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Environmental Budget Execution and Greenhouse Gas Emissions: Evidence from Brazilian Municipalities

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Abstract: This paper examines whether municipal environmental budget execution is associated with greenhouse gas (GHG) emissions across Brazilian municipalities between 2000 and 2021. Using fiscal and emissions data for 5,570 municipalities, we estimate two-way fixed-effects models for aggregate Function 18 (Environmental Management) expenditure and its constituent budget subfunctions. We also examine emission dynamics around the implementation of the National Policy on Climate Change (PNMC), exploiting heterogeneity in pre-policy environmental expenditure. The results provide no robust evidence that higher aggregate environmental expenditure is systematically associated with lower emissions. Structural drivers of emissions, particularly primary vegetation loss, exhibit stronger and more consistent associations. Disaggregated estimates reveal heterogeneity across budget subfunctions and emission sectors, indicating that Function 18 is not a homogeneous policy instrument. The findings highlight the limitations of aggregate budget execution as a measure of policy effort and suggest that expenditure composition and implementation capacity are central to environmental expenditure effectiveness.

Keywords: Brazilian Municipalities; Public Expenditure; Greenhouse Gas Emissions.

Execução Orçamentária em Gestão Ambiental e Emissões de Gases de Efeito Estufa: evidências dos municípios brasileiros

Resumo: Este artigo investiga se a execução orçamentária municipal em gestão ambiental está associada às emissões de gases de efeito estufa (GEE) nos municípios brasileiros entre 2000 e 2021. Utilizando dados fiscais e de emissões para 5.570 municípios, estimamos modelos de efeitos fixos bidirecionais considerando tanto a despesa agregada da Função 18 (Gestão Ambiental) quanto suas subfunções orçamentárias. Também examinamos a dinâmica das emissões em torno da implementação da Política Nacional sobre Mudança do Clima (PNMC), explorando a heterogeneidade da despesa ambiental pré-política. Os resultados não fornecem evidência robusta de que maior despesa ambiental agregada esteja sistematicamente associada a menores emissões. Determinantes estruturais das emissões, particularmente a perda de vegetação primária, apresentam associações mais fortes e consistentes. Estimativas desagregadas revelam heterogeneidade entre subfunções orçamentárias e setores emissores, indicando que a Função 18 não constitui um instrumento homogêneo de política pública. Os achados evidenciam os limites da execução orçamentária agregada como medida de esforço governamental e sugerem que a composição da despesa e a capacidade de implementação são centrais para a efetividade do gasto ambiental.

Palavras-chave: Municípios Brasileiros; Despesa Pública; Gases de Efeito Estufa.

JEL Codes: H72, Q56, Q58, R58, H83.

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1 INTRODUCTION

Public expenditure is one of governments' primary instruments for addressing market failures and achieving socially desirable outcomes. Yet higher levels of public spending do not necessarily translate into more effective public policies. The effectiveness of public spending depends not only on the volume of budgetary resources but also on institutional capacity, policy design, implementation quality, and expenditure composition. Accordingly, understanding whether public spending generates measurable outcomes has become a central concern in the public economics literature, particularly in policy areas characterized by complex externalities, such as environmental policy.

Environmental public expenditure provides a particularly relevant setting for assessing the effectiveness of government intervention. Climate change has intensified the demand for public policies aimed at mitigating greenhouse gas (GHG) emissions, preserving natural resources, and promoting sustainable development, thereby increasing the importance of allocating scarce public resources efficiently. In federal countries such as Brazil, local governments play an increasingly important role in implementing environmental policies, while competing budgetary priorities and fiscal constraints reinforce the need to understand whether environmental public expenditure generates measurable improvements in environmental performance (Buchanan; Musgrave, 1960; Colm; Musgrave, 1960; World Bank, 2012).

Despite the expansion of municipal environmental public expenditure in recent decades, empirical evidence on whether these resources generate measurable environmental improvements remains limited, particularly in developing countries. Existing studies report heterogeneous findings on the relationship between environmental public expenditure and greenhouse gas emissions, suggesting that spending alone is insufficient to explain environmental policy effectiveness. Instead, policy outcomes also depend on expenditure composition, institutional capacity, enforcement, and local implementation conditions (Quintela, 2016; Barbier, 2019).

Brazil provides a particularly suitable setting for investigating this question. The country is among the world's largest greenhouse gas emitters, while environmental responsibilities are shared across different levels of government. At the municipal level, environmental public expenditure is classified under Function 18 (Environmental Management), a standardized budget classification established by Ordinance No. 42/1999 and incorporated into the Brazilian public budgeting system (Brasil, 1999). Function 18 encompasses a broad range of environmental policies and administrative activities, yet little is known about whether aggregate expenditure under this function is systematically associated with lower greenhouse gas emissions.

Against this backdrop, this paper examines whether municipal environmental public expenditure is systematically associated with greenhouse gas emissions across Brazilian municipalities during the 2000–2021 period. Specifically, it addresses the following research question:

Is municipal environmental public expenditure systematically associated with greenhouse gas emissions across Brazilian municipalities?

To address this question, we estimate two-way fixed-effects models using panel data for 5,570 Brazilian municipalities between 2000 and 2021. The analysis considers both aggregate greenhouse gas (GHG) emissions and sector-specific emissions from Agriculture, Land-Use Change, Energy, Industrial Processes, and Waste. As a complementary analysis, we estimate a dynamic difference-in-differences specification to examine heterogeneous emission trajectories following the implementation of the National Policy on Climate

Change (PNMC).

The empirical results provide no robust evidence that aggregate municipal environmental public expenditure is systematically associated with lower greenhouse gas emissions. However, the disaggregated analysis reveals substantial heterogeneity across budget subfunctions and emission sectors, indicating that the composition of environmental spending is more informative than its aggregate level for understanding environmental policy effectiveness. These findings contribute to the literature on public expenditure effectiveness by showing that aggregate environmental spending alone is insufficient to explain policy outcomes and that the allocation of resources across policy instruments may be more important than the overall level of expenditure.

The remainder of the paper is organized as follows. Section 2 reviews the theoretical and empirical literature, Section 3 describes the data and empirical strategy, Section 4 presents and discusses the empirical results, and Section 5 concludes.

2 LITERATURE REVIEW

2.1 Environmental Public Expenditure

The effectiveness of public expenditure has long been a central concern in the public economics literature. In the environmental domain, however, evidence on whether public expenditure translates into measurable environmental outcomes remains limited, particularly in developing countries and in Brazil (Quintela, 2016). Existing studies report heterogeneous findings: some identify negative associations between environmental expenditure and pollution or greenhouse gas (GHG) emissions, whereas others find no statistically significant or robust relationship (Barbier; Markandya, 2013; Barbier, 2019; Quintela, 2016). This heterogeneity suggests that expenditure effectiveness depends on institutional, sectoral, and regional characteristics rather than on expenditure levels alone. Identifying the mechanisms through which environmental public expenditure may affect environmental outcomes is therefore central to interpreting the empirical evidence (Mickwitz, 2006; Sterner; Coria, 2013).

