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**Private Participation and its effects on energy  
mitigation in Brazil**

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## **Abstract**

The decarbonization of the energy sector has become a core element of current mitigation efforts, as the sector is responsible globally for the majority of greenhouse gas emissions (GHGs). Among the countries with the highest share of renewable energy production, Brazil is emerging as a potential for public-private cooperation to advance energy transition. Yet, there is still a lack of clarity as to how the private sector has, and may be, affecting mitigation efforts in the country and, as a result, its transition. A knowledge gap persists, as previous literature has shown mixed results for the effects of private participation (PPI) on environmental outcomes, and ambiguities and lack of data undermine further research.

This research paper aims to address these gaps by providing a comprehensive policy and econometric analysis of the impacts of private participation on the energy sector. By employing an Autoregressive Distributed Lag (ARDL) model, this study aimed to assess the short- and long-run implications of PPI in the Brazilian energy case from 2000 to 2022, post-privatization. This study determined an optimal lag of 3 years through lag-order selection statistics but was only able to execute a complete analysis of the data at a lag of one year, due to the temporal limitations of the available data.

Through ARDL, this research paper was able to assess statistically significant short-run effects of PPI on CO<sub>2</sub> emissions, which contradict findings from other authors. However, temporal limitations also restricted the possibility of verifying long-run effects, due to sample size. These constraints highlight the need for further research, employing longer time periods to better understand the dynamics of private participation and its impacts on mitigation. As such, the present paper makes recommendations to develop the collection of national data on private participation in Brazil, to help facilitate the functioning of the hybrid energy market and encourage future and necessary research.

## **Keywords**

Private participation; Energy mitigation; Energy dependency; Brazil.

## **Relevance to Development Studies**

The energy sector is a central pillar of the Brazilian economy, and it has long served as a key instrument through which the government executed centralized development plans that delivered significant benefits to the country. Once privatized, the energy sector underwent substantial regulatory, legislative and institutional changes that still affect it today.

As we approach 2030, the critical climate deadline for reducing greenhouse gas emissions, concrete results for mitigation efforts taken in the past are expected. Though Brazil has been active in climate negotiations, there is still a limited understanding of how the private sector has been engaging in mitigation measures. This limited understanding is reinforced by the institutional characteristics of private participation, where unlike public participation, private parties are not held to the same standards of transparency and accountability to environmental and social causes. As Brazil continues to defend its end goal of sustainable development, through what it considers a “just” transition, it is imperative that an in-depth analysis be taken to understand the impacts of private participation in the energy sector and subsequently on development in Brazil.

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## List of Abbreviations and Acronyms

ADF	Augmented Dickey-Fuller
ADJ	Adjustment Coefficient
AI	Artificial Intelligence
ANEEL	Agência Nacional de Energia Elétrica
ARDL	Autoregressive Distributed Lag
BP/CW	Breusch–Pagan/Cook–Weisberg
CNPE	Conselho Nacional de Política Energética
DOLS	Dynamic Ordinary Least Square
ECM	Error Correction Model

EPE	Empresa de Pesquisa Energética
FDI	Foreign Direct Investment
GHGs	Global Greenhouse Gases
ONS	Operador Nacional do Sistema Elétrico
PND	Plano Nacional de Desestatização
PNE	Plano Nacional de Energia
PPI	Private Participation in Infrastructure
PPPIE	Public-Private Partnerships Investments in Energy
PPPs	Public-Private Partnerships
QQR	Quantile on Quantile Regression
R&D	Research & Development
SIN	Sistema Interligado Nacional

# 1. Introduction

The need for energy today is the biggest contributor to global greenhouse gas (GHG) emissions, with the energy sector being responsible for 75,7% of all GHG emissions in 2021 (World Resources Institute, 2024). Predictions also point to global energy demand growing by 18% until 2050 (McKinsey & Company, 2024). In Brazil, energy demand is expected to grow by 25% to a 353 million toe (tonnes of oil equivalent)<sup>1</sup>, by 2034, an increase of 65 Mtoe from the demand registered in 2024 (EPE, 2024, p. 7; 37).

As a developing country, Brazil's needs for energy grow continuously. Though diversified, around 50% of its energy generation comes today from its hydroelectric plants (ANEEL, 2024, p. 10). This became a disadvantage for the country, as it has faced severe drought crisis in the last decade, which have simultaneously made electricity prices soar and GHGs intensify to support the energy demand (Sousa *et al.*, 2024, p. 2). In the last decade, two major drought periods in 2015 and 2021 led the country to register low water volumes in hydropower reservoirs (Tomasella *et al.*, 2023) and to meet energy demands, thermal power plants were activated (Hunt *et al.*, 2018, p. 208-209). In addition to increasing GHG emissions, this led to a 50-70% increase in electricity tariffs and aggravated an ongoing economic and political crisis (Hunt *et al.*, 2018, p. 209). Among the main causes behind this crisis the authors note a systematic vulnerability of the sector and delays in project completion (Hunt *et al.*, 2018, p. 209). Moreover, in their work Hunt *et al.* highlight that this event is only one within a pattern of energy crisis that have occurred every 10-15 years, suggesting a new possible crisis in the next years (Hunt *et al.*, 2018, p. 208).

While the country has made advances in diversifying the energy mix, some authors consider that it did not take advantage of the opportunities in diversifying its renewable sources, such as wind and solar energy (Viola and

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<sup>1</sup> Unit of energy equivalent to the amount of energy that is extracted from one tonne of crude oil. Utilized as standardized unit to measure energy.

Franchini, 2018, p. 145). This would have happened for a series of reasons – one being political, with strong lobbying for other energy sources dominating in the 2010s (Viola and Franchini, 2018, p. 146), and another notably being financial (ANEEL, 2024, p.11). An analysis of the history of the Brazilian energy sector may demonstrate that as a core part of its national production, energy generation, transmission and distribution have been an integral part of the country’s development plans.

In the energy sector, the presence of the government initially emerged as a result of the centralized policies of the time and the natural monopolistic character of the sector, although its responsibilities have always gone far beyond merely providing a service. The public sector also carries social obligations, and in the energy sector this has meant, for example, ensuring universal access to electricity, regulating tariffs and making the investments necessary to guarantee the sector’s functioning. Consequently, during most of the 20<sup>th</sup> century, the energy sector had been a strategic arena for national development policy, but the financial constraints faced in light of economic crises and political shifts in the last decades have weakened its operation. Over time, fiscal pressures, concerns with efficiency and the need to accelerate energy expansion has driven the Brazilian government to open the sector to private participation.

As such, the Brazilian energy sector has gone through deep regulatory and institutional changes in the last thirty years, since the start of its privatization process in the 1990s. The private sector, in contrast to the public sector, is expected to operate with less bureaucracy, greater efficiency and a focus on profitability. Private participation offers several benefits to the energy sector, such as the flexibilization of contractual arrangements which decrease delays, risk-sharing to reduce fiscal burdens and the mobilization of additional capital to support energy expansion. However, in the last twenty years, the energy sector has also been shaped by concerns regarding Brazil’s energy sufficiency amid supply crises and calls for immediate climate and environmental action. As the energy sector becomes increasingly privatized, with recent transfers of administrative power from state companies to private firms,

questions have risen about whether the private sector is adequately contributing to the country's environmental commitments.

As such, it becomes vital to understand how privatization has shaped the Brazilian mitigation experience, and how it may be impacting current efforts. The Brazilian government has been a central player in international politics for climate efforts and has made ambitious commitments to reduce its environmental impact. Still, concerns arise over whether the Brazilian energy sector is supporting a just transition. To attempt to address these concerns, this paper aims to answer the following research questions:

- I. How has Private Participation in Infrastructure impacted Brazil's energy mitigation?
  - a. How is the energy sector structured legally, institutionally and regulatorily and what influence does this have on mitigation?
  - b. Have investments in the energy sector been directed towards mitigation efforts?
  - c. What have been the short and long-term impacts of private participation on Brazil's CO<sub>2</sub> emissions and Ecological Footprint?

This research paper is organized as follows. Building on the introduction, Chapter 2 will cover the literature review and the theoretical framework of this paper; Chapter 3 will introduce the methodology, methods and data utilized in this study; and finally, Chapter 4 will present the findings and a discussion of the results.

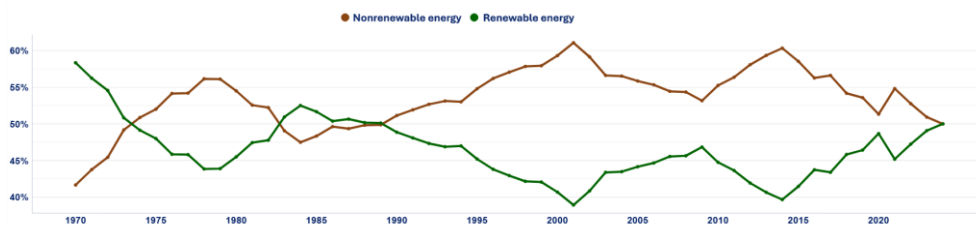
## **1.1. Justification**

This study seeks to understand the impacts of Private Participation in Infrastructure on the Brazilian energy mitigation process. The Brazilian energy sector has gone through considerable changes in the last 30 years, following the wave of privatization that started in the 1990s. Calls for better climate

action from civil society has increased since then, to which some agree Brazil has stepped up as an environmental leader. Others, on the other hand, defend that the Brazilian government has not been active enough (Viola and Franchini, 2018), and question the energy sector’s role in achieving energy transition. As such, it is important to understand how this new structure of the energy sector impacts Brazil’s commitments to sustainable transition.

This is relevant as we approach 2030, by which Brazil promised to “increase substantially the share of renewable energy in the global energy mix.” (Presidency of the Republic of Brazil, 2022, p. 48). As of 2024, the Brazilian energy mix has reached 50% renewable energy composition, though this has been a long process, as can be seen in the figure below (EPE, 2025a):

**Figure 1: Brazilian internal energy supply (1970-2024)**



Source: Translated from EPE, 2025a

Specifically in the energy sector, where the government is still considered a key player, several regulatory frameworks were created to assist in both mitigation and adaptation processes. Parallely, the inclusion of the private sector in the Brazilian energy sector is justified on the grounds of higher efficiency gains and in light of investment needs. It is necessary to understand that the ‘private sector’, as well as the ‘Brazilian government’ should not be interpreted through the ‘actor’ lens, as both of these institutions are constituted by complex and plural processes and actors. As such, understanding their impacts here is about identifying patterns over time on our dependent variables.

Still, there isn’t much of an understanding as to how the private sector’s interests have been shaping the energy sector. The actions Brazilian government, though not unitary, can be found through policies enacted,

frameworks established. The private sector, on the other hand, is much more difficult to monitor, as this depends on the accessibility of data supplied by the firms within the energy sector.

Understanding how the private sector may be shaping the Brazilian energy transition process is thus as important as understanding what the Brazilian government is doing at the same time. Through a time-series analysis, this study aims to also provide policymakers with an understanding of how the Brazilian energy sector, today mostly composed of private participation, has been evolving over the last twenty years in its transition process.

## **2. Literature review**

The inclusion of private participation within the provision of public services has certainly been unique to each context. Be it either through complete privatization, or hybrid models that still require governmental participation, like concessions or Public-Private Partnerships, the inclusion of the private sector to some degree appears to be changing how public services are provided. The impacts of private participation in infrastructure are becoming a focus area as well for research, though conclusions are not consistent among the cases studied. Specifically, in the case of the Brazilian energy sector, there is still little understanding behind how the private sector continues to shape the generation, distribution and transmission sectors and what the impacts are on Brazil's transition process in both the short- and long-run. As such, a considerable gap exists in the literature, which this paper intends to address.

Globally, as each country has their own framework of laws and policies that guide infrastructure policy, it is difficult to compare cases among different contexts. As such, the literature on private participation has been mostly regarding Public-Private Partnerships (PPPs), though a review of the literature shows that in some cases PPPs are possibly used as an umbrella term. This appears to be due to the literature being based off the same dataset analyzed in this Research Paper, the World Bank Private Participation in Infra-

structure (PPI) database. As described in its methodology page, the PPI database records “...contractual arrangements for public infrastructure projects in low- and middle-income countries (as classified by the World Bank) that have reached financial closure, in which private parties assume operating risks.” and shows private and hybrid (private and public) projects (World Bank, no date b).

Though the context may shift from country to country, the PPI database when filtered to Brazil shows an array of different contractual modalities under the classification “PPP”. Being so, it is entirely possible that observations in the literature explored below contemplate different types of private participation in infrastructure, though this was only verified in the Brazilian case within this study. The literature review below will contain the original terminology used by the authors, though it is important to note that the concept and variable “Public-Private Partnerships Investments in Energy” has been abbreviated as both PPPIE and PPI in these texts.

