Periódico Eletrônico Fórum Ambiental da Alta Paulista
Electronic Journal Environmental Forum of Alta Paulista
ISSN 2966-2931 Suporte Online / Online Support - ISSN 1980-0827 Suporte CD-ROM / CD-ROM Support

Edição em Português e Inglês / *Edition in Portuguese and English* - v. 21, n. 1, 2025

Eco-innovation at the Frontiers of Brazil's Economic Growth

Ana Cândida Ferreira Vieira
PhD Candidate in Administration, UNINOVE, Brazil
Professor at UFPB/Campus IV, Brazil
a.candida@uni9.edu.br/ana.candida@academico.ufpb.br
ORCID iD https://orcid.org/0000-0001-5845-6519

Priscila Rezende da Costa
Professor, PhD, UNINOVE, Brazil
priscilarc@uni9.pro.br
ORCID iD https://orcid.org/0000-0002-7012-0679

Leonardo Vils
Professor, PhD, UNINOVE, Brazil
leonardo.vils@uni9.pro.br
ORCID iD https://orcid.org/0000-0003-3059-1967

Submissão: 23/03/2024
Aceite: 25/12/2024
VIEIRA, Ana Cândida Ferreira; COSTA , Priscila Rezende da; VILS, Leonardo. Ecoinovação nas Fronteiras do Crescimento Econômico do Brasil . **Periódico Eletrônico Fórum Ambiental da Alta Paulista**, *[S. l.]*, v. 21, n. 1, 2025. DOI: 10.17271/1980082721120255603. Disponível em: https://publicacoes.amigosdanatureza.org.br/index.php/forum_ambiental/article/view/5603

Periódico Eletrônico Fórum Ambiental da Alta Paulista
Electronic Journal Environmental Forum of Alta Paulista
ISSN 2966-2931 Suporte Online / *Online Support* - ISSN 1980-0827 Suporte CD-ROM / *CD-ROM Support*

Edição em Português e Inglês / *Edition in Portuguese and English* - v. 21, n. 1, 2025

Ecoinovação nas Fronteiras do Crescimento Econômico do Brasil

RESUMO
Objetivo - Apresentar a ecoinovação nas fronteiras do crescimento econômico do Brasil, medido seu impacto por meio do Produto Interno Bruto (PIB), Formação Bruta de Capital Fixo (FBCF) com reflexo na poluição (CO2equivalente) e remoção desses poluentes.
Metodologia - A metodologia adotada é qualitativa, baseada em levantamento documental com análises descritivas e explicativas.
Originalidade/relevância – O estudo destaca a ecoinovação por meio da FBCF e lacunas essenciais ao abordar os custos do crescimento econômico por meio do PIB em relação à poluição ambiental. Esses custos, embora muitas vezes considerados baixos em comparação aos benefícios econômicos imediatos, tornam-se significativamente mais elevados quando os impactos na saúde pública são contabilizados, fator essencial para uma pesquisa acadêmica.
Resultados - Os resultados revelam uma complexa relação entre o crescimento do PIB, investimentos em máquinas e equipamentos (FBCF), poluição e remoção de CO2 ao longo dos períodos de 2008 até 2022
Contribuições teóricas/metodológicas – A ecoinovação, em grande parte, permanece à margem das fronteiras do crescimento econômico brasileiro, devido aos crescimentos insignificantes da FBCF em relação ao PIB. Isso se deve à diminuição dos investimentos em capital fixo, ausência de certificação de Mecanismo de Desenvolvimento Limpo (MDL) por parte das empresas e à falta de empenho das autoridades políticas no combate ao problema do aquecimento global.
Contribuições sociais e ambientais – As estratégias para a formulação de políticas integradas, capazes de equilibrar objetivos econômicos, sociais e ambientais, são essenciais para promover um desenvolvimento sustentável de longo prazo. Essas políticas não apenas asseguram o bem-estar da sociedade ao mitigar os impactos negativos sobre o meio ambiente, como também fomentam a inclusão social, a equidade econômica e a preservação dos recursos naturais para as gerações futuras.

PALAVRAS-CHAVE: Ecoinovação. Crescimento econômico. Emissão e Remoção de CO2.

