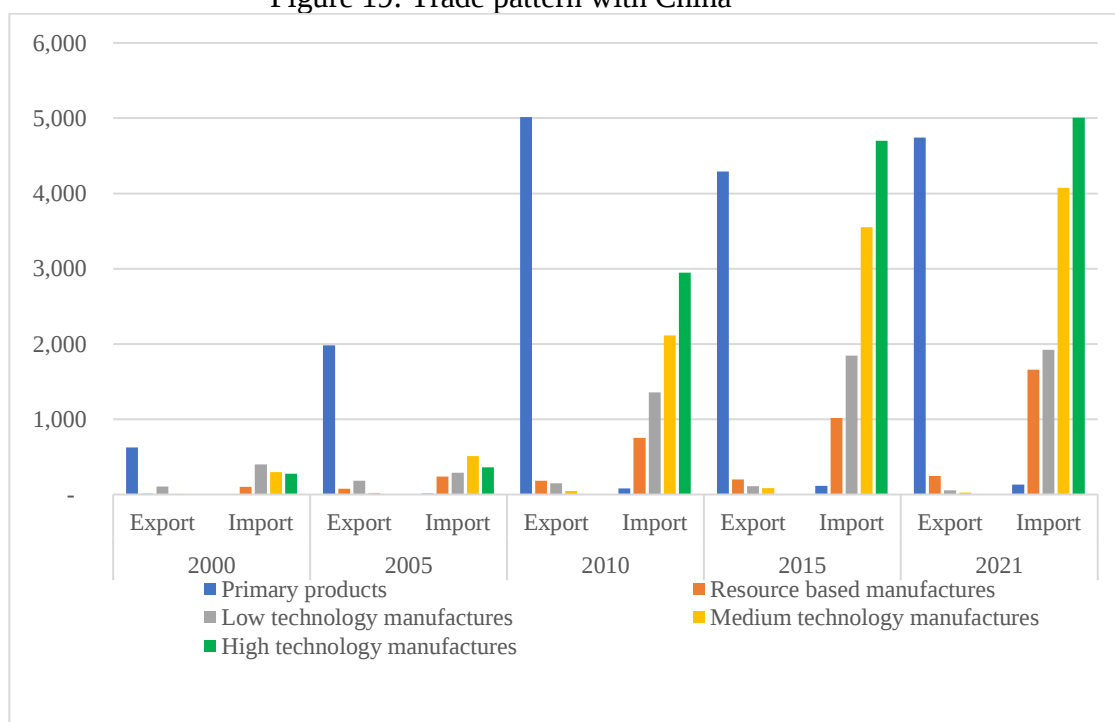
Appendix G: Argentina's trade pattern with its main partners

Figure 18: Trade pattern with Brazil



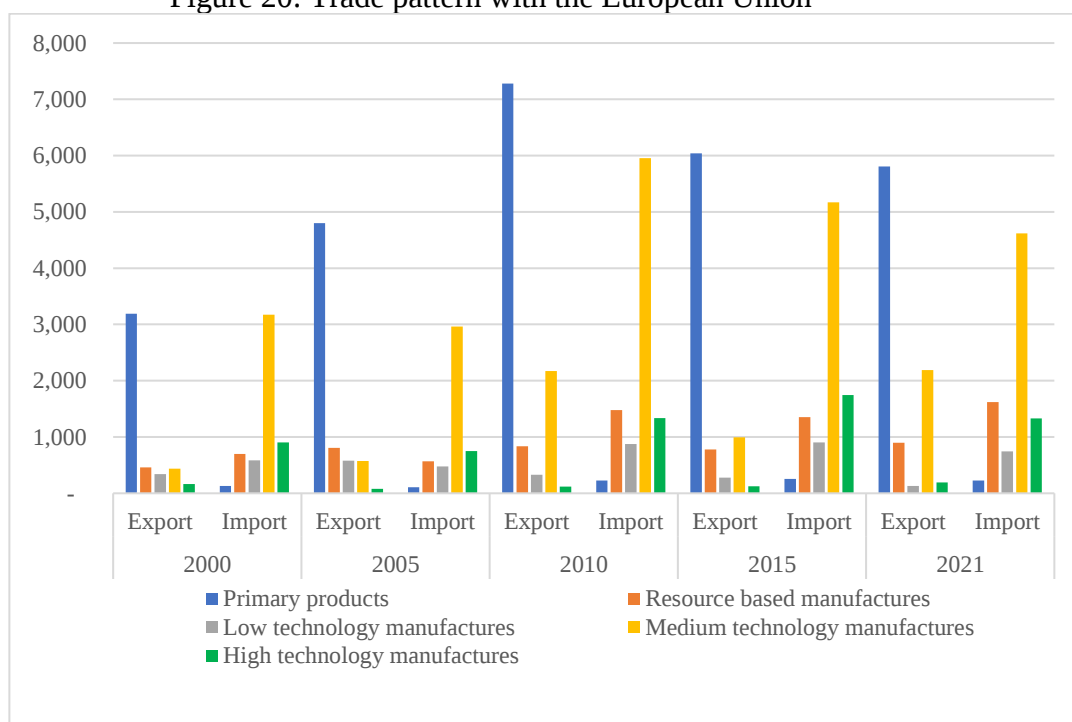
Source: own elaboration from COMTRADE.