In Pakistan, one study which used a mix of the Bayer and Hanck approach and the autoregressive distributed lag (ARDL) model, found that Public-Private Partnerships Investments in Energy (PPPIE) and related sectors were seen to increase the country’s ecological footprint in both the long and short-run (Chunling *et al.*, 2021, p. 13). Though the authors do not conclude that this is in light of fossil fuel projects, they suggest that PPPs in Pakistan be centered on renewable energy sources (Chunling *et al.*, 2021, p. 13). Likewise, in China, Shahbaz *et al.* (2020), investigated the role of Public-Private Partnerships Investments in Energy (PPPIE) on CO<sub>2</sub> emissions and the role of technological innovations. Using a mix of the Augmented Dickey-Fuller (ADF) approach and a bootstrap autoregressive distributed lag (ARDL), the authors showed a positive correlation between PPPs and carbon emissions, but that technological innovations in the energy sector cause a decline in CO<sub>2</sub> emissions (Shahbaz *et al.*, 2020, p. 9). Another study carried out in India by Kirikkaleli and Adebayo (2021, cited in Adebayo *et al.*, 2021, p. 3) used the fully modified ordinary least square, dynamic ordinary least square (DOLS) and frequency domain causality tests, with findings pointing to Public-Private

Partnerships Investments in Energy (PPPIE) actually having negative impacts on CO2 emissions.

In Brazil, three main papers exist on the relationship between private participation and energy. Ahmad and Raza (2020) in their paper investigate the impact of Public-Private Partnerships Investments in Energy (PPPIE), technological innovations, economic growth, exports and foreign direct investment (FDI) on CO2 emissions in Brazil, from 1984 to 2018, using the Ng-Perron unit root test and the autoregressive distributed lag (ARDL) model. The results of this paper point to Public-Private Partnerships Investments in Energy deteriorating environmental quality, through the increase of CO2 emissions, though this can also be mitigated through factors like technological innovations (Ahmad and Raza, 2020, p. 30639). In addition, they found that exports and FDI also deteriorated environmental quality, with the relationship between economic growth and CO2 emissions being an inverted U-Shape (Ahmad and Raza, 2020, p. 30639). Akinsola *et al.* (2021) investigated the effect of Public-Private Partnerships Investments in Energy (PPI) in energy and financial development on Brazil's ecological footprint, using a mix of autoregressive distributed lag (ARDL) and dynamic ordinary least square techniques. Their main findings point to similar results seen globally, with economic growth and Public-Private Partnerships Investments in Energy increasing environmental degradation and renewable energy and financial development decreasing it (Akinsola *et al.*, 2021, p. 10077). Moreover, within the energy sector, another study by Guoyan *et al.* (2023, p. 68144), who used quantile-on-quantile regression (QQR), looked into the relationship between Public-Private Partnerships Investments in Energy and environmental degradation over ten developing countries and from a period between 1998 to 2016. They showed that "...higher PPP investment in energy [in Brazil] causes a decline in CO2 emissions." (Guoyan *et al.*, 2023, p. 68152). This study, however, shows that this impact becomes insignificant over time, as the PPPs in Brazil have mostly focused on fossil fuel sources (Guoyan *et al.*, 2023, p. 68152). A summary of the key literature used can be found in the table below:

**Table 1: Summary of literature review**

Authors	Pub- lishing date	Countries analyzed	Time pe- riod ana- lyzed	Method used	Explana- tory vari- able	Depend- ent Vari- able	Findings
Chunling <i>et al.</i>	2021	Pakistan	1992- 2018	Bayer and Hanck test, Au- toregres- sive Dis- tributed Lag (ARDL), Dynamic Ordinary Least Squares (DOLS)	PPP in- vestment in energy (PPPIE) and Tech- nological Innova- tions (TI), economic growth (GDP) and trade openness (TO)	Ecologi- cal Foot- print	PPPIE, TI, GDP and TO all in- crease the ecological footprint <b>both in the long- and short-run</b>
Shahbaz <i>et al.</i>	2020	China	1984- 2018	Aug- mented Dickey- Fuller (ADF) and boot- strap ARDL	PPPIE, TI, eco- nomic growth (GDP), exports and FDI	CO2 emissions	PPPIE, exports and FDI increase CO2 emissions, while TI decreases them. Linear and non- linear real GDP per capita (eco- nomic growth) presents an in- verted U- shaped as- sociation with CO2 emissions (Environ- mental Kuznet's Curve, EKC).
Adebayo <i>et al.</i>	2021	India	1990- 2015	Bayer and Hanck test, ARDL, DOLS and fully modified ordinary least	PPPIE, Renewa- ble En- ergy Con- sumption (REN), TI, eco- nomic growth (GDP)	CO2 emissions	PPPIE and GDP increase CO2 emissions, <b>in the long and short run.</b> TI and REN,

				squares (FMOLS)		decrease emissions, <b>in the long and short run.</b>	
Ahmad and Raza	2020	Brazil	1984- 2018	Ng-Per- ron unit root test and ARDL	PPPIE, TI, eco- nomic growth (EG), ex- ports and FDI	CO2 emissions	PPPIE has negative effect on CO2 emissions, while TI and ex- ports have a positive effect. EG shows in- validation of EKC hypothe- sis. FDI has a neg- ative, but insignifi- cant effect on emis- sions.
Akinsola <i>et al.</i>	2021	Brazil	1984- 2017	ARDL, DOLS	PPPIE, economic growth (GDP), REN and Financial Develop- ment (FD)	Ecologi- cal Foot- print	PPPIE and GDP increase ecological footprint, while REN and FD de- crease it.
Guoyan <i>et al.</i>	2023	Brazil, Ar- gentina, Bangladesh, India, China, Malaysia, Mexico, Peru, Thai- land and the Philippines.	1998- 2016	Quantile- on-quantile re- gression (QQR), OLS	PPPIE	Environ- mental degrada- tion (CO2 emissions in kilo- tons)	PPPIE de- creases CO2 emissions, but after some time it does not make sig- nificant impacts.

Source: Adapted from multiple sources (see reference list)

The current literature on Public-Private Partnerships Investments in Energy and its relationship with renewable energy production, both globally and those specific to Brazil, bring important findings that are relevant to the research proposed in this paper. Overall, the literature demonstrates that the

effects of private participation on several environmental outcomes vary across contexts, methodologies and time periods. Specifically in Brazil, while some studies show that private participation in energy has a negative effect on the environment, others point to it improving a country's ecological footprint or at least doing so in the short run. As such, this leaves a considerable gap in understanding how private participation can impact Brazil's transition towards renewable energy sources. Moreover, the time periods analyzed could be pointing to possible biases, as many projects in the energy sector targeted non-renewable sources, as shown by Guoyan *et al.* (2023). As the papers only analyze data until 2018, it is possible that new projects that have occurred after this time period influence the final results. This paper thus intends to address the gaps identified, and in doing so to contribute to the literature on how private participation is shaping the energy sector in Brazil.

## 2.1. Infrastructure and Development

Infrastructure development has been historically one of the first steps taken by policymakers towards modern development. By "infrastructure", this study refers to what the World Bank 1994 report *Infrastructure for Development* defines as "economic infrastructure", which includes services from public utilities, public works and other transport sectors<sup>2</sup> (Besant-Jones *et al.*, 1994, p. 2). As noted by Prud'homme (2004, p. 3), "infrastructure" itself is a relatively new word, but that has been adapted into a variety of contexts. Prud'homme (2004) notes six characteristics of infrastructure that complement its concept:

1. That "products" of infrastructure are capital goods, that is, they are not consumed directly but instead provide a service;

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<sup>2</sup> As cited by Besant-Jones *et al.* (1994, p. 2), "This Report focuses on *economic infrastructure* and includes services from: Public utilities – power, telecommunications, piped water supply, sanitation and sewerage, solid waste collection and disposal, and piped gas. Public works – roads and major dam and canal works for irrigation and drainage. Other transport sectors – urban and interurban railways, urban transport, ports and waterways, and airports."

2. Infrastructure is only useful when complete (e.g. a bridge only serves its purpose when constructed), and despite the increase in demand for infrastructure over time, it is a lengthy process to execute;
3. Infrastructure is long-lasting, and requires maintenance;
4. Infrastructure is space-specific, and infrastructure investments shape regional economics and policy;
5. Infrastructure implies some form of public participation;
6. Infrastructure is consumed by households and firms, and it increases welfare and output directly as a result of this.

These characteristics, according to Prud'homme, can be used to begin to define the notion of infrastructure, and exclude its use in cases not represented by the initial definition of the concept by Besant-Jones *et al.* (1994) (Prud'homme, 2004, p. 6). And while investment in infrastructure has been shown to incentivize production, and in general generate welfare, establishing a causal relationship between infrastructure and development has proved to be challenging (Foster *et al.*, 2023, p. 2). Though it is clear that the construction of roads, or guaranteeing access to electricity, produce benefits for the public, and certainly encourages production at the firm level, there is still no concise understanding of *how* this impacts development.

Development is also a challenging concept to define, given that it is shaped by normative and subjective considerations. The concept is often measured through indicators related to growth and well-being, which are both intrinsically related to this discussion on infrastructure. The concept of development explored in this research paper is that of economic development, defined by Roemer as “(...) the degree to which an economy has implemented an efficient and just distribution of economic resources.” with the level of development as a function of equal opportunity (Roemer, 2013, p. 189; 196). This concept emphasizes how welfare and inequality are addressed through a just allocation of economic resources, which we can extend to the universal provision of public services in Brazil, where social well-being emerges as a direct outcome of equitable access to essential services.

Prud'homme states that the main line of research understands infrastructure through an extended production function, by which output (Y) is not only

contemplated by labor (L) and capital (K), but also by infrastructure (G) (Prud'homme, 2004, p. 11):

$$Y = f(L, K, G)$$

Though “output” itself does not only define development, within econometrics it is a variable used to measure impacts on growth. Output levels can also provide insights into how efficiently economic resources are used. Prud'homme also notes that there is an issue of reverse causality in understanding the relationship between infrastructure and output. That is, infrastructure could be leading to output, but it can also be argued that greater output may lead to new infrastructure construction (Prud'homme, 2004, p. 11).

Cadelon *et al.* (2013, p. 888) suggests that the relationship between infrastructure and output is strongly nonlinear. The authors claim output depends on the level of infrastructure already available (Cadelon *et al.*, 2013, p. 888), and may be represented by a threshold model, that is, one that “...(specifies) that individual observations can be divided into classes based on the value of an observed variable” (Hansen, 1999, p. 346 cited in Cadelon *et al.*, 2013, p. 888). In their study, Cadelon *et al.* shows this by concluding that infrastructure investments bring higher productivity until a certain threshold, that is, when there is already a sufficient network of infrastructure established (Cadelon *et al.*, 2013, p. 909). This, however, is a threshold not achieved yet by most developing countries, where then the productivity gains are much higher than in other investments (Cadelon *et al.*, 2013, p. 909-910). This is particularly the case for telecommunications and electricity, which intrinsically depend on a network being established to function adequately, as shown by Cadelon *et al.* (2013, p. 909).

It is important to note that though infrastructure is a necessary condition for economic development and growth, it is alone not enough (Besant-Jones *et al.*, 1994, p. 15). According to Besant-Jones *et al.* (1994, p. 17), adequate

quantity and reliability (i.e. quality) of infrastructure is critical for development, a point also highlighted by Prud'homme (2004) when citing maintenance requirements. Still, one study found that electricity infrastructure formation explains 17% of observed structural transformations in the country between 1970 and 2006 (Perez-Sebastian *et al.*, 2020, p. 58). When considering the Brazilian energy sector, these points become more clear.

## 2.1. The Brazilian energy sector

The Brazilian energy sector has evolved considerably since the 19<sup>th</sup> century, when it was first inaugurated with the first large-scale energy generation plant Marmelos-Zero completed in Juiz de Fora, Minas Gerais in 1889 (ANEEL, no date). 1889 was also the year that the former Monarchy of Brazil fell and a new Republic state was constituted which, through the Constitution of 1891, gave states and municipalities ample administrative autonomy (Gomes and Viera, 2009, p. 301). As such, as demand for electricity grew in cities, some local governments sought foreign resources to construct new power plants.

Light, a Canadian company, and Amforp, an American company, were the biggest players at that time and by 1930 they had control over 70% of energy generated in Brazil (Gomes and Viera, 2009; Saes and Sasse, 2012 cited in Caporrino, 2021, p. 18). Both firms not only took on energy generation construction but bought out national companies in what José Luiz Lima<sup>3</sup> called a "...tactical division of market." (Cmed, 1995 cited in Gomes and Viera, 2009, p. 302). From 1890 to 1930, through private initiative, the Brazilian energy sector's installed capacity had an increase of 61.709,52% (Lima, 1983 cited in Gomes and Viera, 2009, p. 302).