Eco-innovation at the Frontiers of Brazil's Economic Growth

ABSTRACT
Objective – To present eco-innovation at the frontiers of Brazil's economic growth, examining its impact through Gross Domestic Product (GDP), Gross Fixed Capital Formation (GFCF), and its relationship with pollution (CO2 equivalent) and the removal of these pollutants.
Methodology – A qualitative approach was adopted, utilizing documentary data and incorporating descriptive and explanatory analysis.
Originality/Relevance – This study emphasizes eco-innovation through GFCF and identifies critical gaps in addressing the costs of economic growth, measured via GDP, in relation to environmental pollution. While these costs are often considered low compared to immediate economic benefits, they become significantly higher when the impacts on public health are accounted for—an essential factor for academic research.
Results – The findings reveal a complex relationship between GDP growth, investments in machinery and equipment (GFCF), pollution, and CO2 removal during the period from 2008 to 2022.
Theoretical/Methodological Contributions – The study highlights that eco-innovation remains on the periphery of economic growth frontiers due to the modest growth of GFCF relative to GDP. This is attributed to reduced fixed capital investments, the lack of Clean Development Mechanism (CDM) certification by companies, and insufficient political commitment to addressing global warming.
Social and Environmental Contributions – The formulation of integrated policies that balance economic, social, and environmental objectives is crucial for promoting long-term sustainable development. Such policies not only mitigate negative environmental impacts and enhance societal well-being but also foster social inclusion, economic equity, and the preservation of natural resources for future generations.

KEYWORDS: Eco-innovation. Economic growth. CO2 emission and removal.

Periódico Eletrônico Fórum Ambiental da Alta Paulista
Electronic Journal Environmental Forum of Alta Paulista
ISSN 2966-2931 Suporte Online / *Online Support* - ISSN 1980-0827 Suporte CD-ROM / *CD-ROM Support*

Edição em Português e Inglês / *Edition in Portuguese and English* - v. 21, n. 1, 2025

Ecoinnovación en las Fronteras del Crecimiento Económico de Brasil

RESUMEN

Objetivo – Presentar la ecoinnovación en las fronteras del crecimiento económico de Brasil, midiendo su impacto a través del Producto Interno Bruto (PIB), la Formación Bruta de Capital Fijo (FBCF) con reflejo en la refexión (CO2 equivalente) y la remoción de estos contaminantes.

Metodología - La metodología adoptada es cualitativa, basada en un levantamiento documental con análisis descriptivo y explicativo

Originalidad/Relevancia – El estudio destaca la ecoinnovación a través de la FBCF y las brechas esenciales al abordar los costos del crecimiento económico mediante el PIB en relación con la contaminación ambiental. Estos costos, aunque a menudo se consideran bajos en comparación con los beneficios económicos inmediatos, se vuelven significativamente más altos cuando se toman en cuenta los impactos en la salud pública, un factor esencial para la investigación académica.

Contribuciones Teóricas/Metodológicas: La ecoinnovación, en gran medida, permanece al margen de las fronteras del crecimiento económico debido a los incrementos insignificantes de la FBCF en relación con el PIB. Esto se debe a la disminución de las inversiones en capital fijo, la ausencia de certificación del Mecanismo de Desarrollo Limpio (MDL) por parte de las empresas y la falta de compromiso de las autoridades políticas en la lucha contra el calentamiento global.

Contribuciones Sociales y Ambientales – Las estrategias para la formulación de políticas integradas, que sean capaces de equilibrar los objetivos económicos, sociales y ambientales, son fundamentales para promover un desarrollo sostenible a largo plazo. Estas políticas no solo garantizan el bienestar de la sociedad al mitigar los impactos negativos en el medio ambiente, sino que también promueven la inclusión social, la equidad económica y la preservación de los recursos naturales para las generaciones futuras.

PALABRAS CLAVE: Ecoinnovación. Crecimiento económico. Emisión y Remoción de CO2.