Environmental public expenditure may affect greenhouse gas emissions through several complementary channels. First, resources allocated to environmental monitoring and regulatory enforcement may strengthen governments' capacity to detect environmental violations and ensure compliance through inspections, fines, embargoes, and other sanctions (Andersen *et al.*, 2002; Assunção; Gandour; Rocha, 2015). In Brazil, environmental enforcement also relies on technological monitoring infrastructure, including satellite-based systems such as the Program for Monitoring Deforestation in the Brazilian Amazon by Satellite (*Programa de Monitoramento da Floresta Amazônica Brasileira por Satélite*, PRODES) and the Real-Time Deforestation Detection System (*Sistema de Detecção de Desmatamento em Tempo Real*, DETER), which expand the capacity to detect deforestation and fires (Diniz *et al.*, 2015; INPE, 2024). Monitoring and enforcement mechanisms are particularly relevant to land-use change and agricultural emissions, which account for a substantial share of Brazil's greenhouse gas emissions (Observatório do Clima, 2024).

Second, environmental expenditure may support territorial conservation and strengthen state capacity. Resources devoted to protected areas and ecosystem preservation may restrict land conversion and agricultural expansion, potentially reducing emissions associated with land-use change and forest degradation (Nepstad *et al.*, 2014; Soares-Filho *et al.*, 2010). Investments in personnel, equipment, institutional infrastructure, and technical capacity may also improve environmental policy implementation and enforcement (Evans, 2012; Skocpol, 1985). The effectiveness of these mechanisms is likely to vary across sectors and municipalities according to productive structures, environmental pressures, institutional capacity, and regulatory effectiveness (Cole; Elliott, 2003; Mickwitz, 2006; Sterner; Coria, 2013).

In Brazil, municipal environmental expenditure is recorded under Function 18 (Environmental Management), a standardized budget classification established by Ordinance No. 42/1999 (Brasil, 1999). Function 18 comprises the following expenditure subfunctions: Environmental Preservation and Conservation, Environmental Control, Recovery of Degraded Areas, Water Resources, and Meteorology (Brasil, 1999, 1964). Because these subfunctions finance distinct policy instruments and administrative activities, aggregate environmental expenditure may conceal substantial heterogeneity in its association with environmental outcomes (Barbier, 2019; Quintela, 2016).

The municipal level is particularly relevant in this context because environmental policy implementation occurs within a decentralized fiscal and administrative structure. Local governments differ substantially in fiscal capacity, administrative resources, and exposure to environmental pressures, which may affect their ability to translate budgetary allocations into effective policy implementation. Consequently, similar levels of environmental expenditure may be associated with different environmental outcomes across municipalities, reinforcing the importance of examining expenditure effectiveness at the local level.

2.2 Empirical Evidence

Empirical evidence on the effectiveness of environmental public expenditure remains limited and mixed. Cross-country and regional studies using panel-data and STIRPAT specifications report heterogeneous associations between environmental expenditure and greenhouse gas emissions. Using an unbalanced panel of 117 developed and developing countries from 2000 to 2023, Yilmaz (2025) identifies a negative association between environmental protection expenditure and GHG emissions, although the estimates are not statistically significant across all specifications. For the European Union, Georgieva (2024) reports a significant inverse relationship between environmental investment and emissions over 2008–2022. Similarly, applying an extended STIRPAT model to Canadian provinces, Aziz, Hossain, and Lamb (2024) finds that public and private environmental protection expenditures are associated with lower long-run GHG emissions, with a stronger estimated association for private expenditure.

Related evidence emphasizes the role of institutional and financial conditions in shaping environmental outcomes. Using GMM, Method-of-Moments Quantile Regression, and Granger causality tests for South Asian Association for Regional Cooperation countries, Mehmood *et al.* (2024) documents heterogeneous relationships between financial inclusion, governance, and carbon emissions. More broadly, the available evidence suggests that the relationship between environmental public expenditure and environmental outcomes varies across countries and institutional settings. Differences in institutional capacity, enforcement intensity, expenditure composition, and policy implementation may contribute to the heterogeneous findings reported in the literature (Barbier, 2019; Quintela, 2016). This evidence motivates empirical analyses that explicitly consider expenditure composition. Accordingly, this study examines whether municipal environmental public expenditure is systematically associated with greenhouse gas emissions across Brazilian municipalities and whether these associations vary across budget subfunctions and emission sectors.

3 DATA AND METHODS

3.1 Data Sources and Variable Description

To construct the municipality-level panel dataset for 2000–2021, we combine data from several public sources. Greenhouse gas (GHG) emissions are obtained from the Greenhouse Gas Emissions and Removal Estimating System (SEEG) (Observatório do Clima, 2024), while municipal environmental expenditure is obtained from the Brazilian Public Sector Accounting and Fiscal Information System (SICONFI) (STN, 2023). Socioeconomic data, including Gross Domestic Product (GDP), Gross Value Added (GVA), and population, are drawn from the Brazilian Institute of Geography and Statistics (IBGE). Additional controls include primary vegetation loss from MapBiomas (MapBiomas, 2024), rural credit from the Central Bank of Brazil (Banco Central do Brasil, 2024), administrative environmental violation notices issued by IBAMA, and formal employment relationships from the Annual Social Information Report (RAIS) (RAIS, 2023).

The dependent variables are municipality-level GHG emissions, measured in tonnes of carbon dioxide equivalent (CO_2e). Following the sectoral classification adopted by SEEG and the IPCC (IPCC, 2022), we consider total emissions and emissions from five sectors: Agriculture, Energy, Land-Use Change, Industrial Processes, and Waste. These sectors capture emissions associated with agricultural and livestock activities, energy production and consumption, vegetation conversion and fires, industrial processes, and solid waste and wastewater management, respectively.

The variable of interest is municipal public expenditure under Function 18 (Environmental Management), obtained from SICONFI (STN, 2023). Function 18 is the standardized functional classification for local government budget execution in environmental management established by Ordinance No. 42/1999 (Brasil, 1999). Table 1 presents its budget subfunctions.