That same year, in 1930, Brazil was already experiencing the shocks of the Wall Street crash of 1929 through the Revolution of 1930, which put

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<sup>3</sup> José Luiz Lima, a professor at the University of São Paulo (USP), with extensive work on the Brazilian electric sector (Gomes and Viera, 2009, p. 299).

Getúlio Vargas in power (Gomes and Viera, 2009, p. 303). The Vargas government sought to centralize government and put forth policies that required municipalities to have a concessionary relationship with the federal government (Gomes and Viera, 2009, 303). As a result, foreign investment went down dramatically, and the energy sector suffered difficulties in maintaining power plants. This scenario, and the growing demands for energy in the country, led the government to centralize energy generation. This strategy was maintained throughout the 1940s and mid-1950s, where Brazil was recovering from the effects of the Second World War (Gomes and Viera, 2009, p. 305-306).

With the inauguration of Juscelino Kubitschek in 1956, the centralized model began to thrive under the Target Plan (*Plano de Metas*), which prioritized the development of select sectors, including energy (FGV, no date). Institutional changes came in 1962, with the establishment of Eletrobrás (Centrais Elétricas Brasileiras S.A.), created to become a holding for national energy firms and gained the responsibility of constructing and operating generation plants and transmission lines (Gomes and Viera, 2009; Eletrobrás, no date). This expansion coincided with what is deemed as the “Brazilian Miracle”, a period from 1968-1973 where the country obtained high growth rates (ONS, 2003, p. 98). By 1979, Eletrobrás had purchased both Light and Amforp, ending foreign investment in the energy sector (Gomes and Viera, 2009). The energy sector also saw the start of diversification in the 1970s with the shocks felt by the 1973 and 1979 Oil Crisis, which pushed other countries to seek alternate fuels (Gomes and Viera, 2009).

Developing the energy sector became, during this period, a matter of expanding the presence of the government and of economic growth. New public companies were established to expand electric coverage to other regions of Brazil (Gomes and Viera, 2009, p. 308). However, the following decade would be marked by the Fiscal Crisis of the 1980s, which negatively impacted the government’s investment capacity (Gomes and Viera, 2009, p. 27). Though, as shows ONS, the expansion of the energy sector was slowed down,

but generation installed capacity and transmission connectivity were expanded during this time (ONS, 2003).

By 1990, the Brazilian government had no financial conditions to continue expanding the energy sector, and the state-owned companies had debts from the difficulties of the Fiscal Crisis (Gomes and Viera, 2009, p. 312). This context, alongside a wave of neoliberalism swept through Latin America, prepared the way for private participation in energy in the country. In 1993, government began to reduce the public's role in the sector through a restructuring process put in place to stimulate competition and attract private investment once again (Bradshaw, 2017, p. 158). This shift was sustained in the policy sphere by the National Plan of Privatization (*Plano Nacional de Desestatização*, PND) (ONS, 2003, p. 221). Privatizations of state-owned energy companies began soon after. According to Bradshaw, "By 2003, around 70% of distribution assets and 30% of generation capacity were privatized" (Bradshaw, 2017, p. 158).

The privatization of the Brazilian energy sector also created new regulatory agencies within the sector. In 1996 under Law n. 9427, the National Agency of Electric Energy (*Agência Nacional de Energia Elétrica*, ANEEL) was created to govern the electricity sector, through the regulation and supervision of generation, transmission, distribution and the sale of electricity (Bradshaw, 2017, p. 158). In 1998, the National Operating System (*Operador Nacional do Sistema Elétrico*, ONS) was created to administrate the National Interconnected System (*Sistema Interligado Nacional*, SIN) and in 2004 the Energy Research Enterprise (*Empresa de Pesquisa Energética*, EPE) was created to research and plan for energy expansions (Bradshaw, 2017, p. 158). This shift from the previous state monopoly to the hybrid model now in place centered private participation as the main financier of energy, with the government in place to regulate. The 1990s were also influenced by international and domestic advocacy for clean energy, highlighted by the Rio-92 Conference (Bradshaw, 2017, p. 159).

In 2001, Brazil went through its biggest energy crisis due to critically low reservoir levels in generation plants responsible for, respectively, 70% of energy storage capacity for the Southeast/Center-West and 99% of storage capacity for the Northeast regions (ONS, 2003, p. 319). In response, a nationwide energy rationing system was put in place until 2002, seeking to reduce individual consumption until reservoir levels were normalized (ONS, 2003, p. 323). Additionally, policies to further diversify the Brazilian energy sector were put into place to prevent a future crisis, though others have occurred since then. According to Bradshaw (2017, p. 159), “Until 2001, there had been no significant incentives for renewable energy technologies in Brazil (...) The crisis called into question the broader policy environment that had strongly relied on the stable performance of the country’s hydrological resources.” As a result, “alternative renewables” like wind power, biomass and small-scale hydroelectric plants were studied as options to reduce the country’s reliance on its large hydroelectric plants (Hochstetler and Kostka, 2015 cited in Bradshaw, 2017, p. 160).

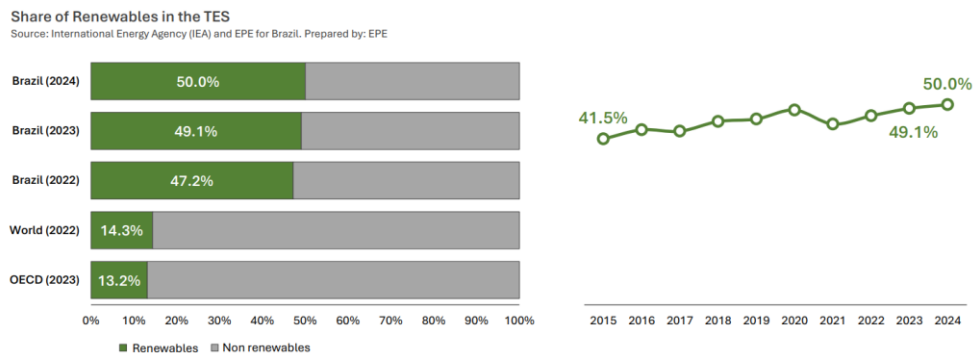
The adoption of alternative renewable sources became the new strategy of the energy sector, up until 2007, when oil prices in the country increased exponentially and drove the government to invest in the oil industry and the newly discovered Pre-salt reserves (Viola and Franchini, 2018, p. 112-113). As a result, oil production grew about 20% between 2006 and 2010 (Viola and Franchini, 2018, p. 113). Parallely, the country made concrete climate commitments, with the National Plan for Climate Change, finalized in 2008, and the enactment of Law n. 12.187 in 2009, which destinated public incentives only to renewable sources and called for the gradual reduction in the use of fossil fuels (Viola and Franchini, 2018, p. 116). The Brazilian government’s position at this time appeared to be fragmented, as domestically and internationally the country pushed for environmental action, whilst also heavily investing in its non-renewables.

Between 2011 and 2016 economic growth became central, with the country facing its worst recession in history in 2015 (Viola and Franchini, 2018, p. 46; 159). Political disruptions, corruption scandals in the oil sector and the

impeachment of President Dilma Rousseff in 2016 deeply shook the country at this time. As shown by Viola and Franchini, energy diversification was mixed during this time: hydroelectric projects faced delays, solar energy wasn't explored, fossil fuel production continued to grow and both the wind and ethanol industries experienced growth (Viola and Franchini, 2018, p. 142). Dilma's impeachment and the political shift that came with Michel Temer, her successor and former Vice-President, established a more market-friendly government with strong fiscal austerity (Viola and Franchini, 2018, p. 183), a pattern that followed the government of Jair Bolsonaro, elected in 2019.

Today the Brazilian energy sector is considered to be one of the most diversified and renewable in the world, with a share of 50% of energy generated in 2024 being from renewable sources (EPE, 2025b). As seen in Figure 2, this demonstrates an increasing trend in the past decade.

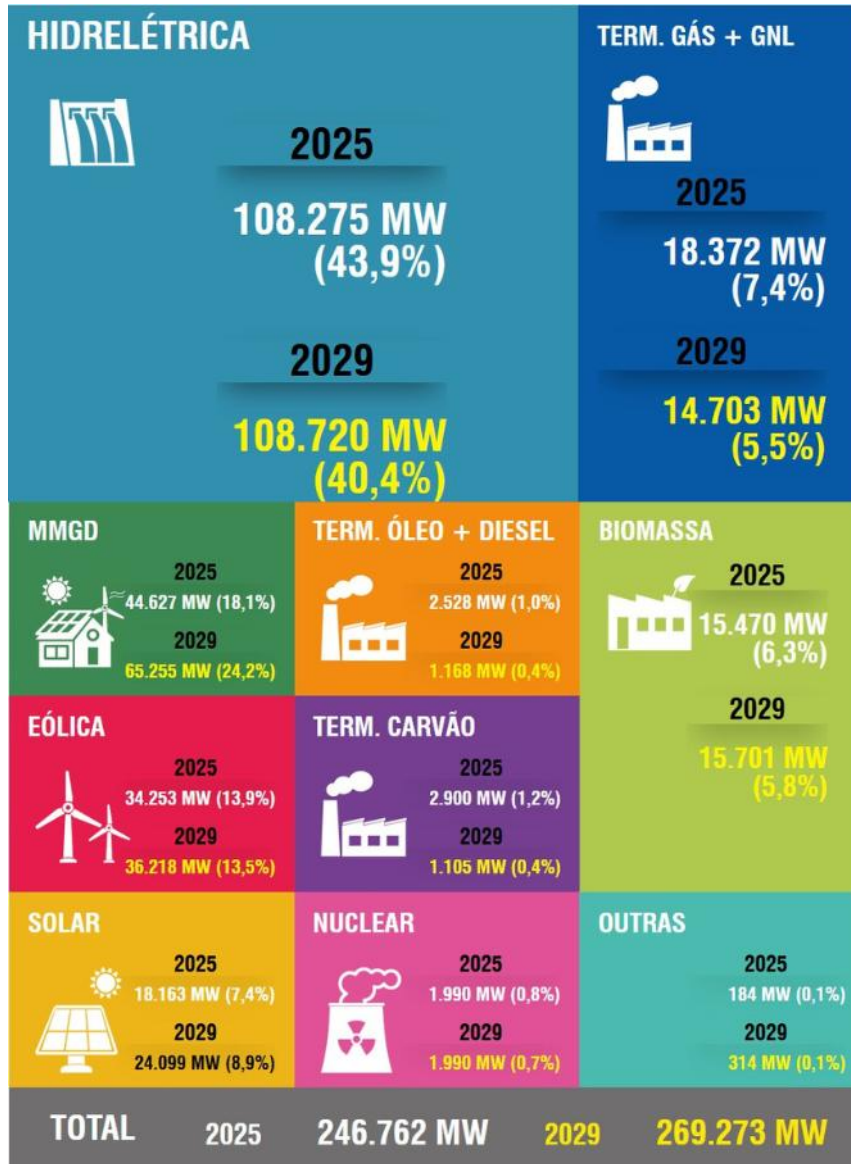
**Figure 2: Share of Renewables in the Total Energy Supply (TES)**



Source: EPE (2025)

The sector is still characterized by a strong participation from hydroelectric generation (43,9%, as of 2025), followed by wind power (13,9%) and solar power (7,4%). Based on Figure 3 below, one growing sector is that of Distributed Micro and Minigeneration plants, which are individual generation plants (usually solar panels), representing 13,9% of energy generated in 2025 (ONS, 2025). This, however, represents small energy plants that do not fall under the market regulation that oversees other generation plants.

