Public expenditure and GHG emissions in Brazil: A Structural Decomposition Analysis for the 2000-2019 period

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ABSTRACT

Brazilian public spending has dominated the center of the economic debate in recent years. The contours of this debate encompass discussions on the dynamics of public debt, economic growth, and inflation, as well as analyses that focus on assessing the impacts of the fiscal crisis and proposed adjustments on the provision of public services and the institutional capacity of the State. However, a central question remains unaddressed, which is: what is the impact of Brazilian public spending on national emissions? This type of approach has never been prioritized in the debate about public expenditure, and there are no previous studies that account for this estimation. However, with the aggravation of the climate crisis and the fundamental importance of public spending in its resolution, an assessment of its impact on emissions became rather than pertinent, urgent. This article aims to fill this knowledge gap by providing an initial estimation of greenhouse gas emissions generated by Brazilian public spending in the three levels of government. Additionally, we propose a structural decomposition analysis of these emissions as a means to better understand the elements driving their increase. The exercise is conducted through Input-Output modeling and covers the period from 2000 to 2019.

I. INTRODUCTION

In the last two decades, primary public expenditure amounted, on average, to 30.6% of the Brazilian GDP (IMF, 2023). However, there is a significant variation in public spending in this period, not only in its magnitude but also in its composition. At least two major events resulted in important level and composition changes: (i) the Growth Acceleration Program, which resulted in the expansion of public investment after 2007, and (ii) the fiscal adjustment and the fiscal ceiling in the second half of the 2010s, which resulted in a sharp contraction of the discretionary expenditures.

To date, several studies have focused on analyzing Brazilian public spending, seeking to answer a wide range of questions. The most frequent ones refer to the impact of public expenditure on economic cycles, public debt, inflation, and income distribution.

More recently, in the context of environmental crises, the analysis of Brazilian public spending gained new contours. Several studies turned their focus to measure and evaluate the quality of environmentally related public spending, with especial attention to those related to climate change (Garson, 2017; Brazil, 2018; Young et al., 2018; Tozato et al., 2019; Alvarenga *et al.*, 2019). The adoption of climate expenditure classifiers (budget classification systems) is an essential step to identify, track and evaluate sectoral climate spendings, allowing decision makers to find financial gaps in the pursuit of mitigation and adaptation goals.

Despite the relevant contribution given by the above-mentioned studies, the absence of climate-related budget tags and classifiers hinders the systematic tracking of climate-related public expenditure in Brazil. Hence, the attempts to measure public spending on climate action rely on sporadic efforts and non-standardized methodologies, which lead to time discontinuities and comparability problems among these studies.

The relevance of having a system for tracking climate change expenditure is undeniable. However, when it comes to tackling climate change, the amount spent on climate action is a mean to an end, not an end in itself. The utmost goal of climate action is to drop emissions and to build resilience, therefore, those should be the impact indicators to evaluate climate policies. That is to say; besides tracking financial flows to climate action, governments should be working on developing methodologies to measure the impact of public spending as a whole on GHG emissions and resilience capacity. Yet, no attention has been given to this matter in Brazil (or, to the authors' knowledge, elsewhere).

Given the knowledge gap in this field, this paper aims to estimate GHG emissions from the Brazilian public expenditure between 2000 and 2019, identifying the driving forces and, from there, recommending policies capable of decarbonizing public investment and government consumption.

To estimate the emission from public expenditure, this paper uses an environmentally extended input-output model that integrates three different databases: (i) a time series of Input-Output tables (IOT) at constant prices, developed by Passoni and Freitas (2022), (ii) A vector of emission intensity by industry, developed by Alvarenga, Costa, and Young (2021) and (iii) A vector of public investment by industry, developed by Miguez and Freitas (2021). Finally, to identify the main elements driving the growth in GHG emissions from the Brazilian public expenditure, the paper carries out a Structural Decomposition Analysis (SDA) that breaks down the public expenditure GHG emissions into six effects: scale, composition, product mix, technology, trade pattern, and emission intensity. The first three components of this decomposition strictly relate to the magnitude and quality of the Brazilian public expenditure, while the rest of them are pertinent to productive structure that interacts with public expenditure to generate emissions.

2. Background of the research:

2.1. Context

Between 2000 and 2019, the average growth rate of primary public spending was 2.7% per year at the federal level in all three levels of government. However, there is significant variability in these rates over time. For example, at the federal level, primary public spending grew at an average rate of 4.6% per year between 2000 and 2004, followed by a rapid acceleration from 2005 up to 2010 that brought this rate to 7,3% per year (See Table A1, in Appendix 1). After 2011, the Brazilian economy slowed down. Nevertheless, primary spending kept growing by over 4% per year up to 2014, when the country's fiscal situation began to show more evident signs of deterioration. This deterioration led to an unprecedented spending cut in 2015 of around R$ 70 billion (equivalent to 1 percentage point of Brazilian GDP at the time) (Passoni and Miguez, 2021).

Despite the cuts, the fiscal situation remained complex, culminating in the following year in the approval of the fiscal regime of the spending ceiling (EC 95/2016). With a validity of 20 years from its approval, the new regime limited the expansion of primary spending at the level of inflation rate observed in the previous year, freezing its real value at the 2016 level (base year).

Several studies measure the impacts of the Brazilian fiscal crisis and, more specifically, the spending ceiling on the provision of public services and on the level of public investments (Rossi, Dweck and Oliveira, 2018; Passoni and Miguez, 2021; Oliveira and Dermann, 2021). By setting the fiscal ceiling base year in 2016, the new regime picked a point in time when public spending had already been depressed by successive budget cuts during the 2015 and 2016 fiscal years. Many areas of public administration were already suffering from resource insufficiency. One of the most affected was environmental management (Gramkow, 2018; Alvarenga et al., 2019; Freitas, Carvalho and Oviedo, 2022). With the economic and demographic growth expected to happen during the validity of the new fiscal regime, the insufficient provision of public services is likely to become more evident.

All the changes in primary spending levels came along with great variations in the composition of public spending. From 2005 onward, public investment rates took off, especially after the launch of the Growth Acceleration Program in 2007. As a result, the average growth rates of public investment of the central government reached 26.1% per year in the 2005-2010 period, well above the primary spending in this period. Consequently, the share of public investment in the total primary spending of the federal government jumped from 1,38% in 2004 to 4.92% in 2010 (excluding the investments in Federal state-owned enterprises).

Despite the economic slowdown between 2011 and 2014, the public investment of the central government steadily grew in this period, keeping the share of public investment in primary spending above 3.7%. Nevertheless, the budget cuts and the Brazilian fiscal ceiling forced the public investment rates downwards in the following years. Due to its essentially discretionary nature, public investments are commonly placed at the forefront of short-run efforts to solve fiscal imbalances (Orair, 2016). In fact, from 2014 to 2019, the central government investment fell from 4.01% to 1.78% of the federal government's primary spending.