Table 1: Environmental Management Budget Subfunctions

Code	Subfunction	Description
541	Environmental Preservation and Conservation	Protection of fauna, flora, ecosystems, and environmentally relevant areas, including soil conservation and preventive measures against environmental degradation.
542	Environmental Control	Prevention, monitoring, and control of different forms of pollution, including water, air, and soil contamination, as well as noise pollution.
543	Recovery of Degraded Areas	Recovery, rehabilitation, and reintegration of degraded areas, with the aim of enabling their urban or rural use, particularly in locations subject to recurrent flooding or erosion processes.
544	Water Resources	Planning, coordination, regulation, control, and supervision related to the use, management, and integrated development of water resources, with the aim of reconciling multiple uses and ensuring their sustainable utilization.
545	Meteorology	Development, coordination, and maintenance of systems, agencies, and instruments for monitoring and studying climate and weather, including the analysis of climate variability and meteorological conditions.
999	Other Environmental Management Subfunctions	Expenditures that do not fall within the preceding subfunctions because of insufficient information or because their nature does not permit classification under the specific categories.

Source: Authors' own elaboration based on Brasil (1999) and Quintela (2016).

As shown in Table 1, Function 18 aggregates subfunctions with distinct policy rationales and instruments. Treating environmental expenditure as a homogeneous aggregate may therefore conceal subfunction-specific associations with GHG emissions. Accordingly, the empirical analysis considers both aggregate Function 18 expenditure and its individual budget subfunctions.

The empirical specifications include time-varying controls related to economic scale, productive structure, sector-specific emission drivers, and institutional capacity. GDP *per capita* captures local income and economic activity, while industrial and agricultural GVA *per capita* account for differences in municipal productive structures. These variables are particularly relevant because industrial activity may be associated with Energy and Industrial Processes emissions, whereas agricultural activity is closely related to Agriculture and Land-Use Change emissions.

Primary vegetation loss, measured in hectares, captures a direct driver of Land-Use Change emissions. Rural credit is included as a proxy for agricultural investment and the expansion or intensification of agricultural activity. Finally, administrative environmental violation notices issued by IBAMA proxy federal environmental enforcement, while formal employment relationships in regulatory activities proxy bureaucratic and human-capital capacity at the municipal level.

All monetary variables are expressed in constant 2021 prices using the Extended National Consumer Price Index (*Índice Nacional de Preços ao Consumidor Amplo*, IPCA), calculated by IBGE. The sample begins in 2000, the first fiscal year following Ordinance No. 42/1999, and ends in 2021, the latest year for which municipal GDP data were available at the time of manuscript preparation. The resulting dataset is an unbalanced panel covering Brazil's 5,570 municipalities.

3.2 Empirical Model

3.2.1 Baseline Fixed-Effects Model

This study employs panel-data models to examine the relationship between public environmental expenditure and GHG emissions across Brazilian municipalities. This approach is appropriate given the substantial socioeconomic and geographic heterogeneity among the 5,570 municipalities, as it allows for controlling for unobserved time-invariant heterogeneity (Greene, 2003; Gujarati; Porter, 2011; Wooldridge, 2016).

The baseline specification is a two-way fixed-effects (TWFE) model with municipality and year fixed effects. The fixed-effects specification is preferred to the random-effects model based on the Hausman specification test (Hausman', 1978). The estimated equation is:

$$\ln(y_{i,t}) = \alpha + \beta_1 \ln(\exp_{i,t}) + \beta_2 \ln(\exp_{i,t-1}) + \boldsymbol{\gamma}'\mathbf{X}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}, \tag{1}$$

where $\ln(y_{i,t})$ denotes the outcome variable, measured as *per capita* GHG emissions in municipality i and year t; $\ln(\exp_{i,t})$ denotes contemporaneous *per capita* expenditure on environmental management; and $\ln(\exp_{i,t-1})$ denotes its one-period lag. The inclusion of lagged environmental expenditure allows for potential delays between budget execution and changes in emissions, recognizing that such associations may not materialize contemporaneously. Accordingly, β_2 captures the estimated association between environmental expenditure in period $t-1$ and emissions in period t. The vector $\mathbf{X}_{i,t}$ contains the control variables, including GDP *per capita*, the industrial and agricultural components of Gross Value Added, primary vegetation loss, rural credit operations, and institutional proxies. Municipality fixed effects, μ_i, absorb time-invariant municipal characteristics, including persistent geographic and biophysical attributes, whereas year fixed effects, λ_t, absorb common time shocks. Finally, $\varepsilon_{i,t}$ denotes the idiosyncratic error term. Under the log-log specification, the coefficients on continuous variables expressed in logarithms can be interpreted as elasticities.

3.2.2 Identification Strategy and Endogeneity

The main threat to the identification of coefficients β_1 and β_2 arises from potential endogeneity between environmental expenditure and greenhouse gas emissions. First, simultaneity may arise because municipalities with higher emission levels may subsequently increase expenditure on environmental management. Second, time-varying unobserved factors, including institutional changes, characteristics of local public management, or municipality-specific shocks, may simultaneously affect environmental expenditure and emissions. Finally, temporal persistence in emissions may also affect the estimated relationships.

The baseline specification does not include the lagged dependent variable, $\ln(y_{i,t-1})$, because its inclusion in a fixed-effects model with a finite time dimension may induce Nickell bias (Nickell, 1981). In view of these limitations, the article complements the TWFE analysis with a difference-in-differences framework drawing on the estimator proposed by Callaway and Sant'Anna (2021). The purpose of this complementary exercise is to examine emission trajectories around the implementation of the National Policy on Climate Change (PNMC).

The procedure examines the evolution of emission trajectories across municipalities classified according to different levels of pre-PNMC environmental budgetary effort observed between 2000 and 2008. It also provides a complementary assessment of the consistency of the patterns obtained from the TWFE models. This exercise is intended to characterize the temporal dynamics of emissions rather than to establish a strict causal relationship between municipal environmental expenditure and greenhouse gas emissions.

The empirical design uses the implementation of the PNMC, enacted in 2009 and implemented from 2010 onward, together with differences in environmental budget allocations observed during the pre-PNMC period. Budgetary effort is measured by the average municipal expenditure committed under Function 18 (Environmental Management) from 2000 to 2008. This measure is based on the premise that municipalities allocating larger amounts of resources to environmental management before the PNMC exhibited greater pre-existing budgetary effort in this policy area. Municipalities are classified into the first and fourth quartiles of the distribution of this expenditure measure, thereby forming lower- and higher-budgetary-effort groups.

Because this classification is constructed from observed budget execution before policy implementation rather than from an exogenous source of variation, the resulting groups may differ in pre-existing structural characteristics. Accordingly, the estimates should be interpreted as evidence on heterogeneous post-policy emission dynamics across municipalities with different levels of pre-policy environmental expenditure. Their interpretation therefore relies on the plausibility of the parallel-trends assumption rather than on equality of observed characteristics across groups.

