

Environmental Degradation and the Omitted Side of the Dutch Disease: Evidence on the Brazilian Economy (2003-2022)

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Abstract

While major economies have sought to reduce greenhouse gas emissions in line with the Paris Agreement, Brazil has experienced rising emissions since 2010, driven mainly by renewed deforestation and agricultural frontier expansion. This article investigates the relationship between Dutch disease, understood as reprimarization and premature deindustrialization, and environmental degradation in Brazil. Using a dynamic panel data model for Brazilian states from 2003 to 2022, the study shows that a commodity-export-led development pattern has intensified ecological degradation while constraining productive sophistication. The findings support the existence of an environmental Dutch disease in Brazil.

Keywords: Dutch disease, CO₂e emissions, Brazilian economy, Ecological transition.

JEL Code: 044; Q54; L52.

1. Introduction

Environmental challenges have garnered increasing attention over recent decades, primarily due to the accelerating impacts of climate change on human well-being, ecosystems, and the global economy.

In response, 195 countries ratified the Paris Agreement in 2015, committing through Nationally Determined Contributions (NDCs) to reduce greenhouse gas (GHG) emissions with the aim of limiting global warming to 1.5°C above pre-industrial levels, or, under more conservative scenarios, to 2°C (IPCC, 2023). Various regions, notably Europe and China, have undertaken comprehensive strategies and investments to achieve substantial GHG reductions by 2030 and to reach climate neutrality by 2050 (European Commission, 2018; Climate Action Tracker, 2024; European Council, 2024).

Although Brazil is also a signatory and initially pledged to cut emissions by 37% by 2025 and 43% by 2030, these targets appear increasingly unattainable given the persistent rise in deforestation and other emission sources. Despite updates to its NDCs, Brazil's GHG emissions remain elevated, driven primarily by land use and forest changes alongside growing contributions from agriculture, livestock, and the energy sector (SEEG, 2023, 2025). At the core of this regressive trajectory is the trend, since the early 2000s, of a growth model based on the reprimarization of the

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economy, or neo-extractivism, which intensifies the challenges of balancing economic development with urgent environmental goals, an equilibrium critical to contemporary policy discourse.

In the current Brazilian development model, the continuous increase in the production of primary and natural resource-intensive goods requires growing land occupation, generally through illegal burning and deforestation, pushing agricultural and mineral frontiers to the limits of the Amazon rainforest. The negative impacts of this model are precisely the destruction of fauna and flora, exposure of soil to erosive processes with changes in the quantity and quality of surface and underground water resources, unbridled increase in pollutant gas emissions, among other aspects that significantly contribute to global warming and climate change.

These environmental outcomes are not merely collateral effects of Brazil's growth strategy but reflect a largely neglected dimension of the Dutch disease phenomenon that has affected the country for decades. Traditionally, Dutch disease has been associated with the processes of reprimarization and premature deindustrialization of the Brazilian economy, which help explain its weak technological dynamism and low productivity growth over time. Yet, the environmental costs embedded in this development trajectory remain insufficiently explored, both in the empirical literature and in policy debates that aim to reconcile economic development with environmental and climate sustainability.

From this perspective, transitioning to a green economy emerges as both a critical imperative and a strategic opportunity for Brazil to address the structural constraints imposed by Dutch disease while advancing sustainable development over the coming decades. This process involves profound transformations in productive, technological, and institutional paradigms, with significant implications for industry, agriculture, and services. In particular, the industry plays a fundamental role in this transition, both as a sector to be transformed and as the main source of innovations and the diffusion of sustainable technologies (Rodrik, 2022; Mazzucato, 2021). In other words, to seize the opportunities presented by this new global economic landscape and engender a trajectory of sustained long-term growth, it is imperative for Brazil to undergo an ecological structural change that significantly increases the participation of the green manufacturing sector in the economy and drives ecological technological progress and environmental efficiency.

This paper investigates the interrelations between Dutch Disease, productive structure, and their implications for economic development and environmental degradation in Brazil. It also identifies key challenges to the ecological transition of the Brazilian economy, highlighting the crucial role of the industrial sector in this process. The study employs a dynamic panel data model for Brazilian states from 2003 to 2022 to test the hypothesis that Dutch Disease in Brazil has intensified environmental degradation.

In addition to this introduction, the paper is organized into six sections. The second section presents the theoretical and empirical foundations of Dutch Disease and its implications, while also establishing a connection between Dutch Disease and environmental degradation. The third section examines Brazil's current model of economic development, emphasizing its effects on the productive structure and environmental deterioration. The fourth section provides an empirical analysis of Dutch Disease and environmental degradation in Brazil, exploring how resource dependence and structural dynamics influence both development and ecological outcomes. The fifth section discusses the main challenges facing the Brazilian economy and outlines key policy implications. Finally, the sixth section summarizes and synthesizes the central issues addressed throughout the paper.

2. Dutch disease in the context of environmental crisis

The concept of Dutch disease emerged to explain the declining share of manufacturing in GDP observed in the Netherlands following the discovery of substantial natural gas reserves in the North Sea in 1959, with the term coined by *The Economist* in 1977. This resource discovery, combined with rising global demand for the commodity, reportedly led to expanded exports and real appreciation of the Dutch currency, thereby undermining the competitiveness of the manufactured goods export sector. Despite early journalistic and policy-oriented interest in this phenomenon, rigorous theoretical economic frameworks for explaining and delineating the mechanisms underlying this apparent paradox did not materialize until the early 1980s.

Corden and Neary (1982) are frequently cited as the foundational contribution to Dutch disease theory, although a substantial theoretical literature on the topic was emerging simultaneously. The authors formalized the argument within a neoclassical three-sector model in which increased commodity exports, particularly in energy, generate positive effects in two sectors, namely the commodity-producing sector and the non-tradable sector associated with traditional services, while leading to a contraction of the third tradable sector producing manufactured goods. Subsequently, scholars such as Auty (1993) and Sachs and Warner (2001) introduced the term “natural resource curse,” a concept that is broader in scope but has often been used interchangeably with Dutch disease to describe declining competitiveness and lower long-term growth rates in economies experiencing natural resource booms⁵.