Periódico Eletrônico Fórum Ambiental da Alta Paulista
Electronic Journal Environmental Forum of Alta Paulista
ISSN 2966-2931 Suporte Online / *Online Support* - ISSN 1980-0827 Suporte CD-ROM / *CD-ROM Support*
Edição em Português e Inglês / *Edition in Portuguese and English* - v. 21, n. 1, 2025

1 INTRODUCTION

Since the advent of the mechanical loom to the era of the internet and mobile telephony, innovation has played a crucial role in the economic growth of many nations (Koeller *et al.*, 2019). However, environmental issues such as global warming, deforestation, and ecosystem degradation have not always been adequately considered during this process of technological evolution (Mavi *et al.*, 2022). It is in this context that eco-innovation emerges, proposing a set of innovations aimed at mitigating the adverse environmental impacts caused by human activities (Khaw *et al.*, 2023). As highlighted by Koeller *et al.* (2019), anthropogenic activities have contributed to worsening environmental problems, while eco-innovation seeks to align technological progress with sustainable economic development.

One of the main challenges in balancing innovation and sustainability is the global increase in temperatures, predominantly caused by the disruption of the carbon cycle and the growth of greenhouse gas (GHG) emissions (Haller *et al.*, 2023). These changes have triggered profound climate shifts, threatening the planet's environmental stability (Borowski, 2022). In this context, there is a growing need for awareness about the impacts of carbon dioxide (CO2) and climate change, as well as the implementation of stricter regulations. The Kyoto Protocol, for instance, compelled companies to integrate eco-innovation into their operations, production processes, and management strategies as part of an effort to mitigate these effects (Fethi and rahuma, 2020).

Eco-innovation, therefore, emerges as a response to the environmental challenge, promoting the development of technologies and processes that minimize the negative impacts of energy use, reduce CO2 emissions, and promote a cleaner and more efficient working environment for the economy (Lu, 2022). Many of these innovations are rooted in the idea of a sustainable circular economy, which seeks to restore materials and energy throughout the value chain, reduce waste, and limit emissions into the environment (Thakker and bakshi, 2023).

In this context, this research seeks to answer the following question: How does eco-innovation manifest itself at the frontiers of economic growth in Brazil, with the aim of mitigating pollution from economic activities? This study is justified by the relevance of the topic and the urgent transition that is necessary, from traditional innovation management to eco-innovation, in order to achieve sustainable results from both an economic and social perspective.

Although some level of pollution may be considered socially acceptable – that is, as long as nature can recycle it efficiently (Khan and Idrees, 2023) – the problem arises when companies neglect the associated social costs, overlooking the significant increase in these impacts (Haller *et al.*, 2023). With growing awareness of the importance of adopting measures that minimize environmental damage, it is imperative that companies improve their management practices and incorporate environmentally friendly technologies and practices. The implementation of sustainable solutions is no longer an option but has become an urgent necessity in contemporary society (Haller *et al.*, 2023).

In this study, eco-innovation is considered in alignment with the Sustainable Development Goals (SDGs), particularly SDG 9, which addresses innovation and infrastructure; SDG 8, related to decent work and economic growth; and SDG 13, focused on climate action

(United Nations Brazil, 2016). Additionally, Scolari and Strauhs (2024) argue that the SDGs provide opportunities for sustainability studies in academia. Thus, eco-innovation has the potential to contribute to these studies, achieve environmental goals, and minimize negative externalities, such as pollution (Khan and Idrees, 2023), thereby promoting social well-being. Furthermore, it plays a fundamental role in strengthening the sustainable circular economy, offering competitive advantages in the market, and driving sustainable economic growth (Thakker and Bakshi, 2023).

This introduction lays the foundation for the structure of the article, organized into key sections. First, it presents a theoretical review of the concept of eco-innovation, focusing on the most recent academic and policy discussions. Next, the general objective of the research is outlined, followed by a description of the methodology used, which details the steps of the research process. Subsequently, the results obtained are analyzed and discussed, highlighting the practical implications of eco-innovation. Finally, the article concludes with final reflections on the research findings and a list of references that support the study.

1.1 Vision of Eco-Innovation to Mitigate Greenhouse Gas Emissions

In Brazil, the adoption of the Sustainable Development model gained prominence during the United Nations Conference on Environment and Development (UNCED-92), held in Rio de Janeiro in 1992 and organized by the United Nations Environment Programme (UNEP) (Barbieri, 1997). This event resulted in several important documents, among which Agenda 21 stands out (Coutinho, 2014).