In this setting, the application of the framework proposed by Callaway and Sant'Anna (2021) differs from its canonical treatment-timing design. The PNMC constitutes a common institutional intervention affecting all Brazilian municipalities; consequently, there is no genuinely untreated comparison group. Identification therefore does not arise from differential policy adoption but from comparisons of emission trajectories across municipalities with different levels of environmental budgetary effort measured before PNMC implementation. The dynamic event-study analysis assesses the plausibility of parallel pre-policy trends by examining estimated coefficients for periods preceding the policy. Accordingly, the results should be interpreted as associational evidence consistent with the adopted institutional design rather than as causal estimates.

3.2.3 Mechanism Analysis and Extensions

To assess how environmental management expenditure is related to emissions, the baseline model is extended to explore heterogeneity across budget subfunctions. As discussed in Section 3.1, Function 18 aggregates distinct types of environmental actions. Therefore, to investigate whether the estimated relationships are associated with more direct policy instruments, such as environmental control and enforcement-related activities, or with more indirect interventions, we re-estimate the model by replacing aggregate expenditure with a vector of expenditures across the relevant subfunctions:

$$\ln(y_{i,t}) = \alpha + \sum_{k\in\mathcal{K}} \beta_k \ln(\exp_{k,i,t}) + \boldsymbol{\gamma}'\mathbf{X}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}, \qquad \mathcal{K} = \{541, 542, 543, 544, 545, 999\}, \tag{2}$$

where $\exp_{k,i,t}$ denotes *per capita* expenditure in environmental management subfunction k: 541 (Environmental Preservation and Conservation), 542 (Environmental Control), 543 (Recovery of Degraded Areas), 544 (Water Resources), 545 (Meteorology), and 999 (Other Environmental Management Subfunctions). This decomposition allows us to assess whether the estimated relationships are concentrated in expenditure categories more closely associated with environmental preservation and control, such as subfunctions 541 and 542, or in comparatively indirect components, such as subfunction 545. Specifications including lagged values of these expenditures are also estimated.

A further extension examines the role of institutional capacity and environmental enforcement. Environmental management expenditure may exhibit limited effectiveness when governments lack the administrative capacity required to translate budgetary resources into policy implementation. To examine this channel, Equation (3) augments the baseline specification with proxies for federal environmental enforcement, measured by IBAMA environmental violation notices, and bureaucratic capacity, measured by formal employment relationships in regulatory activities from RAIS:

$$\ln(y_{i,t}) = \alpha + \beta_0 \ln(\exp_{i,t}) + \delta_1 \ln(\text{notices}_{i,t-1}) + \delta_2 \ln(\text{staff}_{i,t-1}) + \boldsymbol{\gamma}'\mathbf{X}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}. \tag{3}$$

The baseline analysis therefore relies on a log-log TWFE specification with municipality and year fixed effects, exploiting within-municipality variation over time. As a complementary exercise, the analysis incorporates a dynamic difference-in-differences framework drawing on Callaway and Sant'Anna (2021) to examine the temporal evolution of emission trajectories and assess whether the resulting patterns are consistent with those obtained from the main specification.

Statistical inference is based on heteroskedasticity-robust standard errors clustered at the municipality level. To assess robustness and further investigate the mechanisms underlying the estimated relationships, the empirical analysis includes: (i) sequential inclusion of control variables; (ii) disaggregated estimations by environmental expenditure subfunction; (iii) inclusion of proxies for environmental enforcement and institutional capacity, including IBAMA violation notices and formal employment relationships in regulatory activities; and (iv) sector-specific estimations for Agriculture, Energy, Land-Use Change, Industrial Processes, and Waste.

4 EMPIRICAL RESULTS

This section presents the empirical evidence on the relationship between municipal environmental public expenditure and greenhouse gas emissions. The analysis proceeds from descriptive evidence to baseline fixed-effects estimates and a complementary event-study analysis.

4.1 Descriptive Statistics and Exploratory Analysis

We begin by examining the descriptive patterns of the variables included in the empirical analysis. Table 2 reports descriptive statistics for greenhouse gas emissions, municipal environmental public expenditure, and the socioeconomic, environmental, and institutional covariates.

Table 2: Descriptive Statistics for Selected Variables, 2000–2021

Dimension	**Variable**	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**
GHG emissions in tonnes per capita	EMITOT (CO_2e)	25.38	99.73	0.00	6,902.02
	AGRO (CO_2e)	8.56	15.04	0.00	345.39
	ENERGY (CO_2e)	1.05	6.38	0.00	663.63
	LAND (CO_2e)	15.32	93.88	0.00	6,849.26
	INDUSTRY (CO_2e)	0.09	2.22	0.00	260.00
	WASTE (CO_2e)	0.36	0.71	0.00	19.29
Per capita expenditure by budget	18 – Environmental Management Function (BRL)	15.68	47.31	0.00	2,182.10
	541 – Environmental Preserv. and Conserv.(BRL)	8.15	32.37	0.00	2,182.10
	542 – Environmental Control (BRL)	2.75	18.21	0.00	1,321.30
	543 – Recovery of Degraded Areas (BRL)	0.22	6.81	0.00	1,536.09
	544 – Water Resources (BRL)	1.07	15.57	0.00	1,555.65
	545 – Meteorology (BRL)	0.01	0.52	0.00	111.37
	999 – Other Environmental Management Subfunctions (BRL)	2.09	17.23	0.00	1,277.84
Demographics	Population (persons)	34,755.59	206,080.59	836	12,396,372
Income and productive structure	Municipal GDP *per capita* (BRL)	22,717.95	26,690.12	0.00	1,269,528.86
	Industrial GVA *per capita* (BRL)	4,671.70	15,914.31	0.00	1,043,555.79
	Agricultural GVA *per capita* (BRL)	4,725.58	7,834.18	0.00	304,145.76
Deforestation	Primary vegetation loss (ha)	579.90	2,402.05	0.00	157,437.97
Agricultural credit activity	Rural credit operations (number)	202.02	356.45	0.00	8,751.00
Enforcement and institutional capacity	IBAMA environmental violation notices (number)	3.89	16.88	0.00	936.00
	Formal employment relationships in economic and social regulation (number)	0.15	7.27	0.00	1,021.00

Notes: Monetary variables are expressed in constant 2021 Brazilian reais (BRL). GHG emissions are measured in tonnes of carbon dioxide equivalent (CO_2e) *per capita*.
Source: Authors' own elaboration.