These elements are of keen interest for the analysis proposed in this article. Variations in levels of public spending will necessarily result in variations in GHG emissions, given that they will result in changes in the production of goods and services and, therefore, in the emissions levels required to produce them. Changes in the share of public investment in total primary expenditure are also likely to result in changes in emission levels. While a considerable part of government consumption consists of wage bills, the realization of investments requires the production of goods such as cement, steel, and pig iron, among other products whose direct emission factor tends to be relatively high. In this sense, changes in the public consumption to investment ratio tend to be accompanied by shifts in the sectoral composition of public spending and, therefore, in GHG emissions.

One aspect that should be considered is that public spending will produce emissions according to its interaction with the country's productive structure. This means that the same public expenditure level and composition (consumption-investment ratio) can generate different emissions levels if the productive structure changes. Several studies highlight that the Brazilian economy has been through important structural changes in recent years, drawing attention to an ongoing process of premature deindustrialization (Palma, 2005; Bresser-Pereira and Marconi, 2008; Oreiro and Feijó, 2010; Nassif et al., 2013; Passoni, 2019). From a structural point of view, a deindustrialization process may result in a reduction of inter-industrial density due to losses of inter-industry linkages. These losses translate into an increase in the penetration of imported inputs to meet domestic production needs.

Studies such as Neves (2013), Passoni (2019), and Medeiros, Freitas, and Passoni (2020) find evidence of an increase in import penetration, notably from 2008 onwards. In this sense, the higher penetration of imported goods (including inputs) may deceptively suggest that Brazilian public spending is decarbonizing, when in reality, what is happening is a partial displacement of the production of goods and services and their related emissions abroad.

3. Method and Data

3.1 Structural decomposition of emissions from public expenditure

The emissions by Brazilian public expenditure can be obtained from the multiplication of the vector of sectoral GHG emissions intensity ($\boldsymbol{\varepsilon}$, total emissions per unit of gross output) by the inverse matrix of Leontief and the vector of public expenditure, which includes government consumption and public investments ($\boldsymbol{g}$).

Defining $\boldsymbol{\varepsilon}$, we have:

$$\boldsymbol{\varepsilon} = \boldsymbol{e}\hat{\boldsymbol{x}}^{-1} \tag{1}$$

where $\boldsymbol{e}$ represents the vector of emissions (without land use change) by sector.

Therefore, the total emissions associated with the gross output would be given by:

$$\boldsymbol{e} = \boldsymbol{\varepsilon} \times (\mathbf{I} - \mathbf{A_d})^{-1} \times \boldsymbol{g} \qquad (2)$$

where $\mathbf{A_d}$ represents the matrix of domestic technical coefficient and $(\mathbf{I} - \mathbf{A_d})^{-1}$ is the inverse of Leontief.

The definition above represents an environmental extension of the canonical input-output model. The extended model presented here behaves similarly and under the same hypotheses as the original model. In this model, we start by assuming proportionality which is directly connected to Leontief's production function. Then, the technical coefficients are used to measure the fixed relationships between the sectoral output and its input. This means that the production in a Leontief system operates under constant returns to scale. As a result, economies of scale are absent when production increases due to factors such as a reduction in transition costs. The other important aspect is homogeneity, where each commodity or group of commodities is produced only by one industry.

As our objective is to understand the drivers of change in $\boldsymbol{e}$, we propose the decomposition of (2) as follows. First, we define $\mathbf{A_d}$ in a way, we can capture the changes in the share of domestic inputs needed to meet the demand created by the public expenditures vector. Let $\mathbf{\Omega}$ be the share of domestic inputs, and $\mathbf{A}$ represent the matrix of total technical coefficient formed by domestic and imported inputs[1]. So, we have:

$$\mathbf{\Omega} = \mathbf{A_n} \oslash \boldsymbol{A} \qquad (3)$$

$$\mathbf{A_n} = \mathbf{\Omega} \odot \boldsymbol{A} \qquad (4)$$

[1] Here there is another input-output hypothesis, that imports, and domestic production are competitive, which means that it is possible to import all goods consumed nationally or to produce all imported goods. It is necessary to make a reservation for the Brazilian case, as not all goods have perfect substitutes for imported goods, due to structural production issues, with a degree of substitution between them (HAMILTON et al, 2015).

where $\oslash$ and $\odot$ represent the cell-by-cell division and multiplication, respectively. So, the inverse of Leontief can be rewritten as:

$$\mathbf{L} = (\mathbf{I} - \mathbf{\Omega} \odot \boldsymbol{A})^{-\mathbf{1}} \quad \textbf{\textit{(5)}}$$

Secondly, we decomposed total government expenditure ($\boldsymbol{g}$) into three elements: scale, the composition of expenditures, and sectoral composition (product mix)[2]. For this, we express $\boldsymbol{g}$ as a partitioned matrix ($\boldsymbol{G}$) into government consumption ($\boldsymbol{c_g}$) and public gross fixed capital formation (GFCF) ($\boldsymbol{k_g}$) vectors.

$$\boldsymbol{G} = [\boldsymbol{c_g} | \, \boldsymbol{k_g}] \quad \textbf{\textit{(6)}}$$

$\boldsymbol{c_g}$ is the vector of government consumption, which represents all expenditures on the provision of public goods and services free of charge, in whole or in part, by the three spheres of government (federal, State, and municipal), valued at the cost of their production. In the $\boldsymbol{k_g}$ are included investments made directly by the three spheres of government and state-owned companies not dedicated to market production. If a state-owned enterprise is involved in market production (such as the Brazilian company of oil, Petrobras), it is allocated to the non-financial or financial institutional sector (private GFCF) instead of the government institutional sector. This information is essential for our purposes here because it means that $\boldsymbol{k_g}$ strongly correlates with a fiscal budget and policy decisions. If the investments of all state-owned enterprises were included in the share of $\boldsymbol{k_g}$, it would be difficult to understand the extent to which fiscal policy decisions are affecting $\boldsymbol{k_g}$.

Now, let total government expenditure be written as follows:

$$g = i'g \quad \textbf{\textit{(7)}}$$

Then, let's define the **σ** as the vector with the total investment and consumption of the government:

$$\boldsymbol{\sigma} = (i'G)' \quad \textbf{\textit{(8)}}$$

From this, it is possible to calculate the share of each component in total government spending (**θ**):

[2] For more on final demand decomposition methods see Miller and Blair (2009).

$$\boldsymbol{\theta} = \left(\frac{1}{g}\right)\boldsymbol{\sigma} \quad (9)$$

Last but not least, the share of public consumption and GFCF ($\boldsymbol{T}$) spent in each sector is given by:

$$\boldsymbol{T} = (\boldsymbol{G})(\widehat{\boldsymbol{\sigma}})^{-1} \quad (10)$$

Putting (7), (9), and (10) together, we have $\boldsymbol{g}$ expressed in terms of scale, public expenditure composition, and product-mix (sectoral composition):

$$\boldsymbol{g} = \boldsymbol{T}\boldsymbol{\theta}g \quad (11)$$

Now, the total emissions (2) can be expressed as:

$$\boldsymbol{e} = \boldsymbol{\varepsilon} \times (\mathbf{I} - \boldsymbol{\Omega} \odot \boldsymbol{A})^{-1} \times \boldsymbol{T}\boldsymbol{\theta}g \quad (12)$$