Despite considerable heterogeneity in their theoretical assumptions and analytical focus, these models generally argue that resource booms generate revenues that expand national expenditure, both public and private. This expansion tends to induce real exchange rate appreciation and to raise the relative price of non-tradable goods vis-à-vis tradables. As a result, non-tradable sectors expand, while tradable industries exposed to international competition experience a contraction in output or exports, ultimately leading to deindustrialization.

While preserving the classical mechanism whereby resource booms induce chronic real exchange rate overvaluation, an alternative interpretation first elaborated by Palma (2005) and subsequently advanced through New Developmentalism (Bresser-Pereira, 2008, 2020, 2020a; Bresser-Pereira, Oreiro & Marconi, 2019; Bresser-Pereira, Araújo & Peres, 2020) contends that Dutch disease in numerous developing countries, particularly in Latin America and Brazil, need not originate from resource booms. Rather, this approach attributes the ascending predominance of commodity sectors, encompassing both primary and resource-based industrial goods, to liberalizing economic reforms prominently implemented since the 1990s. These neoliberal reforms disrupted industrialization pathways and the development catch-up process, precipitating premature deindustrialization.

Furthermore, as Bresser-Pereira (2020a) elucidates, Dutch disease constitutes a market failure whereby the resource-intensive sector generates negative externalities for other economic sectors, impeding their development despite their utilization of advanced technologies. This market failure reflects a gap between the exchange rate that equilibrates the current account (the market rate) and the exchange rate necessary for technologically sophisticated, efficient economic sectors to maintain competitiveness, termed the “industrial equilibrium exchange rate.”

⁵ For a comprehensive literature review on “Dutch Disease” and “Natural Resource Curse”, see Mien and Goujon (2022).

Consequently, Dutch disease theory within the New Developmentalist framework has demonstrated how commodity specialization represents a substantial impediment to economic development. Regarding empirical evidence on this phenomenon, recent influential studies have substantiated New Developmentalist perspectives (Lashitew & Werker, 2020; Heresi, 2023; Branstetter & Laverde-Cubillos, 2024).

Lashitew and Werker (2020) aimed to assess the direct and indirect effects of natural resources on economic development, in terms of increasing human and physical capital for a group of more than 100 countries. The results show that the direct and indirect effects tend to depend on whether natural resources are measured using abundance indicators (resource income per capita) or dependence indicators (the share of resource income in GDP). The findings indicate that the abundance of natural resources in the 1970s had a positive direct effect on development performance in terms of human and physical capital accumulation, given the level of institutional quality; however, it had a relatively limited indirect effect through the reduction in institutional quality. In contrast, the dependence on natural resources in the 1970s had a strong negative indirect effect on development performance due to its negative relationship with institutional quality, while its direct effect was very limited. Since institutions are the main determinants of development outcomes, the detrimental effect of resource dependence on institutional quality translates into a significant adverse effect on development performance. These results are robust to a series of robustness tests using different measures of institutional quality (Polity IV political institutions, ICRG governance institutions, and Worldwide Governance Indicators) and different types of natural resources (resource income and oil and gas production).

Heresi (2023) shows that Dutch disease occurred during the commodity boom of the 2000s in Chile, even though this was the country with the best macroeconomic governance in Latin America, with counter-cyclical fiscal policy and a sovereign wealth fund. According to the author, due to the exchange rate appreciation associated with the commodity boom, Chilean companies that exported the most lost ground to those that exported less. The commodity boom diverted resources from the exporting sectors due to the appreciation of the exchange rate and from capital-intensive companies due to the increase in the required rate of return on capital. The study, based on microdata from Chile, the world's largest copper producer, showed that the commodity supercycle of 2004-2012 resulted in a 13% to 32% loss in company productivity.

Branstetter and Laverde-Cubillos (2024) show that the natural resource boom of the 2000s stimulated income and consumption growth across many commodity-exporting countries. Focusing on Colombia, the authors document a less favorable consequence of this boom, namely currency appreciation, which contributed to a significant and persistent decline in R&D expenditures and investments in technological upgrading among manufacturing firms. The empirical strategy explores differences in company sales (in products and export destinations) to create specific measures of the companies' exposure to exchange rate shocks, both abroad and domestically. The authors linked these measures of exchange rate exposure with Colombian microdata on R&D investment and technological upgrading. The main finding is that the real exchange rate appreciation led to significant reductions in both R&D investment at the company level and a measure of technological upgrading, including spending on capital goods, technology licensing, worker training, and other expenses related to the adoption of new technologies. Even after the significant decline in commodity prices in the mid-2010s, which led to a substantial and lasting

depreciation of the Colombian currency, R&D investments and technological upgrading remained at moderate levels.

Therefore, the author's results suggest that the natural resource boom, and the associated exchange rate appreciation, had a significant and persistent negative effect on the technological development of Colombian manufacturing companies. These findings hold even after careful attempts to simultaneously control for the increasing competition with Chinese manufacturers, which also had a negative effect on Colombian companies' technology investments, and the effects of trade liberalization both domestically and abroad. Similarities between Colombia and other commodity exporters suggest that the effects documented in this article may be generalized to other developing economies.

A less explored side of the Dutch disease, however, is how it can lead to environmental degradation, with negative externality effects across the globe. Recent studies – detailed below – have begun addressing this gap by identifying a linkage between Dutch disease and environmental degradation, highlighting a range of both direct and indirect effects. Among these effects are the high profitability of specific commodities, which amplifies pressure on natural resources, for instance, through the conversion of forested areas into pastures or plantations; the limited impact on income generation, resulting in reduced investments both in sectors strategic to development and in innovations capable of mitigating environmental degradation; a decrease in funds allocated to environmental financing; among other significant factors.