**Figure 3: Evolution of the installed capacity of the SIN (Oct. 2025 - Dec. 2029)**

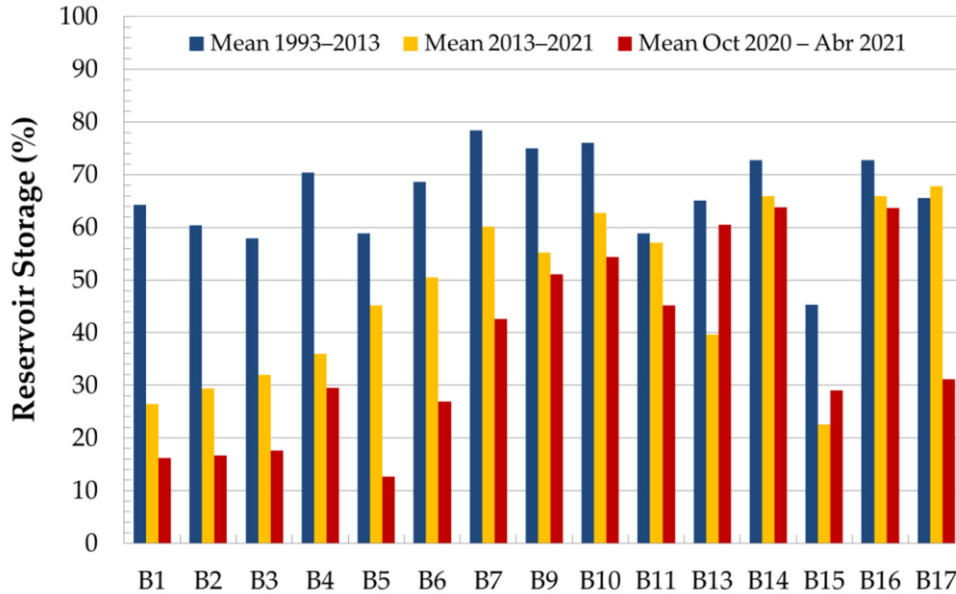


Source: ONS (2025)

The sector has continued since the 2001 Crisis to develop alternative fuel technologies, though hydropower is still the main source of energy generation. This is especially concerning considering water reserves have been decreasing in the last decade, when compared to levels registered between 1993-

2013. As shown by Cuartas *et al.*, strong decreases are observed in all basins, with some differences larger than 35% (Cuartas *et al.*, 2022, p. 18):

**Figure 4: Mean reservoir storages (in %), 1993-2021**



Source: Cuartas *et al.* (2022)

Other droughts have occurred since then, with the most notable being, as cited by Cuartas *et al.* as those from “...2005, 2010, 2015-2016 Amazon droughts, the 2012-2018 drought in Northeast Brazil, (...), [the] 2013-2014 droughts in Southeast Brazil, the 2019 and 2020 droughts in Pantanal, and the 2012-2013, 2019-2020 droughts in southern Brazil” (Cuartas *et al.*, 2022, p. 2). Hydroelectric power is still expected to lead in the next years, as shown by Figure 3 (ONS, 2025) and as highlighted in the national energy plan (*Plano Nacional de Energia*, PNE) for 2050 (Cuartas *et al.*, 2022, p. 2).

Furthermore, the energy sector has also been adapted to address Brazil’s mitigation and adaptation efforts. Brazil is a leading party in climate debates, as highlighted by its heavy involvement in significant climate conferences, like Rio92, COP21 and more recently COP30, which was held in city of Belém. In its PNE, the Brazilian government highlights decarbonized energy systems as a driver of sustainable development, centering in energy scenarios matters of energy geopolitics, innovation, sustainable development, energy

demand, energy security and the role of governance and finance in energy transition (EPE and MME, 2025, p. 12). Nevertheless, it also highlights the importance of supporting a just energy transition, where “just” reflects the social inequalities that lead to a higher vulnerability in the face of climate change, but also the economic growth necessities of the country.

The sector has also changed its structure completely since the first instances of electricity in the country. Today, the Brazilian energy sector is still a hybrid model but contains much more complexity in its agreements with the private sector. Different contractual modalities have allowed for alternative energy sources to be explored, but there is little understanding behind the current impacts of the private sector on this transitional process and on mitigation as a whole.

### **2.1.1. Legislation, policies and the differences in contractual modalities**

At the start of the 1990s, the Brazilian energy sector still carried centralized institutional characteristics, which attributed decision-making and regulation to the government. Since privatization, the sector has gone through regulatory, institutional and legal changes to adapt to the diminished presence of the government. In addition, new contractual modalities were introduced in the energy sector to allow for more flexibility in new public-private projects. These adaptations created the regulatory framework that is still used to this date, therefore understanding how the energy sector is organized is crucial to capture the intensity of the impacts of private participation.

The first step to reforming the energy sector was with the approval of Law n. 8.631, which set end-consumer tariffs to the costs of energy firms and reflected their cash-flow needs (Ferreira, 2000, p. 195). This legislation sought to address the economic burdens on the energy sector that had worsened in the previous decade, but legislators pushed to keep the end-consumer tariffs lower than the ongoing inflation, to benefit the population (Ferreira, 2000, p. 190). The energy reform was thought not to be an isolated policy,

but one that would accompany the restructuring of the Brazilian economy through the Real Plan (*Plano Real*) (Ferreira, 2000, p. 195), enacted in 1993 to control inflation and establish a new currency, the Brazilian Real, which remains in use today. Though inflation was controlled after the introduction of the Real, considerable pressure was put on energy firms by fixing tariffs below the inflation rate, which cut their profits. One consequence was the reduction in the investment these firms made in energy, a vital component for energy expansion. Consequently, a large part of these firms had no other choice but to expand by borrowing (Ferreira, 2000, p. 190). This scenario led to a further constraint of the energy sector, which pushed the Brazilian government to seek new solutions.

In 1995, Law n. 8.987, known as the Concessions Law (*Lei Geral de Concessões*) was approved and established the first step to including the private sector within the provision of public services. The Concessions Law established to the Federal, State, Municipal and Federal District governments the competency of firming contracts with private companies, which would be established through an auction (Brasil, 1995a). Although Law n. 8.987 is known as the Concessions Law, it specifies that the public services that would fall under its legislation are objects of concessions or “permissions” (*permissão/permisões*). According to the legal text of the Concessions Law, a concession is defined by law as

(...) the total or partial construction, conservation, renovation, expansion or improvement of any structure of public interest, delegated by the granting authority, through bidding, with free competition or competitive dialogue, to a legal entity or consortium of companies that demonstrate the capacity to carry it out, *at its own expense and risk, in such a way that the concessionaire’s investment is remunerated and amortized through the operation of the service or the work for a determined period* (Brasil, 1995a, article 2, own emphasis).

It is also clear within Law n. 8.987 that “the granting of a public service concessions, whether or not preceded by the execution of said project, shall be *formalized by means of a contract*, which must comply with the terms of this

Law, the relevant regulations and auctioning guidelines” (Brasil, 1995a, article 4, own emphasis). As emphasized above, a key component of concessions is that it is formalized by a fixed term contract, through which the government, at the levels described, concede the right to execute a public service to a company or group of companies, who must independently finance this project through the charging of fees to end-consumers.

The same law defines permissions as “(...) the delegation, on a precarious basis, through bidding, of the provision of public services, granted by the conceding authority to a private individual or a legal entity that demonstrates the capacity to perform them, at their own expense and risk” (Brasil, 1995a, article 2). In article 40, specific to permissions, the Law states that permissions are to be firmed through “adhesion contracts” (*contratos de adesão*), which can be revoked unilaterally by the grantor (i.e. the Brazilian government) at any time, characterizing its precarious nature (Brasil, 1995a, article 40). By the terms of Law n. 8.987, the main differences between a concession and a permission would be thus (i) the type of contract established; (ii) the duration of the contract established (whether fixed term or precarious); and (iii) the charging of fees (not specified, for permissions, what that would entail).

In the same year of 1995, Law n. 9.074 was enacted to complement the Concessions Law by establishing norms for granting and extending concessions and permits for public services (Brasil, 1995b). Within Law n. 9.074, the energy sector receives its own chapter, within which it outlines that from that date energy projects must be contracted through this law and Law n. 8.987 (1995), among other applicable regulations (Brasil, 1995b, article 4). Law n. 9.074 also fixes the duration of energy concessions to 30 years from the contract signing, with a possible extension of a maximum of an equal period (Brasil, 1995b, article 4, paragraph 3). Moreover, it specifies that this must be done through the previously mentioned concessions and permissions but adds the use of authorizations (*autorização/autorizações*) for the energy sector (Brasil, 1995b, article 4). Legally, there is much more ambiguity regarding authorizations than any other form, as this term is included from Law

n. 9.074 onwards, though there is no definition provided on what this type of contract would entail. de Mello states that, within the context of the provision of public services, authorizations refer to the cases where the provision of public services is indeed at issue, but it must be resolved on an emergency basis, until the appropriate procedures are carried out and either a permission or a concession is granted (de Mello, 2015, p. 715).

Law n. 9.074 also creates the structure for de-verticalization of the sector, by determining that the firms registered as distributors in the SIN cannot also participate in generation and transmission (Brasil, 1995b, articles 5, 6 and 7). This was vital to ensuring the principles of competition by separating generation, distribution and transmission, though the latter two are still considered to be natural monopolies due to the infrastructure needed in place to provide services (Estache and Rodriguez-Pardina, 1998, p. 16). In addition, this law also outlines specifically within the energy sector the objects of concessions and authorizations. As of 2016 (with the correction through Law n. 13.360), the object of concessions is to be for:

the use of hydraulic potential and the installation of thermoelectric power plants with capacity greater than 50.000 kW, intended for the execution of a public service; and the use of hydraulic potential superior to 5.000 kW and equal to or less than 50.000 kW intended for the exclusive use of the self-producer and for independent energy production (Brasil, 1995b, article 5).

Authorizations, on the other hand, as defined by this law, are destined for the implementation of thermoelectric plants with potency superior than 5.000 kW and the use of hydraulic potential superior than 5.000 kW and equal to or inferior than 50.000 kW, both intended for the exclusive use of the self-producer and for independent energy production (Brasil, 1995b, article 7).

Yet, though Law 9.074 specifies contractual modalities for the case of hydroelectric and thermal power, there is certainly legal ambiguity in understanding what the case would be for other fuels. It can be understood from analyzing the relevant laws that the restructuring of the Brazilian energy sec-

tor states what should be considered as a concession (i.e., hydraulic and thermoelectric generation with capacity over 50.000kW), and thus the rest would fall under the more flexible and precarious authorization adherence contracts. This would be the case for other renewable sources, like wind and solar energy, as indicated by sectoral sources (DS New Energy, 2021; Pinheiro Neto Advogados, 2025). Ambiguity in contractual modalities, however, may be negatively affecting the openness of the energy sector internationally, as a deep understanding of the legislation is necessary for firms to operate in the sector.

To regulate these projects several institutions were created. As noted in the previous chapter, three main institutions were created: ANEEL, in 1996; ONS, in 1998; and EPE in 2004. Apart from these agencies, other relevant regulatory agents were established, such as the National Energy Policy Council (*Conselho Nacional de Política Energética*, CNPE) in 1997, created to advise the President on energy policy (OECD, 2021, p. 52), and the Chamber of Electric Energy Commercialization, created in 2004 to manage the energy market (Brasil, 2004, article 4). By the end of 1990s and the start of the 2000s Brazil reached a delicate point. At this time, it was expected that privatization and the regulatory restructuring of the energy sector would have improved economic conditions. As noted by Tankha (2009, p. 75), the success of the privatization of the energy sector was dependent on an expected cascade of economic effects. Privatizing the energy sector (alongside the changes made by the Real Plan) would in theory lead to increased foreign investment, which would thus lead a “virtuous circle” of increased quality, profit and reinvestment (Tankha, 209, p. 75). Yet, this was not the case, as electricity prices grew exponentially (106,2% between 1995 and 2001), whilst investment in the energy sector became stagnant (Tankha, 2009, p. 77;79). At the same time, many Brazilians still did not have access to electricity and due to the previous economic crisis social conditions worsened. With the 2003 elections that put Luiz Inácio Lula da Silva (or Lula) in power, other changes were made.

One of the first policies enacted in this new government was the Light for All (*Luz Para Todos*) program, which sought to universalize the access to electricity in Brazil, with over 16 million people receiving electricity during its duration (ANEEL, no date). In 2004 Law n. 10.848 was enacted and sought to restructure the electricity market. After the energy crisis of 2001, it was necessary to increase the supply of electricity, which was done through this law for instance by allowing the commercialization of electric energy, investing in research in energy system expansion planning and dividing fuel costs across all distribution companies in isolated systems (Brasil, 2004a, articles 1, 6 and 7). Moreover, in 2004 the enactment of Law n. 11.079 established guidelines for the bidding and contracting of PPPs in Brazil (Brasil, 2004b).