The changes in total emissions between an initial period (t = 0) and an end period (t = 1) are defined as:

$$\Delta\boldsymbol{e} = \boldsymbol{e}_g^1 - \boldsymbol{e}_g^0 \quad (13)$$

So, from (12), we have:

$$\Delta\boldsymbol{e} = \boldsymbol{\varepsilon}^1 \times (\mathbf{I} - \boldsymbol{\Omega}^1 \odot \boldsymbol{A}^1)^{-1} \times \boldsymbol{T}^1\boldsymbol{\theta}^1 g^1 - \boldsymbol{\varepsilon}^0 \times (\mathbf{I} - \boldsymbol{\Omega}^0 \odot \boldsymbol{A}^0)^{-1} \times \boldsymbol{T}^0\boldsymbol{\theta}^0 g^0 \quad (14)$$

To account for the various forms of decomposition, we utilize the average of polar decomposition, as recommended by Dietzenbacher and Los (1998). The total decomposition (14) and the algebraic form of each effect are shown in Table 1.

Table 1. Summary of structural decomposition

Effect	Algebraic form	Description
Emission intensity effect (15. a)	$(1/2)(\Delta\boldsymbol{\varepsilon})(\boldsymbol{Z}^0\boldsymbol{g}^0 + \boldsymbol{Z}^1\boldsymbol{g}^1)$	Emission changes due to changes in the sectoral emission per unit of gross output ($\Delta\boldsymbol{\varepsilon}$). A positive (negative) sign means the economy has become more (less) intensive in emissions related to the gross output.
Trade pattern effect (15.b)	$(1/2)[\boldsymbol{\varepsilon}^0(\boldsymbol{Z}^1[(1/2)(\Delta\boldsymbol{\Omega}) \odot (\boldsymbol{A}^0 + \boldsymbol{A}^1)]\boldsymbol{Z}^0)\boldsymbol{g}^1 + \boldsymbol{\varepsilon}^1(\boldsymbol{Z}^1[(1/2)(\Delta\boldsymbol{\Omega}) \odot (\boldsymbol{A}^0 + \boldsymbol{A}^1)]\boldsymbol{Z}^0)\boldsymbol{g}^0]$	Emission changes due to changes in the share of imported inputs used in the production of goods and services to meet the demand created by public expenditure ($\Delta\boldsymbol{\Omega}$). A positive (negative) sign means that more (less) emissions are being produced due to the increase in the share of domestic inputs. The higher the domestic share, the higher will be the production of inputs and, thus, the emissions related to it.

Technological effect (15.c)	$(1/2)[\boldsymbol{\varepsilon}^0(\boldsymbol{Z}^1[(1/2)(\boldsymbol{\Omega}^0 + \boldsymbol{\Omega}^1) \odot (\Delta\boldsymbol{A})]\boldsymbol{Z}^0)\boldsymbol{g}^1 + \boldsymbol{\varepsilon}^1(\boldsymbol{Z}^1\boldsymbol{Z}^1[(1/2)(\boldsymbol{\Omega}^0 + \boldsymbol{\Omega}^1) \odot (\Delta\boldsymbol{A})]\boldsymbol{Z}^0)\boldsymbol{g}^0]$	Emission changes due to changes in total technical coefficients ($\Delta\boldsymbol{A}$). A positive sign (negative) means that more (less) carbon emissions are being released since the sectors producing goods and services for the government are now using more (less) inputs.
Product mix effect (15.d)	$(1/2)(\boldsymbol{\varepsilon}^0\boldsymbol{Z}^0 + \boldsymbol{\varepsilon}^1\boldsymbol{Z}^1)\left((1/2)(\Delta\boldsymbol{T})\boldsymbol{\theta}^1 g^0 + (1/2)g^1(\Delta\boldsymbol{T})\boldsymbol{\theta}^0 g^1\right)$	Emission changes due to the sectoral composition of government expenditure ($\Delta\boldsymbol{T}$). A positive (negative) sign means that more emissions (less) are being produced because public expenditure is shifting toward sectors with higher (lower) carbon emission intensities.
Composition effect (15.e)	$(1/2)(\boldsymbol{\varepsilon}^0\boldsymbol{Z}^0 + \boldsymbol{\varepsilon}^1\boldsymbol{Z}^1)\left((1/2)\boldsymbol{T}^0\Delta\boldsymbol{\theta} g^0 + (1/2)\boldsymbol{T}^0\Delta\boldsymbol{\theta} g^1\right)$	Emission changes due to a variation in the share of public investment and government consumption ($\Delta\boldsymbol{\theta}$). A positive (negative) sign means more emissions are being produced because they took over a higher (lower) share of public expenditure.
Scale effect (15.f)	$(1/2)(\boldsymbol{\varepsilon}^0\boldsymbol{Z}^0 + \boldsymbol{\varepsilon}^1\boldsymbol{Z}^1)\left((1/2)(\boldsymbol{T}^0\boldsymbol{\theta}^0 + \boldsymbol{T}^1\boldsymbol{\theta}^1)(\Delta g)\right)$	Emission changes due to a variation in the level of public expenditure (Δg). A positive sign (negative) means that the increase (decrease) in government spending has led to a rise (fall) in carbon emissions

Source: Author's elaboration.

3.2 Data

Neither a time series of Leontief inverse matrices, emission, or public investment vectors are available in official databases. Therefore, this article relies on estimated data on these topics from three different databases (Table 2).

Table 2. Source and variables used in the model

Variable	Database	Source
$\boldsymbol{e}$, vector of emission intensity per industry	The satellite accounts for GHG emissions	Alvarenga, Costa and Young (2022)
$\boldsymbol{\Omega}$, share of domestic inputs in total inputs; $\boldsymbol{A}$, total technical coefficient; and $\boldsymbol{c}_g$, government consumption	Annual Input-Output Tables (IOT)	Passoni and Freitas (2022)
$\boldsymbol{k}_g$, vector of public investment by industry.	Investment absorption matrices (IAM)	Miguez and Freitas (2021)

Source: Author's elaboration.

In this study, we use an emission vector that does not include land use change emissions. Both the IOT and IAM are valued at constant prices.