Figure 19: Trade pattern with China



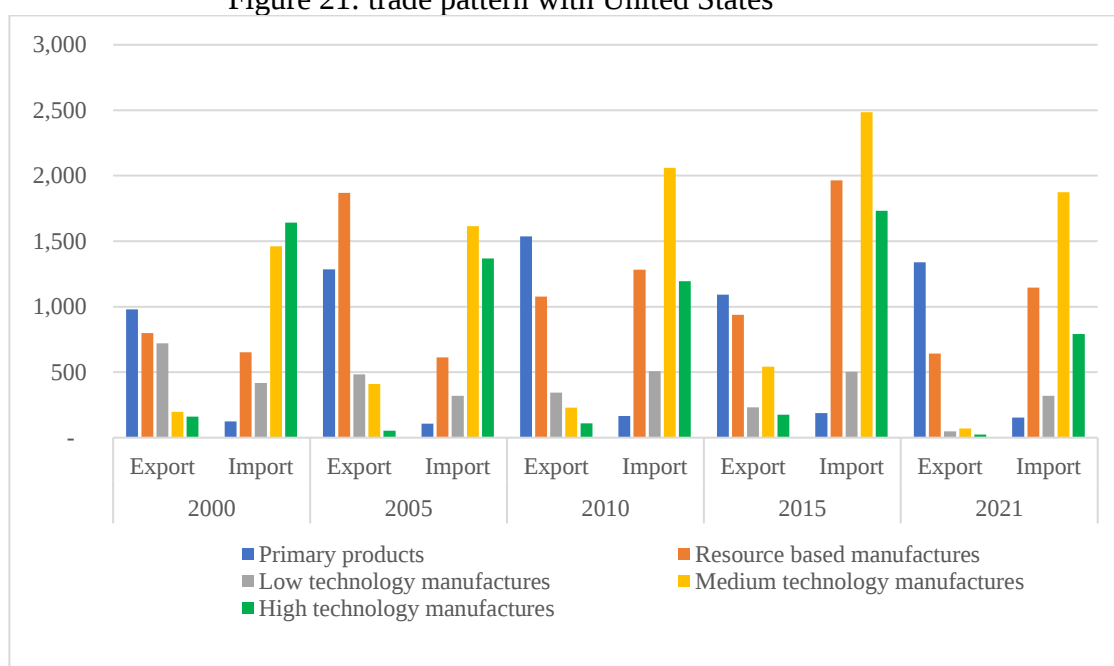
Source: own elaboration from COMTRADE.

Figure 20: Trade pattern with the European Union



Source: own elaboration from COMTRADE.

Figure 21: trade pattern with United States



Source: own elaboration from COMTRADE.

Appendix H: Water, Land, Raw Materials and VA embodied in imports and exports in Argentinian trade.

Figure 22: Land Embodied in Exports and Imports for Argentina (in Thousands of Hectares)