By definition, PPPs are considered to be concessions, though they do not follow the same guidelines as what is referred to as “common concessions”. Instead, PPPs are executed as either “sponsored concessions” or “administrative concessions”, the former consisting of the provision of public services and financed by both the public partner and tariffs to end-consumers, and the latter as a contract firming with the public partner as a direct or indirect user (Brasil, 2004b, article 2). To qualify as a PPP, contracts must be inferior to 10 million Brazilian Reals (approximately 18 million USD) and last up to 5 years or consist of only the supply of labor, equipment or the execution of public services (Brasil, 2004b, article 2). It is important to note that within Law n. 11.079 there are no specific frameworks for the energy sector, and the investment threshold established is well below the average large-scale energy plant. However, the threshold of 10 million BRL does not seem to be legally binding, as is the case of the PPP firming between HCC Projetos Elétricos and the state of Mato Grosso do Sul, to explore solar energy and valued at 134 million BRL (SEMADESC, 2023). The governor of Mato Grosso do Sul stated that this PPP was a step to achieve a carbon-neutral state by 2030, and that it ensures benefits for both the market and the public by allowing tariffs to decrease over time (SEMADESC, 2023). Nevertheless, the presence of

PPPs in the energy sector is still small, in part due to the existing legal frameworks, despite possible benefits that Public-Private Partnerships may offer in terms of risk-sharing.

The ambiguity surrounding the definitions of contractual modalities present in the Brazilian energy sector, as well as the coupling of projects under the umbrella terms of either ‘concessions’ or ‘PPPs’ within databases (as will be explored below), create further difficulties in understanding how the energy sector operates. Though explored above, the legislation applicable to the energy sector and the recent restructuring of the sector creates further uncertainty on a policy-basis, especially when analyzed together with the country’s climate commitments.

While part of the neoliberal privatization process seeks to diminish bureaucracies involved in the provision of public services, the Brazilian energy sector contains heavy regulation and high participation from regulatory agencies, indicating that the presence of the government has perhaps not reduced as envisioned initially by the PND. The privatization of public companies is still a controversial topic, as seen in the recent privatization movements of Eletrobrás, previously the most influential company within the energy sector. Political and public pushbacks over the privatization of the remaining public companies do so in opposition to concerns about lack of access in rural areas, higher tariffs being charged to end-consumers (Agência Senado, 2022) and matters of public sovereignty. The current president of Brazil, Lula, stated in 2024 that the most recent privatization process of Eletrobrás in 2022 was “(...) a crime of harm to the nation” (“(...)um crime de lesa-pátria”) (O Globo, 2024), while political opposition to his government accuse the ruling party, the Workers Party, (*Partido dos Trabalhadores* – PT) of pushing for higher governmental participation in the company to maintain it under their own influence (Gazeta do Povo, 2025).

Political shifts and increasing political polarity in Brazil over the last twenty years have resulted in an array of policies for the energy sector. Yet, according to Teixeira and Feijo (2025, p. 17), “(...) the privatization and divestment policies significantly reduced the state’s capacity to coordinate and

articulate national energy policy. The government has lost the ability to mobilize resources around new industries and projects in the energy chain, which are critical in the context of climate change.”. Though still unclear, it appears the current government under Lula is seeking to reestablish a stronger public participation in the energy sector, as he sanctioned the removal of some public companies from the PND (Teixeira and Feijo, 2025, p. 15). His third term has, nevertheless, pushed for green transition with the private sector, creating subsidies and incentives to attract private investment (Teixeira and Feijo, 2025, p. 19).

### **3. Methodology**

This chapter will present the methodology, method, data and concepts utilized to investigate the relationship between Private Participation in Infrastructure (PPI) on the Brazilian energy mitigation process. To do so, this research proposed evaluating the following research question:

- I. How has Private Participation in Infrastructure impacted Brazil’s energy mitigation?

As mentioned in the introduction of this paper, this research question is incredibly necessary to understand the current position of the Brazilian private sector, and how through privatization it has played a role in possibly shaping Brazil’s mitigation efforts. To answer this question, this study employs an Autoregressive Distributed Lag (ARDL) time-series analysis, between 2000 and 2022. Doing so, this study aims to understand how private participation has shaped the mitigation process over time, in the short and long-run. ARDL was chosen based on the nature of the research question, which questions how PPI impacts mitigation through time, and through the subsequent disqualification of other possible models.

The period of 2000 to 2022 was selected to capture the effects of privatization, which demand some time to stabilize and produce effects on our outcome variables. The year 2000 was selected as our starting point because it marks a period in which the major reforms and privatization processes of the 1990s began to stabilize, but also because each project differs significantly in their implementation time periods, and thus there is no period of time universal to all projects after which effects become observable.

The use of ARDL is specific to time series data, and as such it was necessary to collapse the panel data retrieved from the secondary sources that compose this study. The trade-off to being able to run ARDL is that we lose project-specific (and thus sector-specific and technological contributions), but rather gain insights into how private participation impacts the energy sector as whole. As will be explored in the next section, this is also due to the incompleteness of the data behind the independent variable.

To complement our data, we will also control for two things. The first is GDP, which will be controlled for to account for the overall differences in the economy over time. Our second controls are year shocks, specific for the years 2001, 2004, 2015 and 2021. As seen in previous chapters, 2001 and 2004 were significant years for the energy sector, as in 2001 Brazil faced its most drastic energy crisis, and 2004 was the year of the most recent and reforms. 2015 and 2021, on the other hand, are significant to control for due to the economic conditions in the country at those times, as well as being the most recent energy crises. Controlling for these shocks may provide more stability to our model, by holding the events that took place in these years constant.

As such, the following sections will outline the Statement of AI use, the data utilized in this research paper, the specification and estimation of the ARDL model employed here, as well as the diagnostic tests executed to validate our findings.

### **3.1. Statement of AI use**

This section is to address the use of Article Intelligence (AI) within this research paper, as mandated by the Board of Examiners of the Institute of Social Sciences.

Throughout the research paper process the use of AI was done in very specific circumstances. AI was employed only for brainstorming and technical purposes, such as requesting the explanation through simpler terms for theoretical concepts explored in the literature reviewed, or assistance with translations from Portuguese to English, with both being verified by additional external sources. In absolutely no capacity was AI used for writing purposes, nor for spell-checking or review of this research paper, which this author considers an abuse of the tool. This research paper recognizes the ethical and environmental impacts of AI, and states that its use was moderate and for purely educational purposes.

### **3.2. Data description and variables**

Initially this study was structured on understanding the impacts of private participation on energy mitigation, using public energy firms as a control group. Given the nature of the study, during the research process select databases were analyzed to quantify the variables. The specification of the explanatory variable as ‘Private Participation in Infrastructure (PPI)’ instead of the original indicator was made in light of the lack of data on the different types of contractual modalities explored here. As there is no single dataset that categorizes projects by the type of agreement held, nor one that shows those that are exclusively publicly-owned, this study opted to shift the focus from comparing private participation and publicly-owned projects and their impacts on energy mitigation, and instead to understanding how private participation has, and is shaping, energy transition in Brazil.

The data used to measure Private Participation comes from the World Bank Private Participation on Infrastructure (PPI) database, which “...records contractual arrangements for public infrastructure projects in low- and mid-

dle-income countries (as classified by the World Bank) that have reached financial closure, in which private parties assume operating risks.” (World Bank Group, no date b). The data provides panel data information on PPIs from 1993 to 2023 (World Bank Group, no date a). As will be highlighted below, the explanatory variable will be generated using an interaction between the level of privateness (% of private ownership) and investment in PPI projects, so to capture the joint effects of these two variables. The database also provides insight into the projects’ composition, containing data on the source of energy, total investment and identifies projects as either being “PPP” or “other PPI”.

It is important to note that upon initial analysis some projects labeled as “PPP” appear to not be considered officially as such (as classified by Law n. 11.079). This is, for example, the case of one observation, the Osório Wind Complex (Complexo Eólico Osório) in the state of Rio Grande do Sul, which is considered in the dataset as a “PPP” project. This project, however, is completely privately owned, with ownership divided between Statkraft (80%), Wobben Enercon (10%) and CEEE-G (10%). Yet, the project was financed by the public bank BNDES (National Bank for Economic and Social Development, Banco Nacional de Desenvolvimento Econômico e Social), which may account for it being considered as such (Statkraft, no date). As such, this variable will not be considered in the analysis. The descriptive statistics for the PPI database are as follows:

**Table 2: Descriptive Statistics – World Bank PPI database (1993-2024)**

Variable	Obs	Mean	Std. Dev.	Min	Max
Segment	1272	7.485	2.247	4	12
private	1269	87.59	19.475	15	100
investment	1200	196.327	562.53	.2	14800
technol	1272	7.112	4.168	1	14

Source: Adapted from World Bank (2023)

In total, with the data processed, this data set provides 1,272 observations. The variable ‘private’ captures the percentage of private ownership within PPI projects. Through ‘private’ we can identify that, on average, the projects count on 87% private participation, with the minimum private participation recorded at 15%. In addition, the dataset also includes projects with 100% private participation, which could be the case of projects like Osório Wind Complex, where the ‘PPP’ label is attributed in light of financing by public entities. ‘investment’ captures the total real investment in the projects (World Bank Group, no date b). On average, total investments reached 196 million USD. Within this study a new variable ‘private\_investment’ was generated to capture the interaction between these two variables, and is used as our main regressor.

‘Segment’ is a categorical variable which covers the specific sectors of the energy sector, such as generation, distribution, transmission and any combination of the three, the latter most likely occurring before de-verticalization. Though not included within the ARDL model, through ‘Segment’ it possible to identify that most PPI projects registered in this database between 2000 and 2022 are for electricity generation (51,52%), followed by distribution (17,05%) and transmission (13,55%), as seen below:

**Table 3: Tabulation of Segment (2000-2022)**

Segment	Freq.	Percent	Cum.
Electricity distribution	185	17.05	17.05
Electricity distribution and generation	64	5.90	22.95
Electricity distribution and transmission	32	2.95	25.90
Electricity distribution, generation, and transmission	98	9.03	34.93
Electricity generation	559	51.52	86.45
Electricity transmission	147	13.55	100.00
Total	1085	100.00	

Source: Adapted from World Bank (2023)

As shows Table 3, the concentration of projects in only generation, distribution or transmission is a reflection of the de-verticalization process that occurred in the 1990s, as seen in Chapter 2.

Similarly, ‘technol’ represents the fuel technologies tied to the projects. This allows us to understand the main sources of energy in projects with private participation in Brazil, as can be seen in Table 4:

**Table 4: Tabulation of technol (2000-2022)**

Technology	Freq.	Percent	Cum.
Biogas	2	0.18	0.18
Biomass	57	5.25	5.44
NA	366	33.73	39.17
Coal	4	0.37	39.54
Diesel	70	6.45	45.99
Large Hydro (>50MW)	211	19.45	65.44
Small Hydro (<50MW)	103	9.49	74.93
Natural Gas	43	3.96	78.89
Solar PV	46	4.24	83.13
Wind, onshore	183	16.87	100.00
Total	1085	100.00	

Source: Adapted from World Bank (2023)

As shown above, most projects registered are under “NA” (not applicable), at 33,73%. In the PPI database, though not explicitly cited, NA in the Brazilian case most likely is for transmission projects, which don’t require any direct fuel to operate through, though there are other possible explanations. Large hydropower plants follow at 19,45%, which is representative of the Brazilian energy mix, and onshore wind power is the next largest, at 16,87%. This is surprising as wind energy was speculated by Viola and Franchini (2018), for instance, as not having been explored enough. The non-renewables shown in Table 4 (Coal, diesel and natural gas) make up 10,78% of the projects within the PPI data. As this study has restricted the data to between 2000 and 2022, these percentages give insights into how the energy mix has evolved in the last twenty years. Due to how data is collected, however, the PPI database unfortunately contains many missing values. Though collapsing our variables by year removes the individual characteristics of these projects, it allows us to correct for these missing values and execute a time series analysis. Another important characteristic of the PPI database is that the projects it contains are registered at the financial closure year for their contracts. Though not explicitly mentioned, it is understood that the time it

takes to effectively agree on the terms of an energy contract is large, and so the effects PPIs have on our outcome variables may be delayed.

To measure our outcome variable of ‘energy mitigation’, this study will measure indicators of CO<sub>2</sub> emissions, ecological footprint and investment in Research and Development (R&D) in energy. According to the Grubb *et al.*, mitigation, in the context of climate change, “(...) refers to actions or activities that limit emissions of greenhouse gases (GHGs) from entering the atmosphere and/or reduce their levels in the atmosphere.” (Grubb *et al.*, 2022, p. 194). GHG emissions, however, are not the only measure for mitigation. Ecological footprint, for example, accounts not only for CO<sub>2</sub> emissions, but instead is “a measure [in global hectares] of how much area of biologically productive land and water an individual, population or activity requires to produce all the resources it consumes and to absorb the waste it generates (...)” (Global Footprint Network, no date b). Within energy, it accounts for GHG emissions, land use, cropland, grazing land, forest land and fishing grounds (Global Footprint Network, no date b). This is especially important in the case of Brazil, where LULUCF (land use, land-use change, and forestry) is responsible for both the removal of GHGs and its main emitter, through deforestation in the Amazon and other protected areas (Viola and Franchini, 2018, p. 21). Additionally, mitigation efforts should also account for investments made in areas strategic to the reduction of climate impacts, such as energy Research and Development (R&D). As defined by OECD (2015, cited in ECLAC, 2020, p. 19), R&D “(...) comprise creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge.” R&D in the Brazilian energy sector is guaranteed by ANEEL, through the application of Law n. 9.991, which establishes that the firms that provide public services through concessions or permissions must invest, at the least, 0.5% of their net operating revenue to R&D (Brasil, 2000, article 1). Combined, these three variables compose our definition of energy mitigation in the context of this research paper.