4. Results

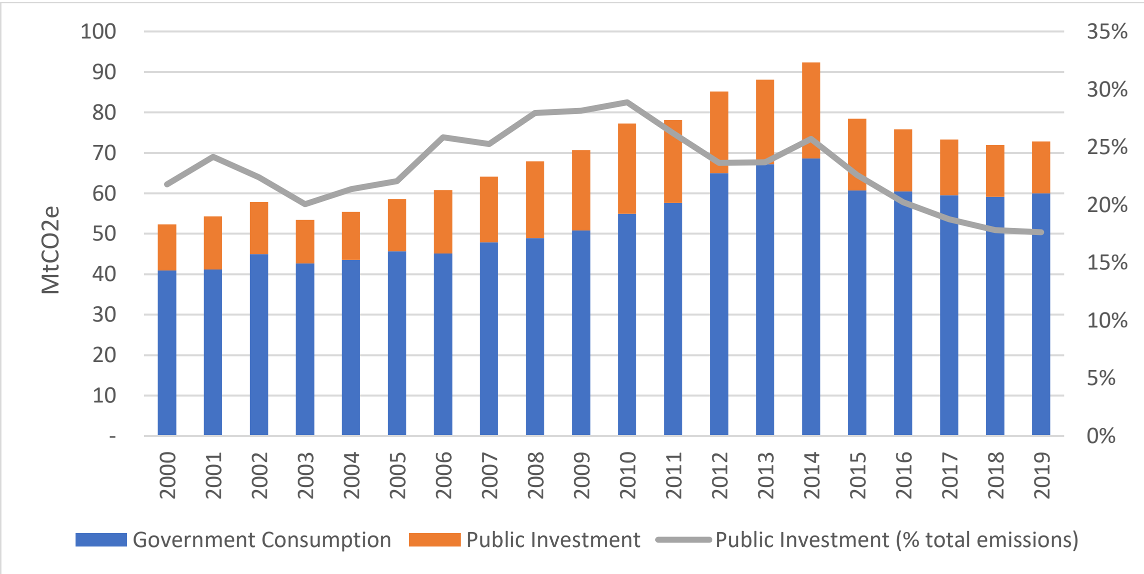
4.1 The trajectory of GHG emissions from Brazilian public spending

Graph 1 shows the evolution of emissions resulting from public spending between 2000 and 2019. As one can notice, there are two very distinct moments: one from 2000-2014, which shows an increasing trend in GHG emissions and seems to accelerate after 2004, and the other, from 2014 to 2019, where the emissions turn downwards.

Between 2000 and 2014, while emissions from public spending grew by 76.58%, public investment emissions increased by 108.5%. As a result, the share of investment in the total emissions of Brazilian public spending jumped from 21.5% to 25.7% in the 2000-2014 period, after having peaked at 28.9% in 2010.

In this period, the investment rates took off in Brazil, especially after 2005. The launching of the Acceleration Growth Program (PAC) in 2007 intensified public investment expansion. In its first edition (PAC I), which goes from 2007 to 2010, the investment increased by an average annual rate of 23%, while primary expenditure grew 8% p.a. In 2011, the government launched PAC II. The public investment average growth rate was more modest (4.2% p.a), but it was still growing faster than primary expenditure as a whole (3.5% p.a).

Graph 1. Emissions from government consumption and public investment and share of public investment in public expenditure's emissions.



Source: authors' elaboration

It is important to mention that public investment engages sectors that are, on average, more carbon-intensive than those producing goods and services to meet the demand created by government consumption. Table 3 shows that public investment emission intensity is roughly 2.7 times bigger than government consumption emission intensity. While the average emission intensity of public investments between 2000 and 2019 was 210.9 tCO_2e per each million of expenditure, this figure for the government consumption was 91.9 tCO_2e/ BRL million. Therefore, every time public investment increases faster than total primary expenditure, some additional emissions are expected through the composition effect, as it will be shown in the next section. In addition, public investment often relies on larger production chains, requiring more inputs and, thus, more emissions in its production.

Table 3. Share in total emissions and emission intensity by public expenditure components

Type of Expenditure	Average Emissions (% of total emissions from public expenditure)				
	2000-2004	2005-2010	2011-2014	2014-2019	2000-2019
Government Consumption	78.1%	73.6%	75.2%	79.5%	76.8%
Public Investment	21.9%	26.4%	24.8%	20.5%	23.2%
Type of Expenditure	Average Emission Intensity (tCO2e/millions of Gross Output)				
	2000-2004	2005-2010	2011-2014	2014-2019	2000-2019
Government Consumption	81.3	76.6	83.0	76.2	78.5
Public Investment	213.2	213.6	199.6	213.3	210.9
Government Expenditure	94.1	92.1	97.0	87.7	91.9

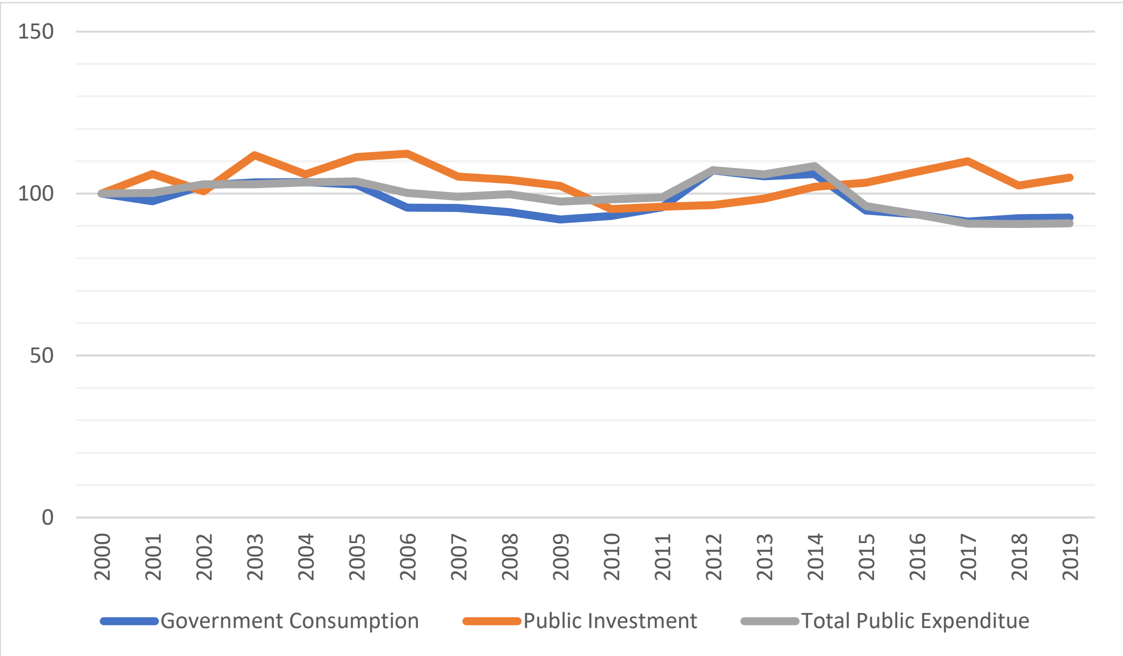
Source: authors` elaboration

After 2014, emissions entered a downward trajectory, which is mainly concentrated in the 2014-2016 period. In this period, a cut of 10.9% in primary expenses took place in the 2015 and 2016 fiscal years, which has been followed by a 17.9% reduction in the emission from public expenditure. After 2017, the emission trajectory stabilized. Indeed, from 2017 to 2019, the emission grew by only 0.6%. This stabilization in the emission trajectory is the side effect of the new Brazilian fiscal regime that left no room for increasing primary expenses. Still, some variation in the GHG emissions can occur through changes in the composition or in the government basket of goods and services or due to changes in the decomposition components related to the Brazilian productive structure.