The CNUMAD-92 was a milestone in raising global awareness of environmental issues, and the United Nations General Assembly responded to calls from society and public officials on climate change by establishing the Intergovernmental Negotiating Committee for the Framework Convention on Climate Change (INC/FCCC). This committee, formed during the conference, played a key role in formulating the foundations that would later lead to the creation of the Kyoto Protocol (1997), one of the first major international agreements aimed at reducing greenhouse gas emissions (Kyoto Protocol, 1997).

Over the following decades, other important conventions took place, including the Copenhagen Agreement and the Paris Agreement, which deepened global commitments to combat climate change (ETHOS, 2016). More recently, the European Green Deal was launched with the aim of making Europe the first continent to achieve climate neutrality by 2050 (Haller *et al.*, 2023). This deal not only reaffirms the commitment to sustainability but also seeks to boost post-crisis economic recovery by promoting a green and sustainable economy. The European Green Deal is seen as a precursor to global strategies aimed at developing a green economy, consolidating the vision that economic growth and environmental protection are not mutually exclusive but can be complementary (Koeller *et al.*, 2019).

This evolution of international agreements reflects a growing understanding that sustainability is essential for the future of nations. Policies focused on eco-innovation and the circular economy play a key role in building a global economy that balances economic growth and sustainability, even in the face of environmental challenges. The transition to a green economy requires adopting new technologies and practices driven by innovations that aim to reduce emissions and conserve natural resources.

According to Koeller *et al*. (2019), the greening of the economy, global mobilizations, and discussions about resource scarcity and the mitigation of greenhouse gas emissions have been directed toward strategies involving solutions based on innovation and sustainable technological development. The goal is to achieve "green production," which, aligned with eco-innovation (Lu, 2022), involves developing goods and processes that encourage more sustainable production and consumption practices through technical advances. This approach focuses on using more advanced technologies compared to traditional ones (Sierzchula *et al*., 2014), aiming to significantly reduce environmental impacts.

However, for clean technologies to be developed and disseminated on a large scale, political intervention is necessary but insufficient (veugelers, 2012). Innovation policies alone do not guarantee success; it is essential that society as a whole embraces innovation. Without societal support, an unfavorable environment for progress is created (Khan and Idrees, 2023). Additionally, these clean technologies directly compete with already established polluting technologies. As Veugelers (2012) notes, the specifics of implementing technologies in the production process often determine whether these innovations will be adopted on a large scale.

Koeller *et al*. (2019) highlight that environmental pollution is not only a consequence of economic growth but also of changes in technological patterns, which often involve intensive energy use and the emission of pollutants. Clean technologies, such as renewable energy generation (Chien *et al*., 2023; Anderhofstadt and Spinler, 2019), waste management innovation (Puertas and Marti, 2021), and using recycled materials (Bocken *et al*., 2012), have proven to be fundamental in this transition. In contrast, so-called "dirty Technologies" still dominate many sectors, such as coal and oil burning, which remain among the largest contributors to environmental pollution (Veugelers, 2012).

This scenario reveals the urgency of accelerating the transition to clean technologies while overcoming resistance from industries that heavily rely on polluting energy sources. The efficiency of clean technologies, compared to dirty ones, presents significant contrasts that benefit various sectors, including the economy, the environment, and society (Fuchsová, 2013; Chien *et al*., 2023).

These contrasts are evident in cost reduction, sustainability, energy efficiency, innovation, and job creation. These differences highlight the importance of investing in clean technologies as an essential strategy for driving sustainable development. Eco-innovation, through this transition, not only promotes economic prosperity but also protects the environment for future generations (Padhan *et al*., 2023).

Although eco-innovation is known by various terms, such as environmental innovation, ecological innovation, sustainable innovation, and green innovation, these approaches share the common goal of preserving natural resources, minimizing waste, and promoting renewable energy sources (Mavi *et al*., 2022). Eco-innovation, which incorporates the environmental dimension into innovation, as Koller *et al*. (2020) state, has become a key strategy for sustainable development and economic growth, representing solutions intentionally designed to reduce the environmental impact of production, consumption, and disposal activities, leveraging opportunities and benefits associated with environmental concerns (Saturnino Neto *et al.*, 2014).