The data reveal substantial heterogeneity across municipalities in both greenhouse gas emissions and environmental public expenditure. Emission patterns also differ markedly across sectors, reflecting the diversity of local productive structures and environmental pressures in Brazil. This heterogeneity motivates the sector-specific analysis and the inclusion of economic, environmental, and institutional covariates in the econometric specifications.

Environmental public expenditure also varies substantially across municipalities and budget subfunctions. Function 18 averages BRL 15.68 *per capita*, with a standard deviation of BRL 47.31, while Subfunction 541 (Environmental Preservation and Conservation) accounts for the largest average expenditure at BRL 8.15 *per capita*. By contrast, expenditure under Subfunction 545 (Meteorology) is negligible, indicating limited use of this classification in municipal budgets and little empirical variation for the econometric analysis.

The heterogeneity within Function 18 suggests that treating environmental public expenditure as a homogeneous aggregate may obscure relationships associated with specific expenditure components (Barbier, 2019; Quintela, 2016). Combining subfunctions with distinct policy instruments and mitigation channels may attenuate the estimated association between aggregate expenditure and emissions. This pattern motivates the subsequent disaggregated analysis by budget subfunction.

Socioeconomic variables also exhibit substantial dispersion across municipalities, reflecting pronounced differences in economic scale and productive structure. Variation in GDP *per capita* and industrial and agricultural GVA *per capita* highlights the heterogeneity of local productive profiles and the importance of accounting for scale and composition channels in the empirical specifications.

Environmental and institutional variables likewise exhibit substantial heterogeneity. Primary vegetation loss is highly concentrated in specific municipality-year observations, reflecting the uneven spatial and temporal distribution of land-cover conversion. Rural credit operations also vary considerably across municipalities, consistent with differences in the intensity of financed agricultural activity.

Finally, IBAMA environmental violation notices and formal employment in regulatory activities exhibit highly concentrated distributions, with most municipality-year observations close to zero. This pattern highlights substantial heterogeneity in enforcement activity and bureaucratic capacity across municipalities. Such institutional differences may condition the ability of local governments to translate environmental budget allocations into effective policy implementation, motivating the inclusion of institutional controls in the empirical specifications.

4.2 Baseline Fixed-Effects Results

To assess the robustness of the estimated coefficients and account for potential omitted-variable bias, we estimate a sequence of progressively richer two-way fixed-effects specifications. Table 3 reports the baseline estimates for total greenhouse gas emissions ($\ln emitot$), sequentially introducing contemporaneous municipal environmental public expenditure, its one-period lag, and additional sets of economic, environmental, and institutional controls. Throughout the analysis, the estimated coefficients should be interpreted as within-municipality associations over time after controlling for municipality and year fixed effects.

Table 3: Baseline Fixed-Effects Estimates: Municipal Environmental Public Expenditure and Total Greenhouse Gas Emissions

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
ln($Env.Public\ Expenditure$)$_{it}$	0.002	-0.0004	-0.002*	-0.001	-0.002*
	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
ln($Env.\ Public\ Expenditure$)$_{it-1}$	–	0.003**	0.002*	0.003***	0.002*
		(0.001)	(0.001)	(0.001)	(0.001)
ln($GDP\ percapita$)$_{it}$	–	–	0.162***	0.142***	0.160***
			(0.025)	(0.025)	(0.025)
ln($Industrial\ GVA\ percapita$)$_{it}$	–	–	-0.006	-0.002	-0.005
			(0.007)	(0.006)	(0.007)
ln($Agricultural\ GVA\ percapita$)$_{it}$	–	–	0.022**	0.022**	0.023***
			(0.009)	(0.009)	(0.009)
ln($Public\ Investment$)$_{it}$	–	–	-0.004**	-0.005***	-0.004*
			(0.002)	(0.002)	(0.002)
ln($Primary\ Vegetation\ Loss$)$_{it}$	–	–	–	0.218***	0.217***
				(0.005)	(0.005)
ln($IBAMA\ Env.\ Violation\ Notices$)$_{it}$	–	–	–	–	0.012***
					(0.002)
ln($Env.\ Regulatory\ Employment$)$_{it}$	–	–	–	–	0.007
					(0.011)
Observations	122,540	116,970	116,841	109,114	116,841
R^2	0.0001	0.0001	0.0130	0.1660	0.0140
Adjusted R^2	-0.0480	-0.0500	-0.0370	0.1240	-0.0360
F Statistic	7.562***	4.707***	243.485***	2,953.706***	191.592***

Notes: Two-way fixed-effects estimates with municipality and year fixed effects. Robust standard errors are reported in parentheses. Statistical significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3 presents the baseline two-way fixed-effects estimates relating municipal environmental public expenditure to total greenhouse gas emissions. The specifications progressively incorporate lagged expenditure and economic, environmental, and institutional controls. The coefficients capture within-municipality associations over time, accounting for time-invariant municipal characteristics and common year-specific shocks.

Specification tests support the choice of the fixed-effects estimator. The F-test and Breusch–Pagan Lagrange Multiplier test reject pooled OLS in favor of a panel-data specification, while the Hausman test rejects the random-effects specification. Accordingly, two-way fixed effects are adopted as the baseline estimator.

Across all specifications, the estimated association between contemporaneous municipal environmental public expenditure and total greenhouse gas emissions remains small. After the inclusion of additional controls, the estimated elasticity ranges from -0.001 to -0.002 and is statistically significant only in some specifications. These estimates provide no robust evidence that higher aggregate municipal environmental public expenditure is systematically associated with lower greenhouse gas emissions.

By contrast, lagged environmental public expenditure is positively and statistically significantly associated with emissions in most specifications. This pattern should not be interpreted as evidence that higher expenditure increases emissions. Rather, it is consistent with endogenous budgetary responses, whereby municipalities facing greater environmental pressures subsequently increase environmental expenditure, although residual time-varying confounding cannot be ruled out.

The coexistence of a small negative contemporaneous elasticity and a positive lagged association provides no evidence of a sustained mitigation pattern and remains consistent with endogenous budgetary responses to local environmental pressures.

The inclusion of primary vegetation loss in Specification (4) increases the R^2 from 0.013 to 0.166 and yields an estimated elasticity of 0.218, the largest association with total emissions among the covariates. This result reinforces the central role of land-use dynamics in municipal greenhouse gas emissions in Brazil. Once this direct emission driver is included, the contemporaneous expenditure coefficient loses statistical significance, while the lagged coefficient remains positive and significant, reinforcing the comparatively weak association between aggregate environmental public expenditure and emissions.