Since fiscal adjustments in the short-run tend to impact more intensively discretionary expenditure, the emissions from public investment decreased much faster than the total expenditure emissions. From 2014 to 2019, the emissions from public investment dropped by 45.9%, while emissions from government consumption and total primary expenditure fell by 12.5% and 21.1%, respectively.

Last but not least, one should notice that no significant improvement in the GHG emissions intensities of public investment took place in the period under review. Over the two analyzed decades, total public expenditure and government consumption dropped their average emission intensities by 9.2% and 7.4%, respectively, and no reduction can be observed for public investment.

Graph 3. GHG intensity of public expenditure - index (2000 = 100)



Source: own elaboration

4.2 Structural Decomposition Analysis

2000-2019

During the period of 2000-2019, emissions derived from Brazilian public expenditure increased by 20.5 MtCO2e mainly due to the scale effect, which accounted for an emission increase of 26.7 MtCO_2e (Graph 3). The scale effect was high for all industry groups, but the manufacturing sector scored the greatest value, as shown in Graph 4.

When it comes to the technology effect, its contribution to carbon emissions was relatively small but yet positive, and a great performance difference can be noticed across the industry groups. While the agriculture sector improved its economic efficiency, the other sectors increased their GHG emissions through the technology effect.

All other effects were negative and partially contributed to offsetting the impact of the increase in public spending on emissions, especially in the manufacturing sector.[3]

Among those effects, the intensity, composition, and change in the trade pattern effects stand out. The first effect reveals that there has been an improvement in environmental efficiency in the production of goods and services in the Brazilian economy that contributed to reducing emissions from public spending. Breaking down the results by industrial groups, one should notice that agriculture was the main responsible for the overall negative intensity effect. This fact is consistent with the thesis that the sector underwent an important process of productivity increase (Costa, 2022), which also explains the negative technology effect of the agriculture sector. In addition, Alvarenga et al. (2023) draw attention to internal changes in this sector. According to the authors, the ongoing process of soybean expansion over pasturelands results in the reduction of agriculture emission intensity, whether because soybean yields higher gross output per hectare than livestock or because the crops are not directly related to methane emissions as cattle ranching. In the meantime, there has been a minor reduction in the emission intensity of manufacturing and an increase in the emission intensity of services.

The contribution of the product mix effect to emission reduction was roughly null, around 44.4 thousand tCO_2e. This low negative product mix effect indicates that the government's basket of goods and services has not shown any significant improvement in terms of environmental quality (when measured in GHG emissions) in the period under review. The disaggregation of the product mix effect by industrial groups reveals that services performed a little better than the primary and secondary sectors in this period.

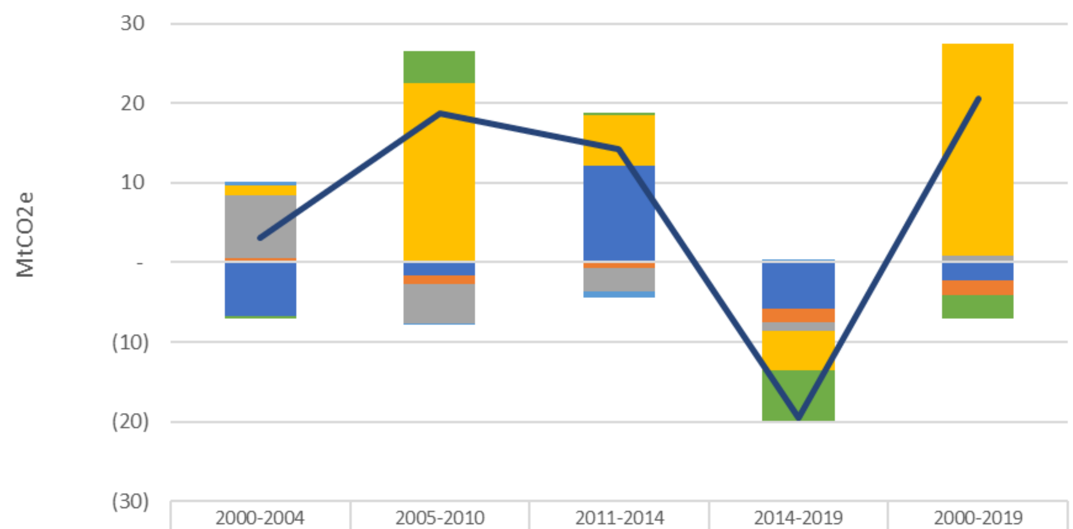
[3] One should notice that even though the secondary sector presented the largest scale effect, it does not account for the largest overall emission increase in the period.

It is essential to highlight that the composition effect was the main element driving emission reduction in this period. This reduction is the result of the smaller share held by public investment in total public expenditure in 2019 compared to the year 2000. Since public investment is more intensive in emissions than government consumption, a reduction in the public investment's share of total primary expenditure tends to be accompanied by a negative composition effect. It is interesting noting that most of the emission reduction from the composition effect took place in the manufacturing sector. This is intuitive since most goods produced to meet public investment demand come from this industry group. Therefore, when public investment drops, the demand for manufactured goods tends to fall more intensively than in other sectors, and so do its emissions.

Although emissions reduction is the ultimate goal of a decarbonization process, the reduction of public investment should not be seen as a means to achieve it. Public investment is a central piece of the State's capacity to continue providing goods and services to the population (Orair, 2016), and several areas in the country suffer from chronic underinvesting, such as infrastructure, health, education, environment, among others (Young et al., 2018; Alvarenga, Costa, and Young, 2021; Kersteneztky et al., 2023). Furthermore, the solution to the climate crisis requires the creation of low-carbon production capacities, which depend on new public and private investments. In addition, new investments in adaptation are also required for Brazil to cope with the effects of extreme weather events.

Finally, the other element to give a significant negative contribution to the GHG emission was the "trade pattern effect". What this component actually shows is that there was an increase in the share of imported inputs in the sectors engaged in producing goods and services to meet the final demand created by public spending. Therefore, the goods are still being produced elsewhere, and so are their emissions. The net impact on the climate of displacing the production of these inputs to another country can be positive or negative, depending on the difference in the GHG intensities between the sectors that used to produce them domestically vis-à-vis the ones that produce them now. The trade pattern effect was higher in the secondary sector than in the others. This may be linked to the effect of Brazilian deindustrialization on interindustry density (Medeiros, Freitas, and Passoni, 2018; Passoni, 2019).