Gu et al. (2023) conducted an empirical analysis examining the effects of intensified natural resource extraction, alongside other variables, on green financing across OECD countries from 2004 to 2020, employing a panel data model. The study further situates its findings within the framework of Dutch disease, assessing how this economic phenomenon may impede the attainment of the climate targets established at the 2022 Conference of the Parties (COP27) held in Egypt. The empirical results indicate that intensified natural resource extraction is negatively associated with green financing during the study period; in other words, higher levels of primary resource extraction correspond to greater difficulties in promoting green finance. These findings suggest that Dutch disease may operate as a mechanism that exacerbates economic-environmental contradictions: intensive resource exploitation leads to currency appreciation, which undermines export competitiveness and consequently reduces resources available for environmental innovations or green finance. Accordingly, public policies should prioritize increasing green financing as a strategy to simultaneously mitigate both the overexploitation of natural resources and the adverse effects of Dutch disease.

Yang and Ngoma (2025) examined the relationship between environmental degradation and the production and export of natural resource-based goods in 30 African countries rich in primary resources. Using a dynamic panel data methodology over the period 2000–2020, the study revealed a positive correlation between accelerated forest conversion, i.e., deforestation, and increased income derived from mineral and forest resource extraction. In other words, when mineral extraction and forest-derived income increase in African countries, there is heightened pressure on forests, a phenomenon which, according to the study, is further exacerbated by income inequality on the continent: in countries with higher inequality, the effects of mineral income on forest conversion tend to be more pronounced. Based on these findings, the main policy implications highlight the need for implementing taxation on such activities or similar instruments as means of compensation and forest conservation.

Araujo, Caldarelli, & Carcanholo (2025) analyze the Brazilian case from 2003 to 2022, finding evidence of a relationship between the expansion of agricultural and livestock activities and mineral extractivism in the country and the deterioration of environmental indicators, particularly regarding greenhouse gas (GHG) emissions, specifically CO₂e. The study indicates that the primary source of these emissions is linked to "land use and forest change," resulting from the conversion of forested areas into agricultural lands and biomass burning, accounting for approximately 48.3% of total emissions in 2022. From an empirical perspective, the authors show that the increase in livestock production and even in the manufacturing industry, which underwent a restructuring process oriented towards less technologically intensive segments strongly linked to natural resources, contributed significantly to the rise in emissions over the analyzed period. Conversely, the evidence indicates that expanded investments in environmental policies and improvements in the productive structure, reflected in greater economic complexity, contributed to reducing greenhouse gas (GHG) emissions.

Finally, Zhou (2023) reflects on the factors contributing to the Dutch disease phenomenon, or the "natural resource curse," in countries abundant in such resources, highlighting environmental deterioration as one of the outcomes. In assessing impacts on development trajectories, the author emphasizes Dutch disease as a factor undermining competitiveness; the crowding-out effects of reprimarization, which displace investments from other productive sectors; the deterioration of terms of trade; and the lack of clarity or uncertainty regarding the ownership and control of natural resources, which hampers productive investment and encourages rent-seeking behaviors. As potential policies or strategies for these countries to "break the curse," the study highlights the importance of industrial diversification, rational exploration of resources, the creation of natural resource revenue funds, improvements in the political system, and the strengthening of environmental governance.

In summary, the literature on Dutch disease consistently underscores that this phenomenon poses greater challenges in lower-income countries, where it exerts multifaceted adverse effects on development processes. Among these effects are environmental degradation manifested through ecosystem destruction and biodiversity loss, deterioration in population well-being, diversion of investments away from critical sectors, and the perpetuation of rent-seeking behaviors. These dynamics underscore the complex interplay between economic and environmental factors, highlighting the urgent need for integrated policy approaches to mitigate the negative consequences associated with the Dutch disease in vulnerable economies.

3. Reflections on the Brazilian Scenario

Since the early 2000s, Brazil has exhibited a development model trend characterized by the re-primarization of its productive structure, marked by the expansion of commodity production and exports, notably in food, minerals, and energy sectors.

In terms of contribution to Gross Domestic Product (GDP), the agricultural sector, which accounted for 7.20% of GDP in 2003, declined steadily until 2010, reaching 4.90% of total GDP, before consistently expanding again to reach 6.08% in 2023 (IPEA, 2025). Similarly, the extractive industry accounted for 2.20% of Brazil's GDP, exhibiting a highly volatile trajectory with a peak of 4.73% in 2022 and a share of 3.64% in 2023. Over the same period from 2003 to 2023, the manufacturing industry's share of GDP declined significantly, from 16.88% to 13.2%, after hitting a historical low of 10.6% in 2020 (IPEA, 2025).