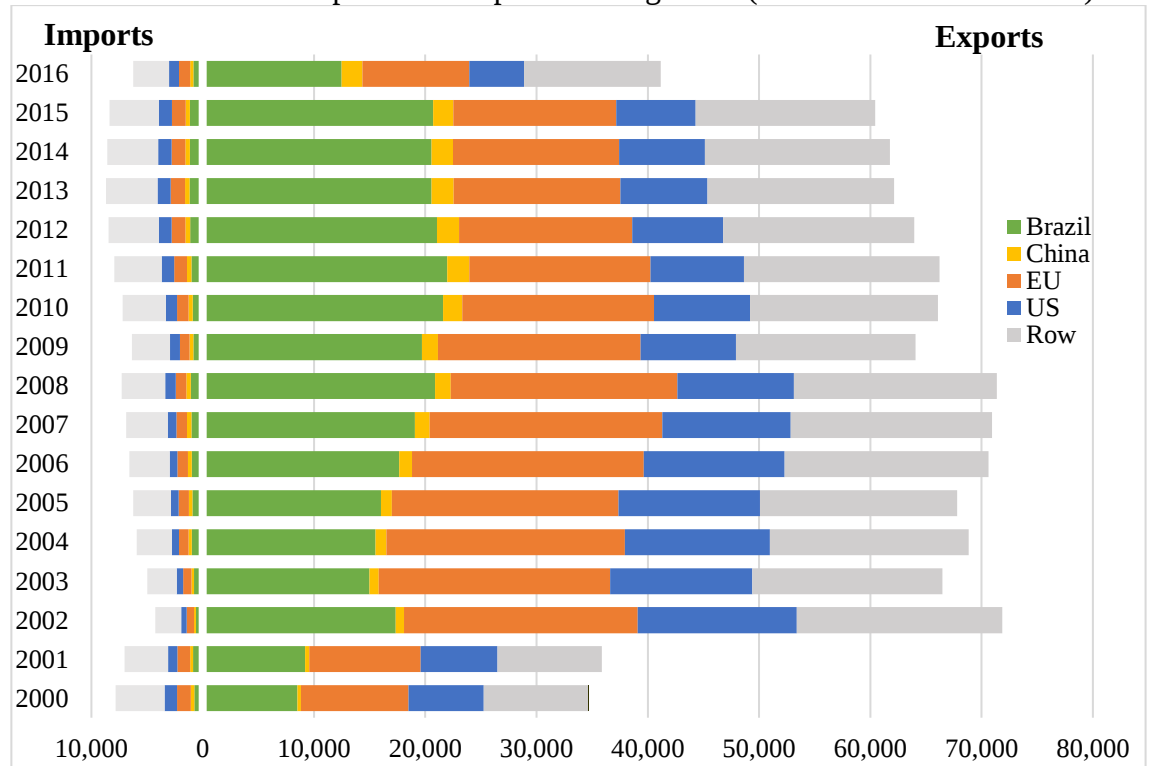


Figure 23: Water Embodied in Exports and Imports for Argentina (in million cubic meters)