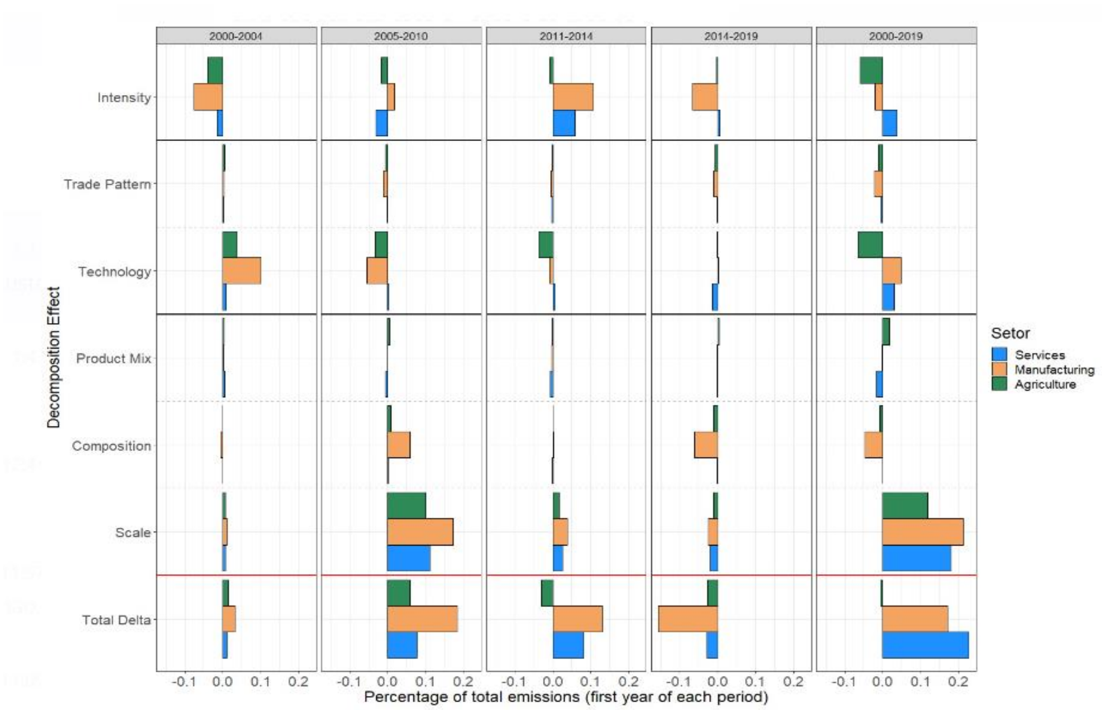
Graph. Structural decomposition of the emissions from the Brazilian public expenditure



	2000-2004	2005-2010	2011-2014	2014-2019	2000-2019
Composition Effect	(308,260)	4,010,911	166,294	(6,407,795)	(2,834,734)
Product Mix Effect	598,958	(151,778)	(740,484)	406,123	(44,366)
Scale Effect	1,246,366	22,510,234	6,375,953	(4,904,454)	26,734,738
Technology Effect	7,778,099	(4,918,970)	(2,924,733)	(1,098,823)	773,207
Trade Pattern Effect	581,968	(1,094,017)	(772,918)	(1,692,012)	(1,897,922)
Intensity Effect	(6,801,405)	(1,681,669)	12,174,840	(5,843,226)	(2,202,576)
Total	3,095,725	18,674,712	14,278,952	(19,540,187)	20,528,348

Source: authors' elaboration.

Graph 4. Decomposition effects by industry group



Source: authors' elaboration.

2000-2004

In this subperiod, the emissions generated in the production of goods and services to meet the demand created by the Brazilian public expenditure increased by 3.1 MtCO2e. The contribution of the scale effect was mild (in comparison to the other subperiods), reflecting the relatively modest increase in primary expenditure in the period, especially regarding public investments. While the primary expenditure grew on average by 4.7% per year, public investments expanded, on average, by 0.5% per year in the three levels of government. No great difference was noticed for the scale effect when broken into industry groups: all sectors presented a quite small, but yet positive scale effect.

The sluggish growth of public investment in this subperiod caused its share in primary spending to fall one percentage point, from 6.4% to 5.4%, which explains the negative composition effect, especially in the manufacturing sector. Regardless of the decrease in the share of investments in total spending, it is interesting noting that the product mix effect was positive, revealing that public expenditure shifted toward more emission-intensive sectors. The agriculture and services sectors were the main ones responsible for the positive product mix effect.

The trade pattern effect was positive (although small) for all three industrial groups, indicating an increase in the share of domestic inputs used to meet the final demand created by government consumption and public investment. The share of domestic inputs increased in all three industrial groups, which all combined resulted in the emission of 581,9 thousand tCO2e.

The technological effect during this period is particularly high. However, this fact may be related to changes in relative prices. During this period, the country underwent various shocks (energy, exchange rate, and commodity prices). Future work should examine the impact of relative prices on environmentally extended input-output analysis[4].

Finally, the intensity effect accounted for a reduction of 6.8 MtCO2e, mostly concentrated in the manufacturing sector. In this particular period, Brazil has gone

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[4] For a matrix deflation methodology, see Passoni (2019)

through a power shortage crisis that led the country to adopt policies to incentivize energy efficiency gains (Gerard, 2013). According to data from the International Energy Agency (IEA), during this period, the primary energy consumption per unit of GDP in Brazil dropped by 8.9%, while the CO_2 intensity of power fell by 2.9% (IEA, 2021).

2005 - 2010:

During this period, there was an acceleration of public spending in Brazil, with an emphasis on the expansion of public investment. Brazilian primary expenditure grew at an annual rate of 6.8% (IMF, 2023), while public investment expanded at a rate of 17.2% per year. These two elements explain the large scale and composition effects, which resulted in an additional emission of 22.5 $MtCO_2e$ and 4.5 $MtCO_2e$, respectively. Both the effects are higher in the manufacturing sector, given that public investment tends to increase demand for manufactured goods (cement, metal alloys, among others).

It is interesting noting that all other effects were negative. With the exception of the negative trade pattern effect, which may indicate a process of interindustry density loss and possibly no positive environmental outcome, the negative value for the other effects is desirable, as it helps to offset the emissions generated by the increase in public spending and in the share of investments in primary expenditure. If public expenditure is to increase at least to match demographic growth and, or economic growth, it is important to have ways to counterbalance the emissions expected from the scale and composition effect.

2011-2014

This period marks the beginning of the deterioration of Brazil's fiscal situation, which resulted in the deceleration of public spending in comparison to the previous one. The primary spending grew on average 3.5% per year in the 2011-2014 period (compared to 6.8% between 2005 and 2010). This fact explains the substantial reduction of the scale effect from 22 $MtCO_2e$ to 6.3 $MtCO_2e$. The composition effect also decreased in comparison to the 2000-2005 period. Nevertheless, since public investment remained growing above the primary expenditure as a whole, the composition effect was positive.

One noteworthy change in comparison to the previous period was the significant increase in the intensity effect, which rose from -1.7 $MtCO_2$ to 12.2 $MtCO_2e$. This surge can be attributed to the Brazilian water crisis, which forced a higher activation of thermoelectric power plants fueled by fossil fuels. Consequently, the CO_2 intensity of electricity produced in Brazil rose by a staggering 79.2% between 2010 and 2015, as reported by IEA (2022). This generated a transversal 'carbonization effect' in the Brazilian economy. However, the manufacturing and services sectors were more affected by it due to their higher energy intensity.