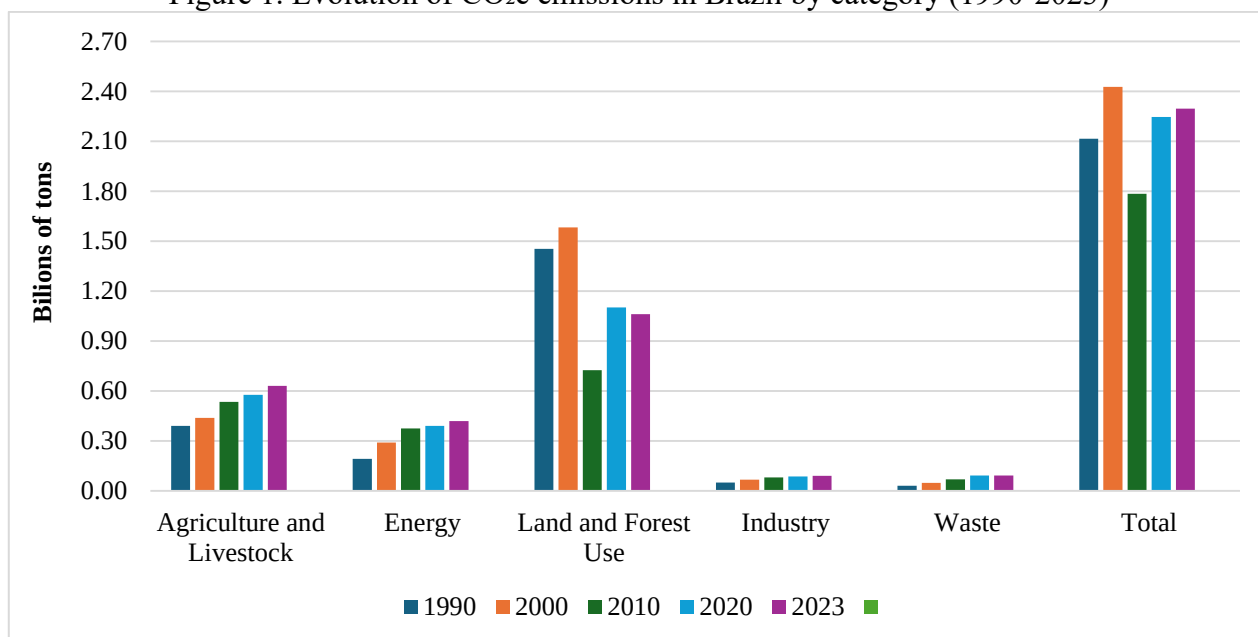
In nominal terms, the agricultural GDP increased from approximately US\$35 billion to US\$132 billion between 2003 and 2023. In real terms (2010 prices), the growth was 86.14% (IPEA, 2025). The industrial sector grew by only 5.94%, while the services sector advanced by 60.75%.

Regarding foreign trade in the same period, agricultural exports expanded nearly twelvefold, rising from US\$6.75 billion to US\$81.3 billion, increasing their share of total exports from 9.3% to 23.9% (FUNCEX, 2025).

As Brazil deepens its agro-export model without making progress in neutralizing the “Dutch disease,” the challenges of reconciling domestic development demands with commitments under the global climate agenda, particularly within the framework of the Paris Agreement (2015), become increasingly complex. According to the most recent data, the country emitted approximately 2.29 billion tonnes of carbon dioxide equivalent (CO_{2e}) in 2023. Furthermore, it accounted for about 3.09% of global emissions in 2022, ranking among the eight largest greenhouse gas emitters in the world⁶.

Figure 1 presents the evolution of CO_{2e} emissions in Brazil from 1990 to 2023, according to five emitting categories, Agriculture and Livestock, Energy, Land Use and Forests, Industry, and Waste. Overall, the trajectory shows that national emissions increased after 1990, peaked around 2.4 billion tonnes in 2000, declined until 2010, and then rose again between 2020 and 2023, approaching levels similar to those observed at the beginning of the century (2.3 billion tonnes).

Figure 1. Evolution of CO_{2e} emissions in Brazil by category (1990-2023)



Fonte: SEEG, 2025

Figure 1 also shows that the primary source of emissions is the category “Land Use and Forest Change,” which results from the conversion of forested areas into agricultural lands and biomass burning, accounting for 46.25% of total emissions in 2022. Agriculture and livestock are the second-largest source of greenhouse gas emissions at 27.5%, followed by energy at 18.30%, with waste and industrial processes representing 3.97% and 3.99%, respectively.

⁶ The largest global emitters in 2022 were: China (25.88%), the United States (11.13%), India (6.67%), the European Union (6.22%), Russia (3.79%), Indonesia (3.11%), Brazil (3.09%), and Japan (2.24%). Together, these eight countries accounted for approximately 56% of global emissions (Climate Watch, 2025).

Although total emissions remained high throughout the 1990–2023 period, sectorally, “land use and forests” consistently remained the primary source of emissions, peaking in 2000 at over 1.5 billion tonnes, which accounted for 65.2% of the country’s total emissions that year. This was followed by a reduction until 2020, which can be attributed to deforestation control and environmental conservation policies implemented in the preceding decades. Among the most important initiatives are the Action Plan for Prevention and Control of Deforestation in the Legal Amazon (PPCDAm), launched in 2003; the Real-Time Deforestation Detection System (DETER), created in 2004; the Amazon Fund and the revision of the Forest Code, both in 2012. In the private sector, the Soy Moratorium (2006) and the Cattle Moratorium (2009) are among the factors that contributed to emission reductions during this period. However, in 2023, emissions have resurged, indicating a partial reversal of this declining trend, mainly driven by the underfunding of environmental protection agencies since 2015 and political interference in their operations, especially between 2019 and 2022 (SEEG, 2023; Borges, 2022).

The described scenario highlights the significance of Brazil's development model and its challenges in achieving sustainability, while underscoring the importance of profound transformations in productive, technological, and institutional systems. These transformations will not be achieved through a sudden rupture of the current model but rather through a gradual redirection of the economy toward increasing levels of sustainability. In this process, productive activities play a central role by seeking to minimize impacts on natural ecosystems and promote cleaner, more efficient production methods. For this reason, Dutch disease and excessive dependence on natural resources are not viable alternatives, neither economically nor socially, in the contemporary context of the climate crisis and the urgency of the energy transition.

The relevance of improving the productive structure can be also illustrated by analyzing carbon dioxide (CO₂) emissions per unit of value added by industry in each country, which is roughly a measure of energy efficiency of industrial production. In addition to being a measure of energy efficiency, reducing this indicator is one of the targets of the United Nations Sustainable Development Goals (SDGs), more specifically Goal 9, which aims to build resilient infrastructures, promote sustainable industrialization and foster innovation. Thus, inclusive and sustainable industrialization plays a fundamental role in achieving this and all other SDGs by 2030, as well as aligning with other global commitments, such as the Paris Agreement.