Companies committed to sustainability seek, through their management, to replace conventional innovative technologies with eco-innovation. These eco-innovations stand out from other products and services by having a lower environmental impact compared to conventional technologies. Thus, eco-innovation is defined as "new or improved techniques, processes, practices, and products that aim to reduce or prevent environmental problems" (Khaw *et al.*, 2023). This definition reinforces the need for a collective commitment to innovative practices that not only benefit businesses but also ensure a sustainable future for the planet.

In this context, companies committed to sustainability are transitioning from conventional technologies to eco-innovation (Sierzchula *et al.*, 2014). This transition is necessary to promote the mitigation of greenhouse gas emissions alongside sustainable economic growth, as stated by Saturnino Neto *et al*. (2014). According to Masiero *et al*. (2023), climate mitigation involves preventing the factors that cause climate change. In this regard, eco-innovation, applied to sustainability management, encompasses activities focused on measuring, analyzing, and improving economic, social, and environmental performance (Khan and Idrees, 2023). Such practices provide actions to mitigate greenhouse gas emissions, generating long-term benefits for the climate. Furthermore, these initiatives contribute to environmental preservation and promote the creation of lasting value for businesses.

However, adopting environmental strategies at the business level requires long-term commitments, particularly concerning financing and the return on investment in eco-innovation, which often materializes only in the long term (Fethi and Rahuma, 2020). Investments in eco-innovation can be challenging, as the benefits associated with pollution reduction do not always reflect in the final product's price (Sierzchula *et al.*, 2014). Nevertheless, as highlighted by Khan and Idrees (2023), eco-innovation not only reduces production costs but can also drive economic growth by addressing issues such as biodiversity loss, resource scarcity, and climate change.

As many companies adapt to prioritize eco-innovation in their social systems (Khaw *et al.*, 2023), future expectations include the influence of carbon pricing and regulations, which could become key factors in stimulating research, development, and the adoption of clean technologies by the private sector (Veugelers, 2012). This dynamic drives innovation and establishes a new business paradigm where sustainability and profitability go hand in hand, creating a virtuous cycle that benefits both companies and society.

2 OBJECTIVE

This article aims to highlight eco-innovation at the forefront of Brazil's economic growth by analyzing Gross Domestic Product (GDP), gross fixed capital formation (GFCF), pollution emissions, and removals (CO2). Additionally, it examines CO2 removals achieved through companies certified under the Clean Development Mechanism (CDM) in Brazil.

3 METHODOLOGY

This study adopted a qualitative approach, utilizing data from reports and websites of agencies responsible for collecting and disseminating information on society and the economy. The data collection enabled a descriptive and explanatory characterization of the dynamics of the proposed study within the Brazilian context, focusing on technologies recorded and reflected in Brazil's social accounting, particularly through Gross Fixed Capital Formation (GFCF).

The decision to use Gross Fixed Capital Formation (GFCF) as an indicator is based on the statistical standards established by the Oslo Manual (OECD and EUROSTAT, 2018). This manual considers investments in capital goods as a key metric for measuring innovation. Therefore, incorporating this data into the study is justified, as it allows for the observation of advancements in machinery and equipment used in companies' production processes and their impacts on pollutant emissions.

As noted by the Brazilian Institute of Geography and Statistics (IBGE, 2020), a portion of the GFCF data relates to investments in machinery and equipment, which constitute investments in capital goods in the economy. These investments form one of the variables in Formula 1 of the Gross Domestic Product (GDP). Gross Domestic Product (GDP), a widely used measure in social and national accounting as well as in macroeconomics, is calculated using the following formula (Feijó and Ramos, 2017; Lopes and Vasconcelos, 2000):

Formula (1)

$$\mathbf{GDP} = C+\mathbf{I}+G+X+M-X$$

Where:

C = Total consumption
I = Total investment
G = Government spending
M = Imports
X = Exports

In this context, the investment component (I) corresponds to companies purchasing investment goods to increase their capital stock and replace existing capital as it depreciates, reflecting innovation within the study. Additionally, the investments included in GDP are derived from GFCF minus inventory variation, as represented in Formula 2 (Feijó and Ramos, 2017):

Formula (2)

$$\mathbf{I}= GFCF - VE$$

Where:

I = Investment
GFCF = Gross Fixed Capital Formation
VE = Inventory variation

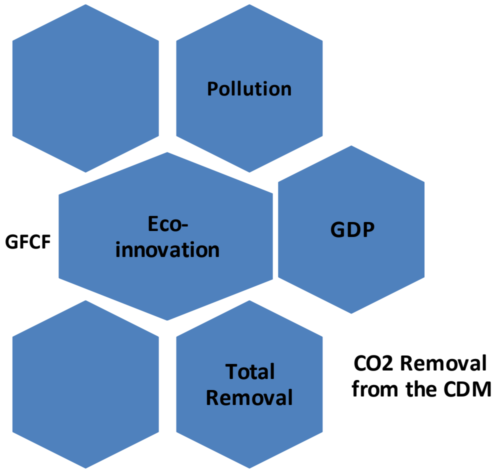
This study focuses on the investment (I) variable, which pertains to companies acquiring investment goods to expand their capital stock and replace existing capital as it wears

Periódico Eletrônico Fórum Ambiental da Alta Paulista
Electronic Journal Environmental Forum of Alta Paulista
ISSN 2966-2931 Suporte Online / *Online Support* - ISSN 1980-0827 Suporte CD-ROM / *CD-ROM Support*
Edição em Português e Inglês / *Edition in Portuguese and English* - v. 21, n. 1, 2025

out (Lopes and Vasconcelos, 2000). Therefore, investment was chosen as an indicator to reflect innovation activities.

In the data collection process, various factors were considered, including pollution, GDP, GFCF, pollution removal (CO2) from the Greenhouse Gas Emissions and Removals Estimation System (SEEG), and pollution removal (CO2) from the Clean Development Mechanism (CDM). These elements are represented and defined in Figure 1.

Figure 1: Data collected from the study in Brazil



Definition of the data collected	Description
Gross Domestic Product (GDP)	Represents the sum of economic activities and the economic growth of a country or region over a given period (FEIJÓ and RAMOS, 2017). Data for this study were extracted from IBGE for the period from 2008 to 2022.
Gross Fixed Capital Formation (GFCF)	Refers to investment goods and services, a widely recognized concept in the economic literature on social accounting (FEIJÓ and RAMOS, 2017). Includes machinery, equipment, labor, and other elements of economic activity. Data were extracted from Cidades@ IBGE for the period from 2008 to 2022.
Pollution (CO2e(t)	Derived from economic activity categories highlighted by the Greenhouse Gas Emissions and Removals Estimation System (SEEG, 2023), including sectors such as industrial processes, waste, energy, agriculture, and land-use change. Measured in CO2e(t) GWP-Ar5 (100-year global warming potential from the 5th IPCC Report). Data were collected from SEEG for the period from 2008 to 2022.
Removal (CO2e(t)	Includes CO2e(t) removal data measured in GWP-Ar5, provided by SEEG. Covers soil organic carbon, removals in protected areas, removals from land-use changes, and removals by secondary vegetation. Data were available from 2008 to 2021. Data for 2022 is not yet available.
Companies Certified for CO2e(t) Removal under the Clean Development Mechanism (CDM)	In Brazil, data were obtained from the CDM Status Report by the Ministry of Science, Technology, Innovation, and Communication (MCTIC). Covers the period from 2008 to 2017. More recent data are unavailable due to the suspension of projects under the Brazilian CDM since November 29, 2021, which effectively terminated the mechanism.

Source: Prepared by the authors, based on IBGE, SEEG, and MCTIC, 2023.

The data extracted from the mentioned sources reflect the performance and relationship between economic growth activities and GDP, as well as the role of machinery and equipment represented by GFCF. This information is crucial for understanding the extent to which innovation and eco-innovation are incorporated into the production processes of companies in Brazil, including the expansion or contraction of pollution and carbon removals, as well as the certification of companies under the CDM.

The data collection aims to analyze eco-innovation at the frontiers of economic growth, examining the relationship between economic growth and the use of machinery and equipment, as indicated by GFCF. These insights help to understand the processes of innovation and eco-innovation in the production activities of Brazilian companies. Additionally, the data includes observations on pollution emissions (CO2e), soil organic carbon removals, removals in protected areas, removals by land-use changes, and removals by vegetation, as well as the participation of companies certified under the CDM in Brazil.