This environmental efficiency loss was partially offset by an increase in economic efficiency, as reflected by a negative technology effect during the period. Additionally, it is worth noting that the product mix effect remained negative. Despite the growth in emissions intensity in Brazil's productive structure during this period, the government managed to shift its consumption basket towards goods and services with lower polluting potential. Lastly, the trade pattern effect remained negative.

2014-2019

The last sub-period was marked by a fiscal crisis that culminated in significant budget cuts, including under the new fiscal regime of spending ceiling. The primary expenditure and public investment grew at an average rate of -0.3% and -7.7% per year, respectively. As a result, both scale and composition effects scored high negative values. In fact, the composition effect was the main driver of emission reduction in this period, which shows how heavily affected public investment is during fiscal crises. It is worth noting that both scale and composition effects are greater for the manufacturing group, meaning that the budget cuts and the public investment retreat affected manufacturing production and emission more intensively.

The intensity effect was strongly negative, resulting from the improvement in the levels of hydropower reservoirs during the period, which reduced the need for electricity production from thermal power plants. In this period, the carbon intensity of Brazilian electricity production fell by 41.5% between 2015 and 2020 (IEA, 2022), mostly impacting the intensity effect of the secondary sector, where industries tend to be more energy intensive.

The technology effect remained negative, driven by the values of the agriculture and, especially, service sectors. Finally, it should be noted that the product mix effect was the only one with a positive value during the period. Although its value is low, it is noteworthy that the government's basket of goods and services has shifted towards those sectors with higher emissions, even though public investments were declining and the productive structure was reducing its emission intensity.

5. Policy recommendation for decarbonizing government expenditure

The integration of climate action into fiscal policy is a relatively recent practice, although significant progress has already been made in several Ministries of Finance at the global level (Coalition of Ministers of Finance, 2023). One of the main advances is the development and adoption of new methodologies for the identification and tracking of climate spending based on the use of budget classifiers or budget tags. These climate expenditure classifiers/tags make it possible to identify the public resources that have a potential impact (direct and indirect) on mitigation, adaptation, and/or preservation of biodiversity (Pizarro, Delgado, Eguino, 2021). However, the main disadvantage of this approach is that it focuses exclusively on the quantification of public expenditures with potential climate impacts without establishing their real incidence in terms of emissions reduction, resiliency, or biodiversity.

The section above presented an estimation of the emissions generated by all primary expenditures in the three levels of government, whether it is directly and positively related to climate or not. Besides, the decomposition proposed helped to identify the main drivers of GHG emissions from public expenditure.

As expected, the emission level is very sensitive to its the magnitude and composition of public expenditure. In periods when government spending increased at high rates and public investments took over a larger share of it, GHG emissions soared. The only period when the level of emissions decreased was between 2014 and 2019, as a result of the successive cuts in primary expenditure that brought the annual public investment growth rate to (-) 0.5%.

However, downsizing government spending is not truly an option for cutting emissions. Several public services are already provided in insufficient quantity or quality in Brazil (Kerstenetzky et al., 2023), a situation that deepened after the fiscal adjustment that took place after 2015. In fact, for some of these services to keep the same level of quality and reach, public spending will have to increase at least to make up for the demographic growth, such as healthcare and education, or for GDP growth, such as environmental management and protection (Young, Alvarenga e Neto, 2014). Besides that, climate change itself will pressure public expenditure upwards due to the investment needs in adaptation and mitigation (Young et al., 2018; Delgado, Eguino, and Lopes, 2021).

Aside from the challenge of reconciling the need for higher public spending with the country's complex fiscal reality, it is critical to consider the impacts that these expenditures will have on emissions. In this sense, it is crucial to promote policy reforms to avoid emissions increasing hand-in-hand with the level of public expenditure and with a change in its composition towards larger participation of public investments. Therefore, two questions emerge: (i) which policies could make other effects compensate for the increase of the scale and composition effects? (ii) which kind of policies could minimize the scale effect and composition effect?

The results in the previous section showed that the product mix effect had a mild contribution to explaining changes in GHG emissions, fluctuating between very modest positive and negative values. For the period as a whole, the product mix contribution to emission reduction was near zero, indicating that the public administration did not succeed in reducing the carbon footprint of its baskets of goods and services.

This highlights the need for integrating instruments capable of improving the allocation of budgetary resources to low-carbon intensity sectors. Such reallocation could also contribute to reducing the impact of a faster increase in public investment on the composition effect, especially if these instruments could channel resources to invest in a low-carbon and resilient infrastructure.

The management reforms needed to achieve these changes include the adoption of new planning tools such as green procurement, green taxonomies, social carbon prices, or the integration of climate risk analysis into public investment management.

According to OECD data, public procurement accounted for roughly 14% of Brazilian total government expenditure in 2017. Redirecting this demand to the acquisition of goods and services with low carbon, and at large, environmental footprint could result in positive environmental outcomes, especially in sectors where it represents a significant portion of the market, such as construction, public transportation, and healthcare services (Harper and Edwards, 2023). Still, according to the authors, green procurement could lead to significant governmental savings by inducing the purchasing of goods with lower operation, maintenance, repair, and disposal costs.

Aside from that, the development of green taxonomies that incorporates climate criteria, including red-flagging projects that could lead to stranded assets and carbon lock-ins, could assist the government in improving the environmental quality of public investment (Daza, 2023, forthcoming). Strengthening the integration of traditional planning instruments, such as national development and investment plans and sectoral territorial plans, with Paris Agreement planning instruments, namely nationally determined contributions (NDC) and long-term strategies (LTS), could also lead to a greater alignment between countries' investment planning and mitigation and adaptation goals (Buttazzoni, Delgado and Alvarenga, 2023 forthcoming). Likewise, mainstreaming social carbon prices (CSP) into the evaluation process of public investment projects could help decision-makers to pick the least environmentally harmful projects. The use of social carbon prices in the ex-ante evaluation of big-scale infrastructure has proven to be useful in fostering low-carbon infrastructure (Cartes, 2023 forthcoming).

It is also important to phase out the subsidies to highly emission-intensive industries in Brazil. In 2021, fossil fuel subsidies amounted to R$ 118,2 billion (INESC, 2022). Other R$ 123 billion in subsidies were given to cattle ranching between 2008 and 2017 (Instituto Escolhas, 2020).[5] In addition to their fiscal impact, such subsidies distort the economic incentives in favor of highly emission-intensive industries, delaying the transition to a low-carbon economy. In terms of the decomposition proposed here, the incentives to these kinds of industries tend to slow down the reduction in the emission-intensities, which will prevent higher negative intensity effect from happening.

Fostering green innovation could help technology effect to have a greater impact on emissions reduction. It is critical to increase the financial and institutional capacity of the Brazilian State to spearhead an ambitious research and development program for green technologies. As recalled by Mazzucatto (2013), states played a pivotal role in pushing disruptive technologies, especially by engaging in highly uncertain R&D

[5] At this point, it is important to remember that land use change emissions are not included in the analysis proposed in this paper, which means that agriculture and energy are the main sources of emissions.

projects in which the private sector was not willing to take part, given the high risks involved.