In this regard, Table 1 shows that while the average CO₂ emissions per unit of value added by industry in the G20 and OECD countries have been declining between 2000 and 2021, indicating greater efficiency in transforming energy into value (even while using a much smaller percentage of renewable energy), Brazil remains stagnant, indicating the country's difficulty in generating value without increasing its carbon footprint. It is interesting to note that this lack of progress in terms of reducing emissions per value added occurs at the same time that the country faces a significant decline in the value added of the manufacturing sector as a proportion of GDP, combined with a decrease in the value added from medium and high-technology industrial activities, while the trends for G20 and OECD averages have shown relative stability or even a slight growth in the manufacturing sector and in high-tech activities.

As a result of these trends, Brazil’s progress towards SDG 9 has fallen short of what has been achieved by most countries, since, in this regard and among 137 countries analyzed, Brazil’s position in the ranking fell from 43rd place in 2000 to 66th in 2021, as shown in Table 1.

Table 1: Progress on SDG 9 - Selected indicators for Brazil, G20 and OECD (2000-2021)

	2000	2003	2006	2009	2012	2015	2018	2021
Carbon dioxide emissions per unit of manufacturing value added (kilograms of CO2 per constant 2015 U.S. dollars)								
Brazil	0.48	0.45	0.40	0.40	0.45	0.46	0.44	0.46
G20	0.50	0.48	0.52	0.56	0.55	0.49	0.43	0.40
OECD	0.31	0.28	0.24	0.22	0.21	0.19	0.18	0.17
Manufacturing value added as a proportion of GDP (%)								
Brazil	13.8	13.7	13.6	12.2	11.7	10.5	10.4	10.0
G20	14.6	14.8	15.8	15.1	16.0	16.4	16.5	16.8
OECD	14.6	14.2	14.8	13.4	14.0	14.0	13.9	13.9
Proportion of medium and high-tech industry value added in total manufacturing value added (%)								
Brazil	34.9	33.2	33.3	33.4	33.8	33.5	32.8	30.5
G20	46.2	45.7	44.6	44.1	44.9	46.9	47.8	46.4
OECD	47.4	47.1	47.1	47.1	48.8	49.5	49.7	47.8
SDG 9 Industry Index rank								
Brazil	43	50	50	49	49	56	61	66

Source: Author's own elaboration based on UNIDO SDG 9 Indicators database (2024).

In summary, while the reprimarization of the productive structure and export basket occurred in the context of increasing environmental degradation, recent evidence indicates that industrial activities exhibit a more aggressive emissions profile the lower their technological content. This fact sheds light on the Brazilian model and its social, economic, and environmental unsustainability.

4. Empirical Analysis of Dutch Disease and Environmental Degradation in Brazil

4.1. Methodology

To analyze the relationship between CO2e. emissions in Brazil and the hypothesis that Dutch Disease in Brazil intensifies environmental degradation, this study employs a methodological framework based on dynamic panel data models. This approach was chosen as it enables the analysis of relationships between variables by simultaneously capturing effects over time and across different units, represented here by Brazilian states.

To address this issue Generalized Method of Moments (GMM) estimators are used. These methods rely on internal instruments derived from the structure of the panel data to provide consistent and efficient estimates and control endogeneity. The Generalized Method of Moments (GMM) is a flexible estimation technique that addresses endogeneity by using moment conditions derived from the model's assumptions. In the context of dynamic panel data models, GMM estimators use lagged levels and differences of the dependent variable as instruments. There are two main types of GMM estimators for dynamic panel data models: the Difference GMM and the System GMM.

The Difference GMM, proposed by Arellano and Bond (1991), transforms the model to eliminate the entity-specific fixed effects by taking first differences. The transformed model is:

$$\Delta y_{it} = \gamma \Delta y_{i,t-1} + \beta \Delta X_{it} + \Delta \epsilon_{it},$$

where Δ denotes the first difference operator. The lagged levels of the dependent variable ($y_{i,t-2}, y_{i,t-3}, \dots$) are used as instruments for the lagged first differences ($\Delta y_{i,t-1}$).

The System GMM, proposed by Blundell and Bond (1998), combines the differenced equation with the level equation to improve efficiency. The system GMM uses lagged differences as instruments for the level equation and lagged levels as instruments for the differenced equation. The system GMM estimator is more efficient than the Difference GMM, especially when the dependent variable is highly persistent.

The GMM estimators rely on the following moment conditions:

$E[y_{i,t-s}\Delta\epsilon_{it}] = 0$ for $s \geq 2, t = 3, \dots, T$, for the Difference GMM, and

$E[y_{i,t-s}(\eta_i + \epsilon_{it})] = 0$ for $s \geq 2, t = 3, \dots, T$, for the System GMM.

The estimations were carried out using the `xtabond2` command, in STATA® 17, for flexible estimation of dynamic panel models via GMM, with both difference and level equations for greater efficiency, especially in highly persistent series.

Regarding possible endogeneity in the models, the explanatory variables were treated as IVs in the level equation, while the lagged dependent variable was instrumented using its own lagged values, both in difference and in level form. The collapse option was chosen to avoid excessive use of instruments.

Estimation validation was based on the Arellano–Bond test for autocorrelation for first and second order, which checks for autocorrelation in the differenced residuals. The absence of second-order autocorrelation supports the validity of the instruments. The Sargan test was used to assess instrument validity and to evaluate overidentification.

4.2 Description of Data and Variables

Table 2 describes the variables used in this study along with their respective details. Based on the literature review and the constructed models, applying the panel data methodology will enable modeling of CO₂ eq. emissions in Brazilian states (27), alongside indicators characteristic of Brazil's productive structure, while accounting for certain control variables. The time frame is from 2003 to 2022, and the data used are annual.