Specification (5) incorporates proxies for environmental enforcement and bureaucratic capacity. IBAMA environmental violation notices are positively associated with emissions, whereas employment in environmental regulatory activities is not statistically significant. The positive enforcement coefficient should not be interpreted as evidence that enforcement increases emissions; rather, it is consistent with enforcement targeting areas under greater environmental pressure or with greater monitoring and detection capacity.

Among the economic covariates, GDP *per capita* and agricultural value added are positively associated with emissions, consistent with the role of economic activity and agricultural production in municipal emission dynamics. Public investment exhibits a modest negative association with emissions.

Taken together, the baseline estimates indicate that aggregate municipal environmental public expenditure is, by itself, an insufficient predictor of environmental outcomes. Instead, the results suggest that expenditure effectiveness depends less on the aggregate volume of resources allocated than on expenditure composition, implementation capacity, and the broader institutional environment in which environmental policies are implemented. This interpretation is consistent with the public economics literature, which emphasizes that the effectiveness of public expenditure ultimately depends on governments' ability to transform budgetary resources into measurable policy outcomes.

These findings provide the rationale for the next stages of the empirical analysis. First, the aggregate Function 18 expenditure is decomposed into its constituent budget subfunctions in order to investigate whether aggregation conceals heterogeneous relationships across different categories of environmental expenditure. Second, the analysis turns to a complementary event-study framework based on Callaway and Sant'Anna (2021), exploiting differences in pre-policy environmental public expenditure to examine the dynamic evolution of emissions following the implementation of the National Policy on Climate Change (PNMC).

4.3 Disaggregated Estimates by Budget Subfunction and Emission Sector

To investigate whether the aggregate specification conceals heterogeneous relationships across expenditure categories, Table 4 reports two-way fixed-effects estimates in which Function 18 (Environmental Management) is decomposed into its constituent budget subfunctions. The models are estimated separately for total greenhouse gas emissions and for the Agriculture, Energy, Land-Use Change, Industrial Processes, and Waste sectors. All specifications include contemporaneous and one-period lagged expenditure by budget subfunction together with the full set of economic, environmental, and institutional controls.

Estimating all budget subfunctions simultaneously allows each coefficient to be interpreted as the marginal association of a given expenditure category conditional on the remaining environmental expenditure components. This specification reduces aggregation bias and provides a more detailed assessment of whether different types of environmental public expenditure exhibit distinct associations with environmental outcomes.

Table 4: Two-Way Fixed-Effects Estimates by Budget Subfunction and Emission Sector

Variables	Total	Agriculture	Energy	Land-Use	Industry	Waste
$\ln(\textit{Env. Preserv. and Conserv.})_{it}$	0.002	-0.001	0.012***	-0.002	0.0005	0.000
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.000)
$\ln(\textit{Env. Preserv.n and Conserv.})_{it-1}$	0.007***	-0.001	0.018***	-0.003**	-0.00001	0.000
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.000)
$\ln(\textit{Env. Control})_{it}$	0.002	-0.0004	0.008***	-0.0003	0.0001	0.001***
	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)	(0.000)
$\ln(\textit{Env. Control})_{it-1}$	0.008***	0.001	0.014***	0.001	-0.001	0.001
	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)	(0.000)
$\ln(\textit{Recovery of Degraded Areas})_{it}$	0.004	-0.002	0.013***	-0.007	0.001	0.001
	(0.004)	(0.002)	(0.005)	(0.004)	(0.001)	(0.001)
$\ln(\textit{Recovery of Degraded Areas})_{it-1}$	0.008**	-0.002	0.016***	-0.003	0.001	0.001
	(0.004)	(0.003)	(0.005)	(0.004)	(0.001)	(0.001)
$\ln(\textit{Water Resources})_{it}$	0.001	-0.002*	-0.004**	0.006**	-0.0002	-0.000
	(0.002)	(0.001)	(0.002)	(0.003)	(0.0003)	(0.001)
$\ln(\textit{Water Resources})_{it-1}$	-0.001	-0.001	-0.012***	0.003	-0.0001	0.001*
	(0.002)	(0.001)	(0.002)	(0.003)	(0.0004)	(0.000)
$\ln(\textit{Meteorology})_{it}$	0.006	-0.004	0.001	-0.029	0.051	-0.003
	(0.035)	(0.016)	(0.022)	(0.019)	(0.046)	(0.002)
$\ln(\textit{Meteorology})_{it-1}$	0.033	-0.003	0.006	0.004	0.047	0.004
	(0.035)	(0.013)	(0.022)	(0.021)	(0.043)	(0.021)
$\ln(\textit{Other Env. Manag. Activities})_{it}$	0.001	-0.001*	0.007***	-0.004**	0.002	0.001
	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)	(0.000)
$\ln(\textit{Other Env. Manag. Activities})_{it-1}$	0.007***	-0.001	0.009***	-0.001	0.001	-0.000
	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)	(0.000)
$\ln(\textit{GDP per capita})_{it}$	0.140***	0.072***	0.138***	0.080***	-0.019	0.009***
	(0.025)	(0.010)	(0.032)	(0.017)	(0.015)	(0.003)
$\ln(\textit{Industrial GVA per capita})_{it}$	-0.002	-0.012***	0.024***	-0.006	0.008*	0.001
	(0.006)	(0.003)	(0.007)	(0.006)	(0.004)	(0.001)
$\ln(\textit{Agricultural GVA per capita})_{it}$	0.021**	0.136***	-0.015	-0.002	0.003	0.013***
	(0.009)	(0.004)	(0.010)	(0.006)	(0.005)	(0.001)
$\ln(\textit{Public Investment})_{it}$	-0.005**	0.006***	-0.020***	0.003*	0.0002	0.000
	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)	(0.000)
$\ln(\textit{Primary Vegetation Loss})_{it}$	0.218***	0.003*	-0.023***	0.402***	-0.001	0.000
	(0.005)	(0.002)	(0.003)	(0.006)	(0.001)	(0.001)
$\ln(\textit{IBAMA Env. Violation Notices})_{it}$	0.005**	0.002**	-0.016***	0.017***	-0.002**	0.001
	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)
$\ln(\textit{Env. Regulatory Employment})_{it}$	0.006	-0.004	0.015**	-0.001	-0.002	-0.001
	(0.011)	(0.004)	(0.007)	(0.006)	(0.010)	(0.001)
Observations	109,114	109,114	109,114	109,114	109,114	108,939
R^2	0.167	0.137	0.031	0.303	0.001	0.014
Adjusted R^2	0.125	0.093	-0.018	0.268	-0.049	-0.036
F-statistic	1.1e3***	8.6e2***	1.7e2***	2.3e3***	7.6***	77.8***

Notes: Two-way fixed-effects estimates with municipality and year fixed effects. All specifications include contemporaneous and one-period lagged environmental public expenditure by budget subfunction together with the full set of economic, environmental, and institutional controls. Budget subfunctions follow the Brazilian functional classification established by Ordinance No. 42/1999. Robust standard errors are reported in parentheses. Statistical significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4 reveals substantial heterogeneity across budget subfunctions and emission sectors. Unlike the aggregate estimates, the disaggregated specification identifies distinct patterns of association depending on the expenditure component and emission sector considered. This finding supports the hypothesis that aggregating environmental expenditure within Function 18 may obscure relationships associated with specific budget subfunctions.