For data on CO2 emissions and on Ecological Footprint, this study will use the same data explored in Ahmad and Raza (2020) and Akinsola *et al.* (2021). For CO2 emissions, the dataset used is the Energy Institute (formerly carried out by BP) database, which contains data from 1965 to 2024 and measures CO2 emissions yearly by million tons of carbon dioxide. An example of the panel data recorded can be found below:

**Figure 1 – Energy CO2 emissions in Brazil**

Carbon Dioxide Emission												Growth rate per annum		Share
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2024	2014-24	2024
Million tonnes of carbon dioxide	515.5	500.7	461.8	466.7	447.5	447.4	417.7	466.8	443.4	448.1	446.7	-0.6%	-1.4%	1.3%

Source: Energy Institute database (2024)

Additionally, the Global Footprint Network database will be used to measure Brazil’s ecological footprint. This database calculates ecological footprint through a country’s consumption, and records data from 1961 to 2024 (Global Footprint Network, no date a). For the purpose of this study, EF will be aggregated through the total amount, to compensate for possible unobserved factors that could also be impacting the other variables. On average, the ecological footprint registered for Brazil between 1961 and 2024 was that of 1.126 billion global hectares. The descriptive statistics can be found below:

**Table 7: Descriptive Statistics – Global Footprint Network database**

Variable	Obs	Mean	Std. Dev.	Min	Max
year	128	1992.5	18.546	1961	2024
builtupland	128	9596997.6	6138834.6	2269777.3	20437104
carbon	128	4820676.5	61055800	0	1.966e+08
cropland	128	7920949.7	40782738	26303318	1.764e+08
fishinggrounds	128	2080705.2	13635505	2532376.5	35189356
forestproducts	128	8.147e+0	7.339e+08	47431128	1.653e+09

8

grazingland	128	1.532e+0	29354130	73991080	1.833e+08
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8

total	128	1.126e+0	7.323e+08	1.733e+08	1.952e+09
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9

Source: Adapted from Global Footprint Network (2025)

The data present on investment in energy generation and investment in R&D comes from the Company of Energy Research (EPE, *Empresa de Pesquisa Energética*), a publicly owned company associated with the Ministry of Mines and Energy (*Ministério de Minas e Energia*), with data spanning from 2010 to 2020. This dataset, while valuable, has a smaller time period analyzed than the other datasets due to a lack of data being registered before then. The database looks at annual investments (in BRL millions) in distribution, MMGD, R&D, energy efficiency, transmission and centralized generation, but this study will only employ annual investments in R&D. The descriptive statistics for the data is as follows:

**Figure 2 – EPE dataset translated**

Variable	Obs	Mean	Std. Dev.	Min	Max
RD	11	743.542	194.45	545.926	1102.277
year	11	2015	3.317	2010	2020

Source: Adapted from EPE (2020)

As such, the descriptive statistics for our final data set is as follows:

**Table 5: Descriptive statistics of final model**

Variable	Obs	Mean	Std. Dev.	Min	Max
year	23	2011	6.782	2000	2022
emissions	23	409.959	63.911	320.639	515.522
totalef	23	5.229e+08	38809729	4.547e+08	5.841e+08
RD	11	743.542	194.45	545.926	1102.277
private invest- ment	23	159.908	78.322	40.326	330.421
gdp	23	4.589e+09	2.600e+09	1.199e+09	1.008e+10
year shock	23	.174	.388	0	1

### 3.3. Model and hypothesis

As seen above, this study considers variables that do not have immediate effects, but delayed effects due to the time it takes to implement projects in the energy sector. As such, as per Wooldridge (2019, p. 337), by using lag distribution we can observe the dynamic effect that an increase in our independent variables,  $x$ , has on our dependent,  $y$ . Lagging our variables will provide insights into how private participation today, and in previous periods, affects measures of energy mitigation. An analysis of lag-order selection criteria ('varsoc' command) in our data identified that the optimal lag would be of 3 years for CO<sub>2</sub> emissions and Ecological Footprint, but 2 years for R&D, likely due to its shortened data (see Annex A). These lags are consistent with the implementation time effects of PPI projects explained previously in Chapter 2 and 3. However, the use of three-year lags in the model was not possible in all cases, due to a small sample size once lagging, which invalidated bounds testing.

Understanding the trends behind a time series is important for verifying its predictability. According to Nkoro and Uko (2016, p. 67), "A time series is said to be a trend stationary process if the trend is completely predictable and not variable, whereas if it is not predictable, we call it difference or integrated stochastic trend or difference stationary process". By predictability, what the authors are stating is that when a time series is stationary, it means that part of the data does not change over time. This is usually not the case, especially for the energy sector in Brazil, which is influenced by changes in policy, economic conditions, ideology of political parties and lobbying, to list some of the factors that may impact possibly results.

As such, the first step of the ARDL technique is to test for stationarity. To do so, like the authors explored in the literature review, this research paper employed the use of the Augmented Dickey-Fuller (ADF) test. The ADF test tests if a variable follows a unit-root process, with the null hypothesis being that the variable contains a unit root, and the alternative hypothesis that it

doesn't (Statacorp, 2023). The ADF tests show the following results for our variables: (i) for 'emissions', it provides a p-value of 0.5965; (ii) for 'totalef', 0.5261; (iii) for 'RD', 0.2715; (iv) for 'gdp', 1.0000; and (v) for 'private\_investment', the p-value is 0.0329 (see Annex B). Considered at a 0.05 threshold, the ADF tests for all variables fail to reject the null hypothesis, which indicates that these variables are non-stationary in level, at I(1).

With the Augmented Dickey-Fuller test results provided, it is possible to then present the model for this study. Following the ARDL approach explored by Pesaran and Shin (1997), our model is as follows:

$$Y_t = \alpha_0 + \sum_{i=1}^p \alpha_i Y_{t-i} + \sum_{j=0}^{q1} \beta_j PPI_{t-j} + \sum_{k=0}^{q2} \gamma_k GDP_{t-k} + \sum_{s=0}^S \delta_s YearShocks_{s,t} + \varepsilon_t$$

with

$Y_t$  representing the dependent variables (CO2 emissions, Ecological Footprint and R&D investment) at time  $t$

$\alpha_i$  representing the coefficient on the  $i$ -th lag of  $Y$

$Y_{t-i}$  representing the lagged dependent variables at lag  $i$

$PPI_{t-j}$  representing private participation at lag  $j$  ( $j=0$  being current value)

$GDP_{t-k}$  representing national GDP at lag  $k$  ( $k=0$  being current value)

$YearShocks_{s,t}$  representing a dummy variable for specific year shocks, for year  $s$  at time  $t$

$S$  representing the total number of years for dummies

$q1$  and  $q2$  representing the maximum number of lags included

$\varepsilon_t$  representing the error term

As ARDL accounts for short and long-run effects, we can hypothesize them separately. Considering the discussion and the literature reviewed in Chapter 2, in the short run it is hypothesized that private participation, when controlling for GDP and specific year shocks, is expected to positively impact emissions, ecological footprint and R&D investment. What this means in

practice is that it is expected that private participation, in the short run, increases CO<sub>2</sub> emissions, increases Brazil's ecological footprint, and increases R&D investment, the latter having a reverse effect on mitigation. In the long run, it is hypothesized that private participation will have an effect on these three variables, though the direction of the effect is to be determined empirically due to mixed evidence analyzed.

## **4. Findings and discussion**

### **4.1. Findings and diagnostics**

Having specified our model and hypotheses, it is possible to estimate ARDL for each of the three outcome variables. As it accounts for both short- and long-run estimates, ARDL is executed in two stages, the first executing the model and the second confirming long-run cointegration through a bounds test. Cointegration is a concept developed by Granger (1983), which states that "(...) non-stationary processes can have linear combinations that are stationary (...)" (Johansen, 2004, p. 1). What this represents is that even if two variables, for example, are non-stationary and thus have mean and variances which vary over time, a pattern can be drawn in their long-term relationship if identified cointegration.

There are several cointegration test variations which account for different sample sizes and orders of integration, including bounds testing, developed for the Autoregressive Distributed Lag model. Bounds testing was created by Pesaran, Shin and Smith (2001) and it tests the existence of a relationship between variables regardless of their order of integration, as long as no variable is integrated at order 2 or above (Pesaran, Shin and Smith, 2001, p. 290). The bounds test considers the null hypothesis as representing no cointegration between dependent and independent variables, with the alternative hypothesis indicating cointegration.

Within our model, with the lag-order selection executed, an optimal lag of three years was identified (see Annex A), but three-year lags significantly reduces our sample size, making bounds testing at this lag unfeasible. Bounds testing is possible at a lag of one year, though doing so also underfits our model and ignores contributions possibly only significant after optimal lags. Obtaining cointegration in a smaller sample offers some difficulties but may be done for example through the use of residual-based bootstrapping, as done by McNown, Sam and Goh (2018). This method, however, was not employed in this research paper in light of time restrictions and unfamiliarity with the application within ARDL.

Issues with sample size could also be corrected by enlarging the time period analyzed, but this takes away from the main theoretical focus of measuring the delayed impacts of private participation after privatization occurred in the Brazilian energy sector. Though authors like Ahmad and Raza (2020) and Akinsola *et al.* (2021) executed ARDL models and cointegration tests (ARDL bounds testing and the Maki cointegration test, respectively), the time periods analyzed in those studies were much larger and tracks PPI from before privatization to present day. While analyzing a larger year sample provides stability in detecting long-run trends, there is a possibility that important structural changes are looked over if not accounted for. As was shown in Chapter 2, a multitude of political, economic and social factors impacted, and still impact, the Brazilian energy sector.

As such, to provide insights into the short- and long-run relationships of our variables, the ARDL model was executed at lag 1 with ARDL bounds testing. Because this is not the optimal lag identified, the model was also executed at lag 3, though no bounds testing was possible. Bounds testing was also not possible at any level for Research and Development investment, as the sample size of that variable is very small (N=10). The variables were adjusted to their natural log versions, except for the dummy variable representing year shocks, to interpret results by percentage. In addition, the ARDL

model was executed including the error-correction term ('ec'), which reparametrizes our model into an Error Correction Model (ECM) and assists in interpretation. The results can be seen below:

**Table 6: ARDL regression on emissions (lag 1, lag 3)**

	(1) D.lemissions	(2) D.lemissions
<b>ADJ</b>		
L.lemissions	<b>0.164</b> (0.284)	<b>0.713*</b> (0.021)
<b>LR</b>		
lprivate_i~t	<b>-0.138</b> (0.488)	<b>0.238*</b> (0.035)
lgdp	<b>0.205</b> (0.103)	<b>-0.131</b> (0.204)
year_shock	<b>0.177</b> (0.551)	<b>0.598*</b> (0.015)
<b>SR</b>		
D.lprivate~t	<b>0.00146</b> (0.946)	<b>0.186*</b> (0.019)
LD.lprivat~t		<b>0.0631</b> (0.076)
L2D.lpriva~t		<b>0.00843</b> (0.756)
D.lgdp	<b>1.263***</b> (0.001)	<b>2.126**</b> (0.005)
LD.lgdp		<b>0.866</b> (0.151)
L2D.lgdp		<b>2.395*</b> (0.013)
D.year_shock	<b>0.0487</b> (0.065)	<b>0.337*</b> (0.017)
LD.year_sh~k		<b>0.110</b> (0.098)
L2D.year_s~k		<b>0.0413</b> (0.200)
LD.lemissi~s		<b>-1.062*</b> (0.043)
L2D.lemiss~s		<b>-1.511*</b> (0.026)
_cons	<b>-0.454</b> (0.294)	<b>-5.929**</b> (0.009)
N	22	20
R-sq	0.709	0.966
adj. R-sq	0.563	0.838
p-values in parentheses		
* p<0.05, ** p<0.01, *** p<0.001		

Table 6 outlines the ARDL model on CO2 emissions. As shows Kripfganz and Schneider (2023, p. 989; 1003), “the first coefficient in the ADJ [(adjustment coefficient)] section of the regression output is the negative speed-of-adjustment coefficient  $\pi_y = -\alpha$ . (...) [it] tells us how fast the process for  $Y_t$  reverts to its long-run relationship when (...) equilibrium is distorted”. According to the authors, a value of  $\alpha = 1$  indicates full adjustment after distortion,  $\alpha = 0$  indicates a complete deviation from equilibrium and  $0 < \alpha < 1$  indicates partial adjustment where equilibrium is achieved over time (Kripfganz and Schneider, 2023, p. 989). For emissions, the values retrieved are 0.164 and 0.713 for lags 1 and 3 respectively. Because they are positive, this indicates rather the opposite of a return to equilibrium in the variables’ long-run relationship, which grows as the variables become more lagged. Instead, this value shows that deviation is amplified rather than corrected, indicating a possibly unstable relationship in the long run.