Table 2 – Variables and descriptons

Variables	Description	Unit	Source
<i>emiss</i>	CO ₂ emissions in carbon equivalent	tons	SEEG (2024)
<i>plant</i>	Planted or harvested area total	Hectare (ha)	(IBGE, 2024)
<i>livestock</i>	Cattle herd	head	IBGE (2024)
<i>gdp</i>	Gross Domestic Product	Brazilian Reais (2022 constant prices)	IBGE (2024)
<i>exp</i>	Exports (FOB) (deflated by the US CPI)	US\$ (FOB)	Ipeadata (2024)
<i>exp_p</i>	Exports of livestock and crops (FOB) (deflated by the US CPI)	US\$ (FOB)	Ipeadata (2024)
<i>cei</i>	Index of Economic Complexity	Index	Dataviva (2025)
<i>amazon</i>	Legal Amazon	Binarie variable: [1] for the states of Acre, Amapá, Amazonas, Pará, Rondônia, Roraima, Tocantins, Mato Grosso and Maranhão; [0] otherwise.	--

Source: Author's own elaboration

For the empirical analysis, five theoretical models were constructed and estimated, each with different compositions of variables. The represented model can be represented by the following equation:

$$\begin{aligned} \ln(emiss_{i,t}) = & \alpha + \lambda_i + \beta_1 \ln(emiss_{i,t-1}) + \beta_2 \ln(plant_{i,t}) + \beta_3 \ln(plant_{i,t})^2 \\ & + \beta_4 \ln(livestock_{i,t}) + \beta_5 \ln(gdp_{i,t}) + \beta_6 \ln(gdp_{i,t})^2 + \beta_7 \ln(exp_{i,t}) \\ & + \beta_8 [\ln(gdp_{i,t}) \times \ln(exp_{i,t})] + \beta_9 [\ln(exp_{i,t}) \times amazonia] \\ & + \beta_{10} \ln(exp_{i,t})^2 + \beta_{11} \ln(cei_{i,t}) u_{i,t} \end{aligned}$$

with:

λ_i = fixed effects by i (states);

u_{it} = idiosyncratic error term.

The inclusion of squared variables and interaction terms between variables aims to increase the functional flexibility of the estimated models and thereby ensure greater robustness of the estimations. The estimations use variables in logarithmic form to directly obtain the respective elasticities.

4.3 Results

The following Table 3 presents the results of the estimated models.

Table 3 – Regression results

	System GMM - Blundell and Bond (1998)				
Variables	Model I	Model II	Model III	Model IV	Model V
<i>L.ln_emiss</i>	0.755***	0.751***	0.758***	0.767***	0.767***
<i>ln_plant</i>	-0.0446**	-0.0417**	-0.416**	-0.373**	-0.0401**
<i>ln_plant</i> ²		0.0131*		0.0117*	0.0127**
<i>ln_livestock</i>	0.172**	0.196**	0.161**	0.180**	0.174**
<i>ln_gdp</i>	-0.220*	-0.062	-0.205*	-0.061	0.420*
<i>ln_gdp</i> ²					-0.020**
<i>ln_exp</i>	-0.237*	-0.123	-0.211*	-0.105	-0.311**
<i>ln_gdp x ln_exp</i>	0.0136*	0.0068	0.0124*	0.0061	0.0176**
<i>ln_exp_p</i> (amazonia=1)	0.0337*	0.0282	0.0339*	0.0289	0.0264
<i>ln_exp_p</i> (amazonia=0)	0.0419**	0.0353*	0.0422**	0.0362*	0.0344*
<i>ln_exp_p</i> ²	-0.00117*	-0.00099*	-0.00117*	-0.00101*	-0.00094*
<i>ln_cei</i>	-0.0437*	-0.0505*			
<i>cons</i>	5.830**	5.582**	5.318**	5.009**	3.084
	Number of obs= 484 Number of groups = 27 Instruments=13 Arellano-Bond test AR(1)=-5.59 (0.00) AR(2)=-0.43(0.66) Sargan test=3.85 (0.146)	Number of obs= 484 Number of groups = 27 Instruments=14 Arellano-Bond test AR(1)=-5.55(0.00) AR(2)=-0.45(0.651) Sargan test=3.57(0.651)	Number of obs= 484 Number of groups = 27 Instruments=12 Arellano-Bond test AR(1)=-5.76(0.00) AR(2)=-0.40(0.690) Sargan test=3.55(0.690)	Number of obs= 484 Number of groups = 27 Instruments=13 Arellano-Bond test AR(1)=-5.78(0.00) AR(2)=-0.41(0.68) Sargan test=3.28(0.681)	Number of obs= 484 Number of groups = 27 Instruments=14 Arellano-Bond test AR(1)=-5.82(0.00) AR(2)=-0.3(0.76) Sargan test=3.38(0.184)

*** 1% significance level

** 5% significance level

* 10% significance level

The results obtained from the econometric estimates of five System GMM models (Table 3) support the central idea of this article that the Dutch Disease in Brazil not only leads to productive reprimarization and deindustrialization but also intensifies environmental degradation. The findings demonstrate that the country's growth trajectory, based on sectors intensive in natural resources, exerts increasing pressure on greenhouse gas (GHG) emissions, in this study, CO₂eq., with particular emphasis on regions marked by agricultural and livestock frontier expansion, such as the Legal Amazon.

It is important highlighting that, in the estimated models, the lagged emissions term (L.ln_emiss) indicates a temporal persistence pattern, reflecting structural lock-in mechanisms in which institutions, technologies, and production chains reinforce the dependence on an extractivist model, hindering the transition toward a low-emission production system (Romero; Gramkow, 2021). This result shows that isolated public policies have limited effects on mitigating emissions unless they are accompanied by deeper structural changes.