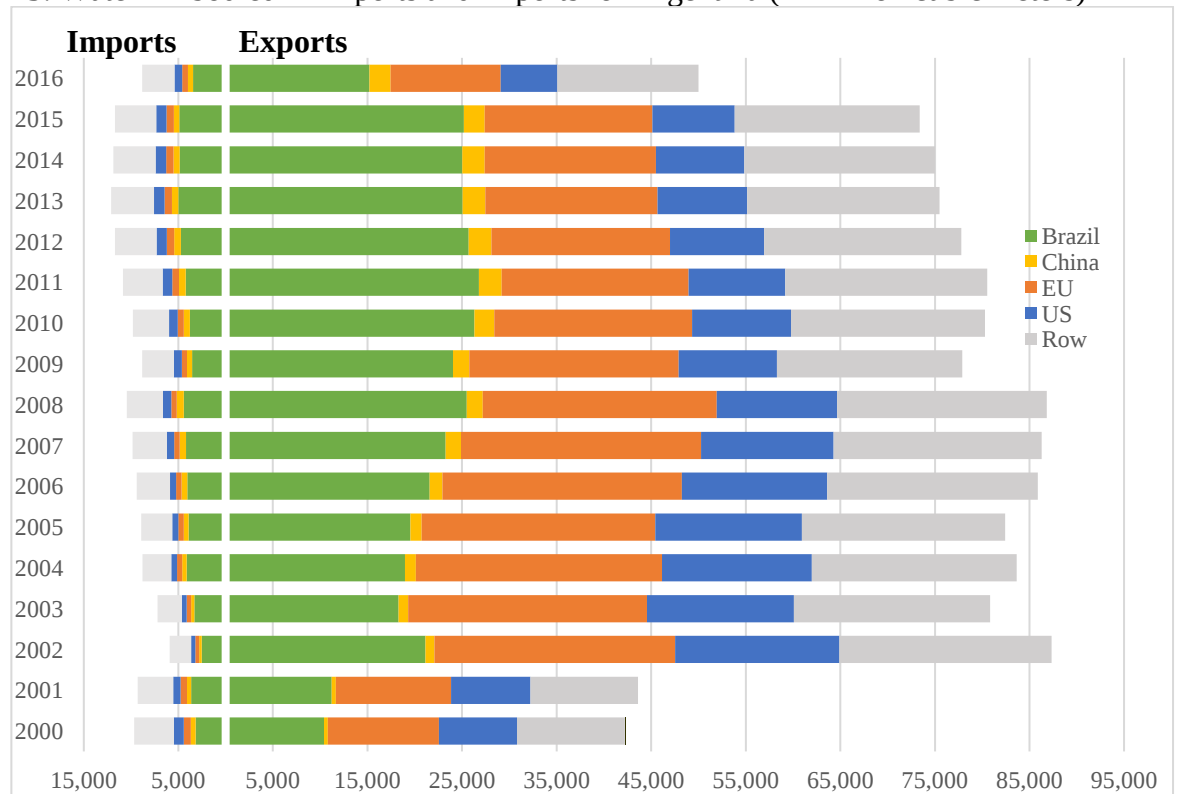


Figure 24: Raw materials embodied in Exports and Imports for Argentina (in million tons)

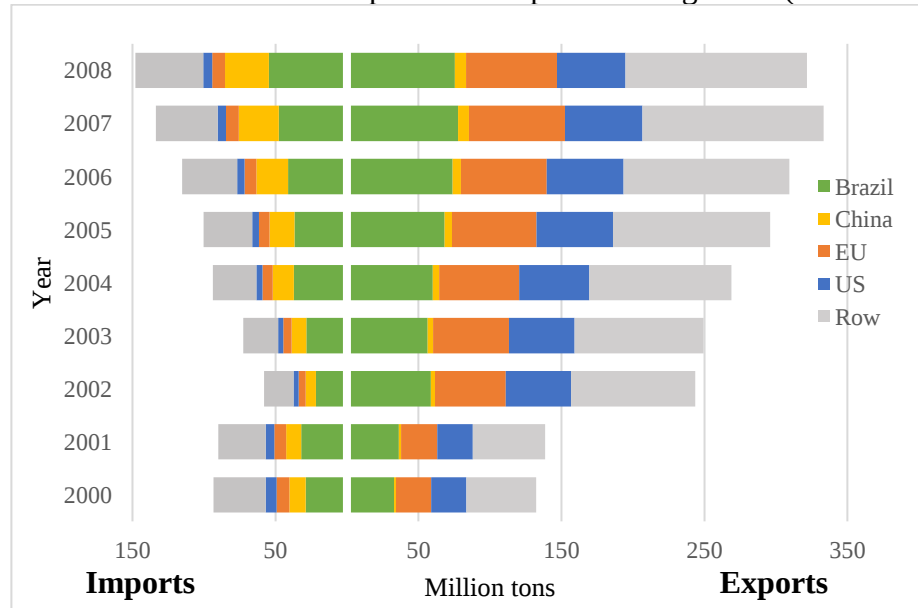
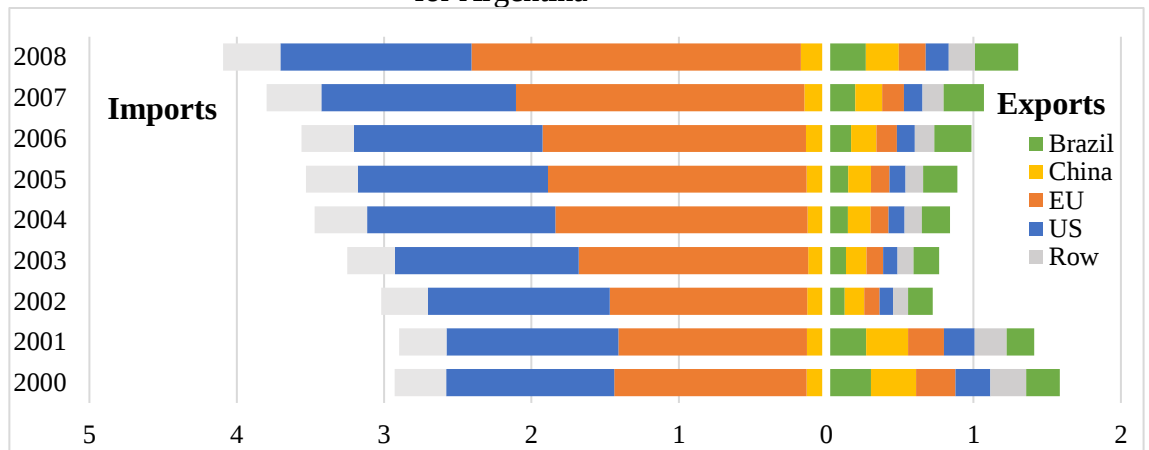


Figure 25: VA (thousand dollars) per tons of raw materials embodied in Exports and Imports for Argentina



Source: own elaboration from EORA database.