Among the environmental controls, primary vegetation loss exhibits the strongest association with municipal greenhouse gas emissions. The relationship is particularly pronounced for Land-Use Change emissions, with an estimated elasticity of 0.402. This result is consistent with Brazil's emissions profile and reinforces the central role of land-use dynamics in explaining municipal emission patterns.

Regarding the expenditure variables, no single budget subfunction displays a systematic pattern of association across all emission sectors. Statistically significant coefficients are instead concentrated in specific subfunctions and sectors, particularly in the Energy sector. These heterogeneous patterns suggest that the composition of municipal environmental expenditure may be more relevant than aggregate spending for understanding its relationship with greenhouse gas emissions.

The absence of a common pattern across subfunctions may reflect the aggregation of expenditures with distinct policy mechanisms. Some budget components finance monitoring, enforcement, or ecosystem conservation, whereas others support administrative or routine activities with less direct links to greenhouse gas emissions.

Structural and institutional variables exhibit stronger and more stable associations with emissions than the expenditure variables. In particular, the magnitude and consistency of the land-use coefficients indicate that structural emission drivers remain central to municipal emission dynamics, whereas the relationship between environmental public expenditure and emissions is comparatively weak and heterogeneous across subfunctions and sectors.

Taken together, the disaggregated estimates reinforce a central finding of this paper: aggregate municipal environmental public expenditure should not be treated as a homogeneous policy instrument. Its relationship with greenhouse gas emissions varies across budget subfunctions and emission sectors, suggesting that aggregate expenditure measures may obscure relevant heterogeneity in the composition and implementation of municipal environmental policy.

4.4 Dynamic Emission Responses Following the National Policy on Climate Change

To complement the baseline fixed-effects estimates, this subsection examines the evolution of greenhouse gas emissions following the implementation of the National Policy on Climate Change (PNMC). Rather than providing an alternative causal identification strategy, this exercise investigates whether municipalities with different levels of pre-policy environmental public expenditure exhibited distinct emission trajectories after the introduction of the PNMC.

Municipalities were classified according to their average Function 18 (Environmental Management) expenditure during the pre-policy period (2000–2008). Municipalities in the first and fourth quartiles of the resulting distribution were classified as having relatively low and high pre-policy environmental expenditure, respectively. This classification is used exclusively to examine heterogeneous emission dynamics following the common institutional shock associated with the implementation of the PNMC in 2010.

The analysis uses the framework proposed by Callaway and Sant'Anna (2021) to examine dynamic differences in emission trajectories across municipalities with heterogeneous pre-policy environmental public expenditure. Because the PNMC was implemented nationwide, the identifying variation does not arise from staggered policy adoption but from differences in pre-policy budgetary exposure. The estimates are therefore interpreted as heterogeneous post-policy emission dynamics rather than causal effects of PNMC adoption.

Figure 1 presents the dynamic event-study estimates, while Table 5 reports the average post-policy treatment effects (ATTs) for total and sectoral greenhouse gas emissions.