The results also indicate that agricultural and livestock activities are key drivers of emissions in the country. For agriculture, a nonlinear pattern (ln_plant and ln_plant²) is observed, with an initial reduction in emissions followed by a subsequent increase as the cultivated area expands, consistent with Silveira et al. (2023). Livestock production (ln_livestock), in turn, has a strongly expansionary effect on emissions, primarily due to the high levels of CH₄ associated with cattle. These activities thus act as transmission mechanisms of the environmental Dutch Disease.

The interaction between GDP and exports (ln_gdp × ln_exp) suggests that when both grow simultaneously, their combined effect on emissions is amplified. This finding reveals that the combination of economic growth and a production structure oriented toward commodity exports creates additional environmental pressures, highlighting the dual harmful nature of the Dutch Disease in Brazil.

Regional effects are also noteworthy, especially those related to the expansion of agricultural and livestock frontiers in the Legal Amazon. The interaction variable between primary exports and this region (ln_exp_p × Amazonia=1) indicates that the environmental impact of primary product exports is significantly greater in the Amazon compared to the rest of the country. This result reinforces the idea that the region functions as a vector of the neoextractivist model, in which agricultural expansion, combined with increased exports, leads to deforestation, biodiversity loss, and higher levels of emissions (Fearnside, 2021; Binswanger, 2019). The results are also positive in Models I and III for primary exports without interaction with the Amazon variable (ln_exp_p × Amazonia=0), indicating that primary exports have an emissions-intensive nature, but these effects are stronger in the states of the Legal Amazon.

In the models that included the variable related to economic complexity (ln_cei), the coefficient was negative, suggesting that states with more diversified and complex production structures tend to emit relatively fewer greenhouse gases. This finding supports the idea that productive and technological diversification serves as a mitigating factor for environmental degradation, in line with the arguments of Romero and Gramkow (2021).

The empirical results support the thesis that Brazil faces an environmental Dutch Disease, in which a growth pattern based on commodity exports not only limits productive sophistication

but also intensifies ecological degradation, especially in the Amazon. The expansion of livestock production and the agricultural frontier emerge as a central transmission mechanism linking external dynamics to domestic emissions.

The findings of this study align with Lashitew; Werker (2020); Heresi, (2023); Branstetter; Laverde-Cubillos, (2024); and the Bresser-Pereira (2020a) idea of Dutch Disease as a market failure that generates negative externalities beyond the economic sphere, extending into the environmental domain. Moreover, this research contributes to the classical literature on Dutch Disease (Corden & Neary, 1982; Palma, 2005; Bresser-Pereira, 2008, 2020, 2020a), which traditionally focuses on the symptoms of industrial weakening and declining technological innovation capacity, by expanding the concept to include its omitted environmental dimension, namely, direct pressure on ecosystems and rising emissions. This omitted dimension arises largely because these effects are still not fully documented in the country's macroeconomic statistics.

5. Discussion and policy implications

Economic growth and development involve complex transformations, among which structural change – the shift toward higher-productivity sectors, especially the manufacturing sector – plays a crucial role in social and economic progress as well documented by literature (Prebisch, 1949; Lewis, 1954; Hirschman, 1958; Kaldor, 1966; Rodrik, 2013).

Empirical evidence shows that economies reallocating labor toward dynamic, high-productivity sectors, such as manufacturing and sophisticated services, tend to experience faster growth and reduced productivity gaps, while specialization in low-productivity activities often leads to stagnation (Marouani, Youssef & Zaki, 2023; McMillan, Rodrik & Verduzco-Gallo, 2014; Świącki, 2017). Policies that encourage the transfer of resources toward innovative, efficient industries are thus essential for sustained growth.

Recently, the debate on structural change has incorporated environmental concerns, as technological progress in manufacturing can enable cleaner and more efficient production models. Studies have emphasized that improving the productive structure contributes to decoupling economic growth from environmental harm (Sánchez, León, & Porcile, 2024; CEPAL, 2024; Gramkow, 2019). Evidence also links higher economic complexity to lower emissions intensity, since complex products rely on more advanced and cleaner technologies (Romero & Gramkow, 2021; Silveira et al., 2023; Zhen & Freire, 2023; Ahmad, Ahmed & Luo, 2024). These findings highlight the central role of public policies in steering structural change toward sustainable development, particularly in regions where growth still depends heavily on natural resource exploitation.

The urgent transition towards sustainability demands a new pattern of industrialization centered on energy efficiency, circular economy practices, and the development of low-emission technologies (Rodrik, 2022; Mazzucato, 2021). In this context, policies that foster technological innovation and strengthen domestic value chains are essential for promoting both competitiveness and environmental sustainability.

However, Brazil faces structural barriers. The reprimarization of its economy since the early 2000s has limited industrial diversification and weakened its capacity for technological

upgrading. Moreover, regional asymmetries persist: areas dependent on extractive and agricultural activities are more vulnerable to deforestation pressures and carbon-intensive production models. It is also important to highlight that the country faces growing risks from extreme weather events, such as droughts and floods, which threaten the economy and productive activities.

In this sense, despite the agricultural sector's importance for the Brazilian economy, maintaining international competitiveness requires fundamentally decoupling sectoral growth from deforestation and soil degradation. This shift demands careful oversight of forest-to-agricultural conversions to preserve biodiversity, a commitment with tangible economic returns. Research by Romeiro et al. (2020) suggests that restoring 12 million hectares of degraded lands, a goal Brazil has pledged to achieve, could yield R\$ 19 billion in returns over a decade, alongside R\$ 742 million in tax revenues. A range of technological innovations can advance this transition. Precision agriculture, biological inputs, integrated pest management, and Crop-Livestock-Forest Integration (ILPF) have demonstrated capacity to reduce environmental pressures while raising productivity between 20-40% across diverse contexts (Barcellos & Cargnin, 2020; Godfray & Garnett, 2014; Neves et al., 2018). Sustainable aquaculture represents another promising avenue, particularly given Brazil's coastal and hydrological resources, though realizing this potential hinges on robust monitoring and traceability frameworks (FAO, 2020).