“LR” in Table 6 represents the long-run coefficients, which can only be validated if bounds testing shows cointegration. For emissions, the F-statistic and t-statistic were 1.143 and 1.115 respectively (see Annex C), which at all levels of significance signifies that we cannot reject the null hypothesis,  $H_0$ : no level relationship. This means that per the bounds test there is no cointegration between the dependent variable ‘emissions’ and the regressors and thus no long-run equilibrium is established. This differs from the results presented by Ahmad and Raza, who indicated cointegration at both the 5% and 10% level of significance (Ahmad and Raza, 2020, p. 30643). Without cointegration established, though the ARDL specification gives us long-run coefficients, these values should not be considered as representative of the long-run effects and so only short-run effects will be interpreted.

The short-run effects (“SR” in Table 6) show positive impacts from private participation on emissions, as hypothesized. With one-year lag and at the current year change (i.e. compared to the previous year), private participation increases emissions by 0.146% (though not statistically significant) and at a three-year lag it increases emissions by 18,6% (statistically significant at 5%).

The p-value between lags also goes down considerably, from 0.946 to 0.019, indicating a more precise estimation with increased lags. At lag 3, the lagged difference for PPI (LD.lprivate\_investment) and the two-year lagged difference (L2D.lprivate\_participation) both have positive impacts, but these are not statistically significant.

Similarly, at the current year change, GDP has at lag 1 and lag 3 positive coefficients, which are both statistically significant and indicate a 126.3% and 212.6% increase in emissions respectively. This maintains throughout lag 3, where at a two-year lagged difference an increase in GDP results in a 239.5% increase in emissions, also statistically significant. The year shock dummy also positively impacts emissions, though significance is only obtained at the current year lag of lag 3. This coefficient signifies that at lag 3, in the years identified as shocks, emissions increases by 33.7%.

Table 7 shows the results of ARDL regression on ecological footprint. Different than with emissions, the ADJ coefficient for ecological footprint is negative at lag 1 (-0.178), but positive at lag 3. What this indicates is that with only one lag, at current year change, there is a correction towards equilibrium, but as more lags are added, this effect is distributed across past periods, and the first lag of EF may be showing a short-term momentum before correction. The bounds test for ecological footprint provided a F-statistic and t-statistic of 3.794 and -1.197 respectively, which when compared to the critical values indicates a failure to reject the null hypothesis (H0: no level relationship) at all levels of significance (see Annex C). This also confirms that there isn't cointegration, and the long-run effects of ecological footprint should not be considered.

**Table 7: ARDL regression on ecological footprint (lag 1, lag 3)**

	(1)	(2)
	D.ltotalef	D.ltotalef
<b>ADJ</b>		
L.ltotalef	<b>-0.178</b> (0.251)	<b>0.496</b> (0.095)
<b>LR</b>		
lprivate_i~t	<b>0.239</b>	<b>0.00236</b>

	(0.321)	(0.986)
lgdp	<b>0.0485</b> (0.638)	<b>0.0885</b> (0.350)
year_shock	<b>-0.279</b> (0.420)	<b>0.482</b> (0.099)
-----		
<b>SR</b>		
D.lprivate~t	<b>-0.0110</b> (0.610)	<b>0.0596</b> (0.340)
LD.lprivat~t		<b>0.0726</b> (0.129)
L2D.lpriva~t		<b>0.0227</b> (0.381)
D.lgdp	<b>0.737**</b> (0.006)	<b>1.276*</b> (0.011)
LD.lgdp		<b>-0.194</b> (0.711)
L2D.lgdp		<b>-0.147</b> (0.753)
D.year_shock	<b>0.0355</b> (0.141)	<b>0.211</b> (0.064)
LD.year_sh~k		<b>0.139</b> (0.070)
L2D.year_s~k		<b>0.0619</b> (0.085)
LD.ltotallef		<b>-0.459</b> (0.310)
L2D.ltotallef		<b>-0.625</b> (0.099)
_cons	<b>3.118</b> (0.285)	<b>-9.034</b> (0.104)
-----		
N	22	20
R-sq	0.678	0.950
adj. R-sq	0.517	0.760
-----		
p-values in parentheses		
* p<0.05, ** p<0.01, *** p<0.001		

For the short-run effects of the regressors on EF, it is possible to see that at current year level, private participation affects ecological footprint negatively at lag 1, i.e. an increase in PPI causes a decrease of 1.1% in ecological footprint. When more lags are included, private participation has positive effects on ecological footprint, with it increasing EF by 5.96%, 7.26% and 2.27% at current year level, one-year lagged difference and two-year lagged difference respectively. None of these results are, however, statistically significant. At the current year level, GDP has positive impacts on EF

(73.7% increase at lag 1 and 127.6% at lag 3), with both results being statistically significant. As more lags are added, however, this relationship becomes negative (-19.4% and -14.7% at the one-year and two-year lagged difference respectively), though this is not significant. Year shocks have, irrespective of the lags added or lagged differences, positive impacts on ecological footprint. At the current year level, lag 1 and lag 3 would, in the year specified as shocks, increase the EF by 3.5% and 2.11% respectively, though none of the results are statistically significant.

Table 8 presents the results of the ARDL regression on Research and Development investment (in BRL millions). As explained before, the R&D investment data used in this research paper has a small sample size (N=10) due to its shortened time series, ranging from 2010 to 2020. As such, only lags of 1 were applied to the ARDL estimation and no long-term effects can be estimated, as bounds testing was not possible. Therefore, this research paper can only look at the short-run effects of PPI, while controlling for GDP and year shocks.

**Table 8: ARDL regression on R&D investment (lag 1)**

	(1)
	D.lRD
<b>ADJ</b>	
L.lRD	<b>-0.968</b> (0.235)
<b>LR</b>	
lprivate_i~t	<b>0.00563</b> (0.994)
lgdp	<b>1.179</b> (0.676)
year_shock	<b>-0.639</b> (0.745)
<b>SR</b>	
D.lprivate~t	<b>0.159</b> (0.745)
D.lgdp	<b>3.334</b> (0.862)
D.year_shock	<b>0.469</b> (0.559)
_cons	<b>-19.52</b> (0.766)

N	10
R-sq	0.713
adj. R-sq	-0.291
-----	
p-values in parentheses	
* p<0.05, ** p<0.01, *** p<0.001	

The adjustment coefficient for R&D investment has a value of -0.968, which suggests that deviations from long-run equilibrium are corrected within a one-year change. However, because the sample size is so small, this evidence should only represent the time period analyzed, as should the other results obtained. At the current year difference, an increase in private participation investment had a positive effect on R&D investment, with a 1% increase in PPI investment leading to a 0.159% in R&D investment. This value, however, is not statistically significant and contains a p-value (0.745). GDP also has a positive effect on R&D investment, with a 1% increase lead to a 333.4% increase in R&D investment, though this is not significant and contains a p-value (0.862). Finally, in years identified as shocks, there is an increase of 46.9% in R&D investment, though similar to the other regressors this value isn't statistically significant, and its p-value is high (0.559).

Having estimated the ARDL model on the outcome variables, it is necessary to carry out diagnostics and robustness checks. Like the authors explored in the literature review, notably Ahmad and Raza (2020) and Akinsola *et al.* (2021), this study employed the use of diagnostic tests to check for serial correlation. Serial correlation was tested through the test by Wooldridge, using the 'xtserial' code created by David Drukker (2002, cited in Drukker, 2003, p. 1). The test produces a null hypothesis, where H0: no first-order autocorrelation. The Wooldridge test produced a p-value of 0.0000 when tested against our three dependent variables, which when compared to the threshold value of 0.05 (5% probability of making a Type I error) allows us to reject the null hypothesis (see Annex D for results).

Heteroskedasticity tests were carried out for lag 1, as it provided full interpretations of the outcome variables. This was done through the Breusch–Pagan/Cook–Weisberg (BP/CW) test for heteroskedasticity ('hetttest'), with H0: Constant variance, and through the Information Matrix Test ('imtest'),

with  $H_0$ : Homoskedasticity ( $H_a$ : Unrestricted heteroskedasticity), and which combines tests for heteroskedasticity, skewness and kurtosis from White (1980) and Cameron and Trivedi (1990) (Statacorp, 2023). At lag 1, the specification for emissions ( $l.emissions$ ) in the BP/CW and Information Matrix tests provided p-values of 0.9946 and 0.3995 respectively, which is over the 0.05 threshold, signifying a failure to reject the null hypotheses they test. This can be confirmed as well for the tests on ecological footprint ( $l.totalef$ ), which registered p-values of 0.4975 and 0.3995 for the BP/CW and Information Matrix tests respectively. In addition, the tests on R&D investment also failed to reject the null hypotheses of the BP/CW and Information Matrix tests, with p-values of 0.1332 and 0.3505 respectively. As such, it is possible to confirm that the residuals of the specifications of this ARDL model suggest homoskedasticity.

## **4.2. Discussion and policy considerations**

This section discusses the implications of this research paper's findings in the analysis of private participation's effects on achieving a just transition in the energy sector, guided by the question "how has Private Participation in Infrastructure impacted Brazil's energy mitigation?". It examines how privatization occurred in the energy sector, following a political and economically driven shift, which led to the restructuring of the sector and the establishment of Brazil's current legislative and regulatory frameworks. Moreover, through an ARDL time series analysis, this study was able to estimate the short-run effects of PPI, when holding GDP and year shocks constant, on three measurements of mitigation: CO<sub>2</sub> emissions, ecological footprint and Research and Development investment. It is important to note that the impacts of private participation on mitigation in the Brazilian energy sector is a complex and insufficiently explored topic. The lack of data, ambiguity in terms and adapted legal processes involved in the Brazilian energy sector contribute, as such, to the existing gap in the literature.

The findings of the ARDL models executed in this paper point to, at least in the short-run, private participation (PPI) (when controlling for GDP and year shocks) contributes positively to emissions, but has no statistically significant impacts on ecological footprint and R&D investment. Regarding CO<sub>2</sub> emissions, PPI only obtains a significant relationship at the optimal lag of three years, with it reflecting an 18,6% increase in emissions at the current year difference (D.lprivate\_investment). The p-values found for the values at lags 1 and 3, at the current year difference, also point to significance increasing with the addition of lags in our model, verifying the findings of the optimal lag test. These findings contradict the findings of Ahmad and Raza (2020), who identified PPI investment ('PPP investment' in their text) as negatively influencing CO<sub>2</sub> emissions in the short run, though in their paper they estimated this influence at an optimal lag of 1 year. These findings also validate the hypothesis of short-run positive impacts specified the methodology chapter.

The ARDL model for emissions also identifies that though GDP was included primarily as a control, the estimated coefficient remains statistically significant at both lags 1 and 3 (p-values 0.001 and 0.005), in the current year difference, and at lag 3 with a two-year difference (L2D.lgdp, p-value 0.013). This suggests that macroeconomic conditions continue to play a significant role in shaping CO<sub>2</sub> emissions, irrespective of the effects of private participation. There may be, however, unidentified variables that are correlated with GDP but weren't accounted for in this model, or issues of endogeneity not addressed. Nevertheless, the significance of its coefficients does corroborate the theoretical discussions presented in Chapter 2, which addresses the contributions of the Brazilian economy to the formulation of energy sector planning. Additionally, significance was found in the estimation of year shocks coefficients, at lag 3 and current year differences. This suggests that in the years where shocks were identified, emissions increased by 33.7%. This dummy variable jointly accounts for the effects of 2001, 2004, 2015 and 2021, which as seen in Chapter 2, were all significant years for the energy sector. This relationship is partly supported by the findings within Chapter 2,

which showed that during periods of water scarcity (2001, 2015 and 2021) emissions increased due to greater reliance on thermoelectric plants.