Climate change will require the development and implementation of new disruptive technologies on an unprecedented scale. Governments and the private sector will have to bear the risk and deal with a very uncertain reality, whether regarding the frequency and intensity of extreme climate events or the technological paradigm that will prevail during the transition to and in a carbon-neutral world.

5. **Concluding remarks**

This article estimated and decomposed the GHG emissions resulting from the production of goods and services needed to meet the demand created by Brazilian public spending in the period 2000-2019. Among the decomposition elements, three are directly related to the level and quality of public spending, namely: the scale, product mix effect, and composition effects. The other elements (intensity effect, technology effect, and trade pattern effect) result from structural characteristics unrelated to public spending itself but interact with it to generate emissions.

The results showed that there are two distinct moments in the emission trajectory: one from 2000 up to 2014 and the other from 2014 onward. The first period was marked by an increasing trajectory in GHG emissions, which follows positive growth rates of primary expenditure and higher participation of investment in it. After 2014 this trend was reversed, and GHG emissions began declining. As the Brazilian fiscal situation aggravated, fiscal adjustment efforts were put forth, severely impacting discretionary expenditure.

Most of the GHG reduction in 2014 and 2019 concentrates on the first two years as a result of the budget cuts of 2015 and 2016. In these two years, emissions from public investment decreased at a much faster rate than emissions from public expenditure as a whole. This is mainly because, in the short term, fiscal adjustments tend to concentrate on reducing discretionary spending. In fact, while primary expenditure dropped by 10.8% between 2014 and 2016, public investment shrank by 41.6%.

The rapid decrease in public investment after 2014 tends to pull emissions downward through at least three channels. The first is the scale effect. A reduction in investment represents a reduction in public spending, leading to a lower demand for goods and services and, therefore, less emissions. The second occurs through the composition effect. According to the results found in this article, the intensity of emissions from public investment is more than twice the value of government consumption's intensity. It is important to highlight in this regard that while government consumption showed a minor improvement in its emission intensity in the 2000-2019 period, no improvement was observed for public investment, which points to the need to mainstream climate change into the public investment management, especially in the planning phase. The third is through the product mix effect. The decline in investments also tends to change the sectoral composition of spending, reducing demand for more emission-intensive goods and services such as cement, metal alloys, and freights, among others. It is important to note, however, that given the relatively small share of investments in primary spending, the product mix effect tends to be more sensitive to changes in government consumption.

After 2017, there was relative stability in the trajectory of emissions, which may be attributed to the implementation of the new Brazilian fiscal regime. The regime limits the real primary spending increase at the 2016 level, leaving less room for the scale effect to stand out.

Finally, the structural decomposition analysis results revealed that emission levels are very sensitive to the magnitude and composition of public expenditure. The emission level scored its highest value in the 2005-2010 period, when primary expenditure was consistently increasing, with public investment expanding at much faster rates than overall government spending. On the other hand, after Brazil increased efforts to adjust fiscal imbalances, a substantial decrease in the scale effect and, particularly, the composition effect took place. It is essential to mention that the product mix effect was either slightly negative or even positive (such as in the 2000-2004 and 2014-2019 periods), indicating that there has been no sizable improvement in the environmental quality of public expenditure in Brazil over the two decades analyzed in this paper.

More importantly, the only period when emissions from public expenditure decreased was when public expenditure and public investment had negative rates. However, if government expenditure is expected to increase in the future, whether because of demographic or economic growth, the insufficient provision of public services, or to cope with climate change, Brazil will have to work on some political reforms to minimize the impact of higher spending levels on GHG emissions.

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DATA APPENDIX

Table A1. Public investment in Brazil (at 2019 BRL billion)

Public Investment (at 2019 BRL Billion)							
Ano	Central Government	State Government	Municipal Government	General Government	Federal State-Owned Enterprises	Public Sector	GDP
2000	15,244	34,167	37,360	86,771	37,790	124,561	4,881,528
2001	22,209	43,740	33,186	99,135	43,222	142,357	5,072,120
2002	23,833	38,823	50,340	112,996	59,096	172,092	5,302,968
2003	10,893	31,301	41,577	83,771	60,552	144,322	5,573,168
2004	11,931	33,089	43,670	88,691	56,000	144,690	5,566,697
2005	18,993	38,696	34,953	92,642	57,599	150,241	5,727,844
2006	22,637	43,079	48,947	114,663	57,407	172,070	5,918,366
2007	26,360	32,607	51,106	110,073	67,442	177,515	6,257,894
2008	29,551	46,514	67,968	144,033	92,471	236,504	6,721,238

2009	**39,485**	**59,004**	**49,417**	**147,905**	**118,145**	**266,051**	**6,622,371**
2010	**60,510**	**80,148**	**64,245**	**204,902**	**134,483**	**339,385**	**7,194,564**
2011	**47,637**	**59,025**	**63,726**	**170,388**	**121,371**	**291,760**	**7,473,280**
2012	**42,540**	**54,613**	**71,530**	**168,683**	**137,250**	**305,933**	**7,590,452**
2013	**51,281**	**72,769**	**49,462**	**173,512**	**149,269**	**322,781**	**7,786,766**
2014	**56,335**	**77,644**	**58,659**	**192,638**	**119,855**	**312,494**	**7,850,915**
2015	**34,634**	**43,833**	**50,293**	**128,760**	**89,733**	**218,493**	**7,552,842**
2016	**29,037**	**35,542**	**47,886**	**112,465**	**57,822**	**170,287**	**7,341,917**
2017	**27,439**	**35,692**	**26,626**	**89,757**	**48,693**	**138,450**	**7,134,042**
2018	**27,895**	**37,554**	**34,709**	**100,158**	**88,614**	**188,772**	**7,318,874**
2019	**25,397**	**26,633**	**41,279**	**93,308**	**58,281**	**151,589**	**7,389,131**
Annual average growth rates							
Period	**Central Government**	**State Government**	**Municipal Government**	**General Government**	**Federal State-Owned Enterprises**	**Public Sector**	**GDP**
2000-2004	**-5.9%**	**-0.8%**	**4.0%**	**0.5%**	**10.3%**	**3.8%**	**3.3%**
2005-2010	**26.1%**	**15.7%**	**12.9%**	**17.2%**	**18.5%**	**17.7%**	**4.7%**
2011-2014	**5.7%**	**9.6%**	**-2.7%**	**4.2%**	**-0.4%**	**2.3%**	**1.7%**
2015-2019	**-7.5%**	**-11.7%**	**-4.8%**	**-7.7%**	**-10.2%**	**-8.7%**	**-0.5%**

Source: authors’ elaboration based on data from FGV (2023) and IMF (2023)

Table A2. Primary expenditure and public investment average growth rates

Period	Primary Expenditure	Public Investment
2000-2004	4.7%	0.5%
2005-2010	6.8%	17.2%
2011-2014	3.5%	4.2%
2015-2019	-0.3%	-7.7%

Source: authors' elaboration based on data from FGV (2023) and IMF (2023)