Beyond sectoral improvements, circular economy principles offer a more systemic pathway forward. Rather than extracting and discarding, this approach fundamentally restructures resource flows and consumption patterns. For industry, this means manufacturers must prioritize product longevity and repairability as essential design principles. Simultaneously, circular practices create new economic opportunities, from resource recovery and upcycling ventures to the development of novel materials with enhanced recyclability, biodegradability, or durability characteristics (Ibaladejo, Henao & Mirazo, 2021; IEDI, 2021).

On the other hand, Brazil has an energy matrix largely based on renewables, expertise in biofuels and potential to develop green hydrogen domestically with a favorable position to lead the green industrial transition in Latin America (ECLAC, 2020; IEDI, 2021; CEPAL, 2024). Strengthening innovation systems, financing mechanisms, and environmental governance can transform these advantages into drivers of sustainable growth and job creation. However, significant efforts are needed. In a study prepared for the OECD, Kruse et al. (2022) updated and analyzed the so-called Environmental Policy Stringency Index (EPS). The index covers the years from 1990 to 2020, across 40 countries (OECD members plus Brazil, China, India, Indonesia, Russia and South Africa) and 13 policy instruments, focusing on climate change and air pollution mitigation policies, such as environmental taxes and fees, subsidies and incentives, legal standards, environmental certification programs, natural resource management strategies, emissions trading instruments, inter alia. Among the 40 countries, Brazil recorded the second-worst index, ahead only of New Zealand.

In this regard, it is worth mentioning that the “Nova Indústria Brasil” (NIB) – a program recently launched by the federal government, seeks to address some of the challenges and opportunities raised in this section by proposing an integrated industrial policy focused on sustainability and digitalization. However, its effective implementation will depend on inter-ministerial coordination, public-private partnerships, and long-term consistency. Additionally, as

demonstrated by Brazil's recent experience, any well-intentioned and well-designed industrial policy is unlikely to realize its full potential in a scenario of excessively high real interest rates, an overappreciated exchange rate in the long term and at the same time highly volatile in the short term, resulting from the combination of a Dutch disease and a development strategy based on external savings.

The success of this proposal to achieve a sustainable development model requires the alignment of industrial, environmental, and social policies. It also entails rethinking incentives, strengthening institutions, and directing structural change toward a path of productive and technological upgrading that reconciles environmental conservation with development, while enhancing climate resilience in the current context

6. Concluding remarks

In this article, we explore the interconnections between the Dutch disease, the Brazilian productive structure, and their implications for economic development and environmental degradation. We argue that environmental degradation is a neglected aspect of Dutch disease. Therefore, Dutch disease results, on one hand, in reprimarization and premature deindustrialization of the Brazilian economy and, on the other hand, in environmental degradation, with negative externality effects across the planet.

Thus, the current development model centered on the exploitation of natural resources, deriving from the Dutch disease, has affected not only the country's potential for economic growth and development but also environmental efficiency. The dependence on commodity production and exports has generated profound environmental impacts, such as intensified deforestation and greenhouse gas emissions. These issues compromise not only Brazil's commitments to the Paris Agreement but also the Sustainable Development Goals (SDGs), which aim to promote more sustainable and inclusive development practices, particularly regarding the construction of resilient infrastructure, promotion of sustainable industrialization, and fostering innovation.

Moreover, although Brazil historically has a significant share of renewable sources in its energy matrix, especially biofuels, UNIDO data show that while average CO₂ emissions per unit of value added by industry in G20 and OECD countries have been decreasing between 2000 and 2021, indicating greater efficiency in transforming energy into value (even using a much lower percentage of renewable energy), Brazil remains stagnant, indicating the country's difficulty in generating value without increasing its carbon footprint.

Interestingly, this lack of progress in terms of reducing emissions per value added occurs simultaneously as the country faces a significant decline in the manufacturing sector's value added as a proportion of GDP, combined with a decrease in the value added of medium and high-technology industrial activities, while trends for G20 and OECD averages have shown relative stability or even slight growth in the manufacturing sector and high-technology activities.

In this sense, the transition to a green economy or an ecological structural change is not only an environmental imperative but also a strategic opportunity to revitalize the Brazilian industrial sector and mitigate or even overcome the Dutch disease. In fact, recent studies indicate a correlation between economic complexity and reduction of greenhouse gas emissions,

suggesting that the production of more complex goods is associated with lower emission intensities.

The empirical results also support the thesis that Brazil is experiencing an environmental variant of Dutch disease, in which a development centered on commodity exports simultaneously constrains productive upgrading and deepens ecological degradation, particularly in the Amazon. The expansion of livestock production and the advance of the agricultural frontier emerge as key transmission mechanisms that connect global demand dynamics to domestic environmental pressures, notably greenhouse gas emissions and deforestation. These findings highlight the structural nature of the challenge: without a reorientation of the development strategy toward diversification and sustainability, Brazil risks reinforcing a path dependency that undermines both long-term economic resilience and environmental preservation.

In summary, to overcome environmental and economic challenges, Brazil needs to implement measures to combat the Dutch disease, promote diversification of the productive structure, strengthen environmental preservation policies, and invest in modern and technologically advanced industrial activities. These actions are crucial to reconcile economic growth with environmental preservation and the achievement of international climate goals, in addition to representing an opportunity for the country to position itself at the forefront of the transition to a low-carbon economy.

However, since the impacts of climate change and environmental degradation transcend national borders, global coordination is fundamental to guide the shift towards a cleaner, greener and less unequal economy at a worldwide level. Only through an integrated and collaborative approach will it be possible to effectively face the challenges of the ecological transition and build a more prosperous and sustainable future for current and future generations.

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