As for ecological footprint, no statistically significant results were found for PPI (holding GDP and year shocks constant), though within lags 1 and 3, respectively, a negative (-0,0110) and positive relationship (0.0596) were found. As such, our hypothesis for ecological footprint is reject, as no significant relationship exists between the two. In this model GDP again shows statistically significant and positive impacts on EF at lags 1 (0.737, p-value 0.006) and 3 (1.276, p-value 0.011), though only at current year differences. This relationship is likely explained by the same factors presented for emissions. Nevertheless, this also validates the findings by Akinsola *et al.* (2021), who were able to identify a causal linkage between EF and GDP. Year shocks, on the other hand, show no statistically significant impacts on ecological footprint, at any lag or level of differences. It is possible that no effect was estimated because ecological footprint is calculated through the total value of EF, which consists of non-energy related factors as well.

As for R&D investment, the findings show no statistically significant relationship between PPI and R&D, holding GDP and year shocks constant. This also rejects the original hypothesis that in the short-run, PPI would affect R&D investment positively. These findings, however, are highly insignificant, with the p-values of the variables in the short-run being well over 0.5. It is understood by this research paper that the estimation of R&D investment in the ARDL model was made unreliable due to the small sample size (N=10), which unfortunately was the only data for R&D in energy in Brazil made available. An analysis of R-sq and the adjusted R-sq show that there is a large difference between the two, indicating that with the current data on R&D investment there are unlikely “irrelevant” variables being corrected for through adjusted R-sq.

Through the findings of this study it is possible to conclude that in the short-run, private participation increases CO2 emissions, but holds no significant relationship with ecological footprint and R&D investment, when con-

trolling for GDP and year shocks. This answers only partly our research question, as no statistically significant relationship was found for EF and R&D investment. Nevertheless, the objectives of this study were carried out, as it includes an in-depth overview of the Brazilian energy sector, identifying how PPI influenced mitigation from a theoretical perspective and satisfying the sub questions proposed: “a. How is the energy sector structured legally, institutionally and regulatorily and what influence does this have on mitigation?; b. Have investments in the energy sector been directed towards mitigation efforts?; and c. What have been the short and long-term impacts of private participation on Brazil’s CO2 emissions and Ecological Footprint?”).

What can be concluded from the data is that to accurately estimate the post-privatization PPI impacts on mitigation, more data needs to be collected by official institutions, like ANEEL, EPE and MME. As mentioned above, the main limitations of this study were related to data, where restricted temporal coverages, missing data and incorrect data significantly hindered the execution of the ARDL model, and others that were considered during this process. Being so, the recommendations that this research paper makes is to invest in the collection and processing of data on private participation in Brazil. The main gap in the literature lies in understanding the impacts of private participation in the Brazilian policy sphere, that is, identifying the way through which private firms shape policy, advance their interests (though there is no singular interest for PPI) and exerts influence through lobbying and other mechanisms. Despite the current government of Lula indicating a regression on privatizing public companies, the lagged effects of past governments’ policies can still impact the structure of the sector. This is not to say that private participation is negatively impacting the Brazilian energy sector; on the contrary, it provides government with flexible contracts and cash flow for projects that would have not been executed if not partly privatized. However, the research conducted suggests that private participation, at least compared to emissions, does cause negative impacts for the mitigation efforts currently in place.

## Annex A: Lag-order selection statistics (VAR)

. varsoc emissions private\_investment gdp year\_shock

Lag-order selection criteria

Sample: 2004 thru 2022

Number of obs = 19

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-646.435				6.4e+24	68.4669	68.5005	68.6657
1	-573.254	146.36	16	0.000	1.6e+22	62.4477	62.616	63.4419
2	-556.995	32.517	16	0.009	2.1e+22	62.4205	62.7234	64.21
3	-513.88	86.229*	16	0.000	3.0e+21	59.5664*	60.0038*	62.1511*
4	.	.	16		-.1.7e-08*	.	.	.

\* optimal lag

Endogenous: emissions private\_investment gdp year\_shock

Exogenous: \_cons

. varsoc totalef private\_investment gdp year\_shock

Lag-order selection criteria

Sample: 2004 thru 2022

Number of obs = 19

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-906.064				4.7e+36	95.7963	95.8299	95.9951
1	-843.723	124.68	16	0.000	3.8e+34	90.9182	91.0865	91.9124*
2	-827.661	32.124	16	0.010	5.0e+34	90.9117	91.2145	92.7012
3	-798.549	58.224*	16	0.000	3.0e+34	89.5315*	89.9689*	92.1163
4	.	.	16		-.2317.97*	.	.	.

\* optimal lag

Endogenous: totalef private\_investment gdp year\_shock

Exogenous: \_cons

. varsoc RD private\_investment gdp year\_shock

Lag-order selection criteria

Sample: 2014 thru 2020

Number of obs = 7

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-236.84				9.1e+24	68.8114	68.4294	68.7805
1	.	.	16		-.1.9e-07*	.	.	.
2	688.249	.	16	.	.	-188.643*	-191.317*	-188.859*
3	675.163	-26.172	16	.	.	-184.904	-187.578	-185.12
4	664.783	-20.759	16	.	.	-181.938	-184.612	-182.154

\* optimal lag

Endogenous: RD private\_investment gdp year\_shock

Exogenous: \_cons

## Annex B: Augmented Dickey-Fuller tests

Dickey-Fuller test for unit root				Number of obs = 22
Variable: emissions				Number of lags = 0
H0:	Random	walk	without	drift, d = 0
	Dickey-Fuller			
	Test		-----	critical value -----
	statistic	1%		5% 10%
	Z(t)	-1.370	-3.750	
	-3.000	-2.630		
<hr/>				
MacKinnon	approximate	p-value	for	Z(t) = 0.5965.

Dickey-Fuller test for unit root				Number of obs = 22
Variable: totalef				Number of lags = 0
H0:	Random	walk	without	drift, d = 0
	Dickey-Fuller			
	Test		-----	critical value -----
	statistic	1%		5% 10%
	Z(t)	-1.515	-3.750	
	-3.000	-2.630		
<hr/>				
MacKinnon	approximate	p-value	for	Z(t) = 0.5261.

Dickey-Fuller test for unit root				Number of obs = 10
Variable: RD				Number of lags = 0
H0:	Random	walk	without	drift, d = 0
	Dickey-Fuller			
	Test		-----	critical value -----
	statistic	1%		5% 10%
	Z(t)	-2.035	-3.750	
	-3.000	-2.630		
<hr/>				
MacKinnon	approximate	p-value	for	Z(t) = 0.2715.

Dickey-Fuller test for unit root				Number of obs = 22
Variable: private_invest~t				Number of lags = 0
H0:	Random	walk	without	drift, d = 0
	Dickey-Fuller			
	Test		-----	critical value -----
	statistic	1%		5% 10%
	Z(t)	-3.022	-3.750	
	-3.000	-2.630		
<hr/>				
MacKinnon	approximate	p-value	for	Z(t) = 0.0329.

Dickey-Fuller test for unit root				Number of obs = 22		
Variable: gdp				Number of lags = 0		
H0: Random	walk	without		drift,	d	= 0
	Dickey-Fuller					
Test			-----	critical	value	-----
statistic		1%		5%		10%
Z(t)	3.305	-3.750				
-3.000	-2.630					
<hr/>						
MacKinnon	approximate	p-value	for	Z(t)	=	1.0000.

## Annex C: ARDL bounds tests (ectest)

Following command: ardl lemissions lprivate\_investment lgdp year\_shock,  
lags(1) ec

```
. estat ectest
```

Pesaran, Shin, and Smith (2001) bounds test

H0: no level relationship F = **1.143**  
Case 3 t = **1.115**

Finite sample (3 variables, 22 observations, 3 short-run coefficients)

Kripfganz and Schneider (2020) critical values and approximate p-values

	10%		5%		1%		p-value	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
F	<b>3.185</b>	<b>4.560</b>	<b>4.058</b>	<b>5.698</b>	<b>6.397</b>	<b>8.717</b>	<b>0.569</b>	<b>0.806</b>
t	<b>-2.561</b>	<b>-3.478</b>	<b>-2.976</b>	<b>-3.967</b>	<b>-3.875</b>	<b>-5.028</b>	<b>0.991</b>	<b>0.997</b>

do not reject H0 if  
either F or t are closer to zero than critical values for I(0) variables  
(if either p-value > desired level for I(0) variables)

reject H0 if  
both F and t are more extreme than critical values for I(1) variables  
(if both p-values < desired level for I(1) variables)

decision: no rejection (.a), inconclusive (.), or rejection (.r) at levels:

	10%	5%	1%
decision	<b>.a</b>	<b>.a</b>	<b>.a</b>

Following command: ardl ltotalef lprivate\_investment lgdp year\_shock,  
lags(1) ec

```
. estat ectest
```

Pesaran, Shin, and Smith (2001) bounds test

H0: no level relationship F = **3.794**  
Case 3 t = **-1.197**

Finite sample (3 variables, 22 observations, 3 short-run coefficients)

Kripfganz and Schneider (2020) critical values and approximate p-values

	10%		5%		1%		p-value	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
F	<b>3.185</b>	<b>4.560</b>	<b>4.058</b>	<b>5.698</b>	<b>6.397</b>	<b>8.717</b>	<b>0.061</b>	<b>0.163</b>
t	<b>-2.561</b>	<b>-3.478</b>	<b>-2.976</b>	<b>-3.967</b>	<b>-3.875</b>	<b>-5.028</b>	<b>0.547</b>	<b>0.771</b>

do not reject H0 if  
either F or t are closer to zero than critical values for I(0) variables  
(if either p-value > desired level for I(0) variables)

reject H0 if  
both F and t are more extreme than critical values for I(1) variables  
(if both p-values < desired level for I(1) variables)

decision: no rejection (.a), inconclusive (.), or rejection (.r) at levels:

	10%	5%	1%
decision	<b>.a</b>	<b>.a</b>	<b>.a</b>



## **Annex D: Wooldridge serial correlation tests**

### **. xtserial emissions private investment gdp year\_shock**

Wooldridge test for autocorrelation in panel data

H0: no first-order autocorrelation

$$F(1, 28) = 311.783$$

$$\text{Prob} > F = 0.0000$$

### **. xtserial totalef private investment gdp year\_shock**

Wooldridge test for autocorrelation in panel data

H0: no first-order autocorrelation

$$F(1, 28) = 4324.730$$

$$\text{Prob} > F = 0.0000$$

### **. xtserial RD private investment gdp year\_shock**

Wooldridge test for autocorrelation in panel data

H0: no first-order autocorrelation

$$F(1, 25) = 6589.347$$

$$\text{Prob} > F = 0.0000$$

## Annex E: Heteroskedasticity tests

For 'l.emissions' at lag 1:

Assumption:	Breusch–Pagan/Cook–Weisberg	test	for	heteroskedasticity
Variable:	Fitted	Normal	error	terms
H0:		values	of	D.l.emissions
chi2(1)	=	Constant		variance
Prob	>	chi2	=	0.00
				0.9946

White's		test	df	p
H0:		Homoskedasticity		
Ha:	Unrestricted	heteroskedasticity		
chi2(21)	=	22.00		
Prob	>	chi2 =		0.3995
Cameron & Trivedi's decomposition of IM-test				
		chi2		
Heteroskedasticity	22.000		21	0.400
Skewness	12.250		7	0.093
Kurtosis	1.060		1	0.302
Total	35.310		29	0.194

For 'l.totafef' at lag 1:

Assumption:	Breusch–Pagan/Cook–Weisberg	test	for	heteroskedasticity
Variable:	Fitted	Normal	error	terms
H0:		values	of	D.l.totafef
chi2(1)	=	Constant		variance
Prob	>	chi2	=	0.46
				0.4975

White's		test	df	p
H0:		Homoskedasticity		
Ha:	Unrestricted	heteroskedasticity		
chi2(21)	=	22.00		
Prob	>	chi2 =		0.3995
Cameron & Trivedi's decomposition of IM-test				
		chi2		
Heteroskedasticity	22.000		21	0.400
Skewness	9.140		7	0.243
Kurtosis	0.180		1	0.671
Total	31.320		29	0.350

For 'l.RD' at lag 1:

Breusch–Pagan/Cook–Weisberg test for heteroskedasticity  
 Assumption: Normal error terms  
 Variable: Fitted values of D.IRD  
 H0: Constant variance = 2.26  
 Prob > chi2 = 0.1332

---

White's test  
 H0: Homoskedasticity  
 Ha: Unrestricted heteroskedasticity  
 chi2(9) = 10.00  
 Prob > chi2 = 0.3505  
 Cameron & Trivedi's decomposition of IM-test  
 chi2

		df	p
Heteroskedasticity		9	0.350
	10.000		
Skewness		7	0.243
	9.140		
Kurtosis		1	0.864
	0.030		
Total		17	0.319
	19.170		

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