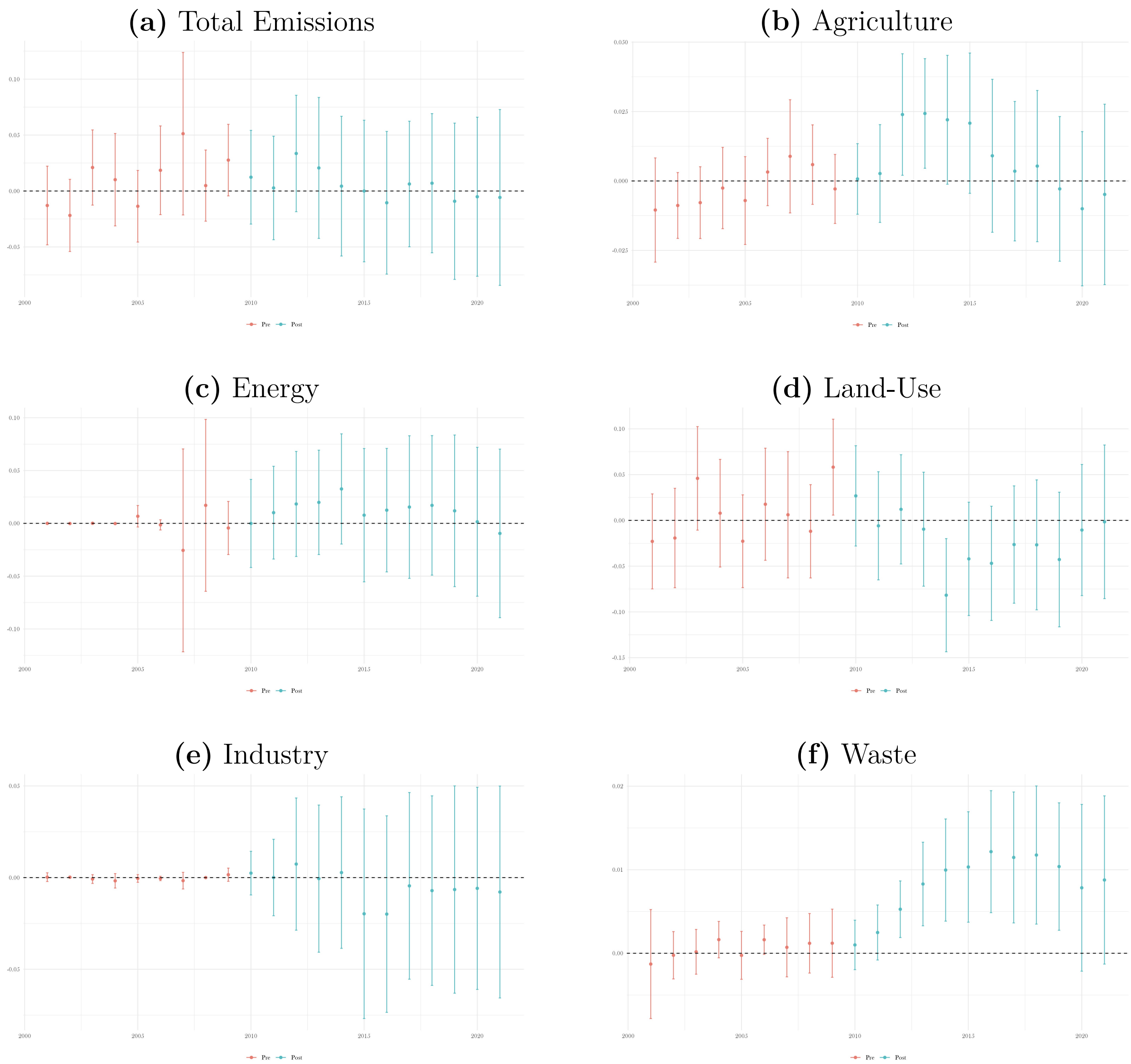
Table 5: Dynamic Event-Study Estimates

Variables	Total	Agriculture	Energy	Land-Use	Industry	Waste
ATT	0.0047	0.0079	0.0115	-0.0213	-0.0050	0.0083***
	(0.0197)	(0.0071)	(0.0207)	(0.0177)	(0.0165)	(0.0020)
95% CI	[-0.03, 0.04]	[-0.00, 0.02]	[-0.02, 0.05]	[-0.05, 0.01]	[-0.03, 0.02]	[0.00, 0.01]
Observations	64,658	64,658	64,658	64,658	64,658	64,658

Notes: Average post-policy treatment effects estimated using the Callaway and Sant'Anna (2021) event-study estimator. Robust standard errors are reported in parentheses. Statistical significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The pre-policy coefficients fluctuate around zero and exhibit no systematic trend. This pattern is consistent with the parallel-trends assumption, indicating broadly similar emission trajectories across municipalities with different levels of pre-policy environmental public expenditure before the implementation of the PNMC.

Figure 1: Dynamic Event-Study by Pre-Policy Environmental Expenditure Group



(a) Total Emissions

(b) Agriculture

(c) Energy

(d) Land-Use

(e) Industry

(f) Waste

Source: Authors' own aleboration.

Following the implementation of the PNMC, the estimated coefficients remain relatively small and, in most periods, are not statistically different from zero. Consistent with these dynamic estimates, Table 5 reports average treatment effects that are close to zero for total greenhouse gas emissions as well as for the Agriculture, Energy, Land-Use Change, and Industrial sectors. These findings indicate that municipalities with higher levels of environmental public expenditure prior to the PNMC did not experience systematically different post-policy emission trajectories than municipalities with lower pre-policy expenditure.

The only statistically significant estimate is observed for emissions from the Waste sector. Although positive and significant at the 1% level, the estimated coefficient is economically small. This result should therefore be interpreted cautiously, as it may reflect sector-specific institutional changes, improvements in emission measurement, or expansions in municipal waste management services rather than the direct effect of environmental public expenditure itself.

Overall, the dynamic evidence is fully consistent with the baseline fixed-effects estimates. Both empirical approaches suggest that aggregate municipal environmental public expenditure, as measured under Function 18, is not systematically associated with lower greenhouse gas emissions. Instead, the findings indicate that environmental policy effectiveness depends less on the aggregate volume of expenditure than on expenditure composition, implementation capacity, and the institutional environment in which environmental policies are executed.

The event-study results reinforce the interpretation proposed throughout this article. Aggregate environmental public expenditure should not be viewed as a homogeneous policy instrument capable of producing uniform environmental outcomes. Instead, the evidence suggests that differences in expenditure composition, local implementation capacity, and regulatory enforcement play a more important role than aggregate expenditure levels in shaping municipal greenhouse gas emissions. This interpretation is consistent with the fiscal neutrality hypothesis for aggregate Function 18 expenditure discussed by Quintela (2016), according to which heterogeneous expenditure components may offset one another when analyzed in aggregate.

5 CONCLUDING REMARKS

This paper examined whether municipal environmental public expenditure is systematically associated with greenhouse gas (GHG) emissions across Brazilian municipalities. The results provide no robust evidence that higher aggregate expenditure under Function 18 (Environmental Management) is systematically associated with lower emissions. Instead, structural emission drivers, particularly primary vegetation loss, exhibit substantially stronger and more consistent associations with municipal emission dynamics.

These findings contribute to the literature on public expenditure effectiveness by highlighting the limitations of aggregate budget execution as a measure of environmental policy effort. The volume of environmental expenditure alone provides limited information about municipal emission dynamics when budget classifications combine policy instruments with distinct objectives and implementation mechanisms. Accordingly, the absence of a robust aggregate expenditure–emissions relationship should not be interpreted as evidence that environmental public spending is ineffective. Rather, it suggests that expenditure composition and the institutional capacity to translate budget execution into effective policy implementation are central to understanding the effectiveness of local environmental policy.

From a public policy perspective, the findings suggest that expanding municipal environmental budgets without improving expenditure composition and administrative capacity may be insufficient to generate measurable reductions in emissions. Greater attention to how environmental resources are allocated, together with stronger monitoring, enforcement, and local institutional capacity, may improve the translation of fiscal resources into effective environmental action. The policy challenge may therefore lie less in increasing aggregate expenditure than in determining what municipalities finance and whether they possess the institutional capacity to implement those interventions effectively.

More broadly, this study highlights a central challenge in evaluating public expenditure: budget execution is an input, not a policy outcome. The relationship between fiscal resources and measurable outcomes depends on the intermediate process through which budgetary inputs are transformed into effective policy implementation. This distinction is particularly relevant in policy areas characterized by multiple intervention channels and substantial institutional heterogeneity, such as environmental management.

Several limitations should be acknowledged. First, the estimates identify conditional associations rather than causal effects and remain potentially affected by time-varying confounding and endogenous budgetary responses. Second, uneven data availability and reporting quality across municipalities may disproportionately affect local governments with lower administrative capacity. Third, the available proxies for enforcement and bureaucratic capacity capture only part of the institutional mechanisms linking budget execution to policy implementation. Finally, spatial spillovers arising from deforestation dynamics, regional enforcement, and shared environmental externalities may violate the Stable Unit Treatment Value Assumption (SUTVA) and attenuate estimated differences across municipalities.

Future research should examine the causal effects of specific budget subfunctions, integrate fiscal information with operational measures of environmental monitoring and enforcement, and exploit identification strategies that better address endogenous budget allocation and spatial interference. Ultimately, evaluating environmental public expenditure requires moving beyond aggregate budget execution toward a better understanding of how fiscal resources are translated into effective policy implementation. Distinguishing between budget allocation and policy delivery is essential for advancing both the environmental economics literature and the broader understanding of public expenditure effectiveness.

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