The collection and organization of the data facilitated the creation of a structured database, the preparation of figures, and the execution of descriptive statistical analyses to achieve the objectives of this study. These analyses were conducted using Microsoft Excel. To examine the relationship between Gross Fixed Capital Formation (GFCF) and Gross Domestic Product (GDP), the methodology employed was based on that of the Brazilian Institute of Geography and Statistics (IBGE, 2020), as represented in Formula 3:

Formula (3)

$$\text{Relationship} = \left(\frac{GFCF}{GDP}\right) * 100$$

The analysis of the data provided insights into the relationship between economic growth (GDP) and pollution in real monetary values (R$), using Formula 4. This formula calculates the monetary value of economic growth per unit of pollution (in tons) by dividing the GDP by the total pollution. The resulting value represents the economic growth associated with each ton of pollution. By applying Formulas 3 and 4, we were able to determine the costs and benefits linked to the lack of adoption of eco-innovation within the Brazilian context.

Formula (4)

$$\text{VP} = \frac{\boldsymbol{GDP}}{\boldsymbol{Tonpollution}}$$

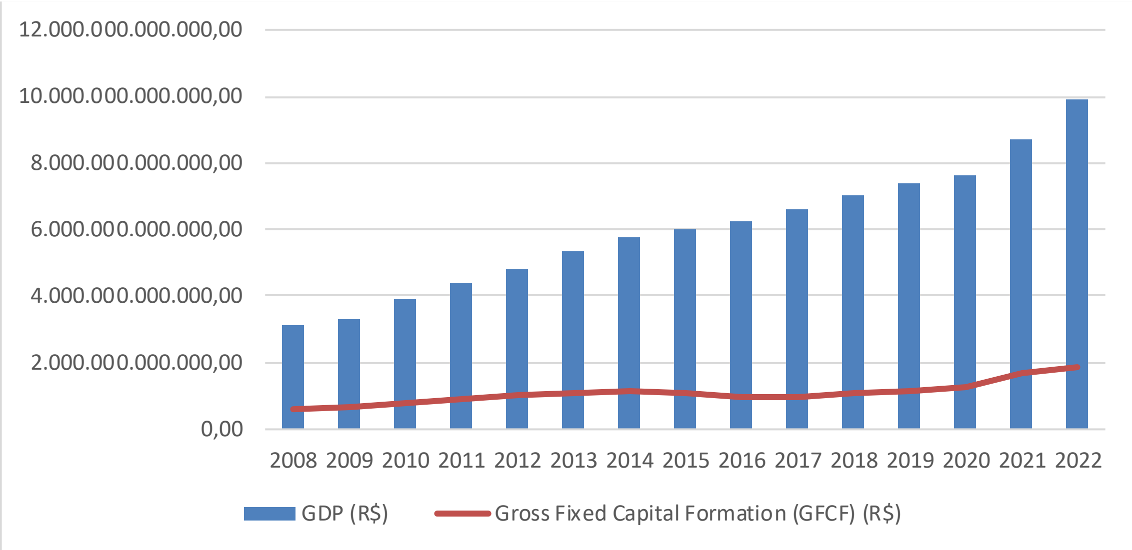
Where:

VP = Values (R$) of economic growth relative to pollution in tons.

4. ANALYSIS OF RESULTS

This study aims to explore the interaction between eco-innovation and economic growth in Brazil, considering variables such as GDP, pollution (CO2), and pollution removal. Brazil, with its vast natural diversity and geopolitical particularities, sustains a diversified production process that includes the production of final goods and services. Figure 2 presents the share of GFCF in Brazilian GDP from 2008 to 2022, revealing continuous GDP growth during the studied years, alongside fluctuations in the contribution of machinery and equipment to Brazilian GDP. These variations reflect the policies adopted during different periods.

Figure 2: Gross Domestic Product (GDP) and Gross Fixed Capital Formation (GFCF) of Brazil



Source: Prepared by the authors, based on IBGE data (2023).

In Figure 2, the relationship between Gross Fixed Capital Formation (GFCF) and Gross Domestic Product (GDP) is analyzed. A notable peak in 2013 shows GFCF contributing 20.9% to GDP. However, this share declined to 15.5% by 2019. A slight increase was observed in 2020, reaching 16.6%. Growth in GFCF between periods was modest, with an increment of 1.1431% from 2018 to 2019 and 1.866% from 2021 to 2022.

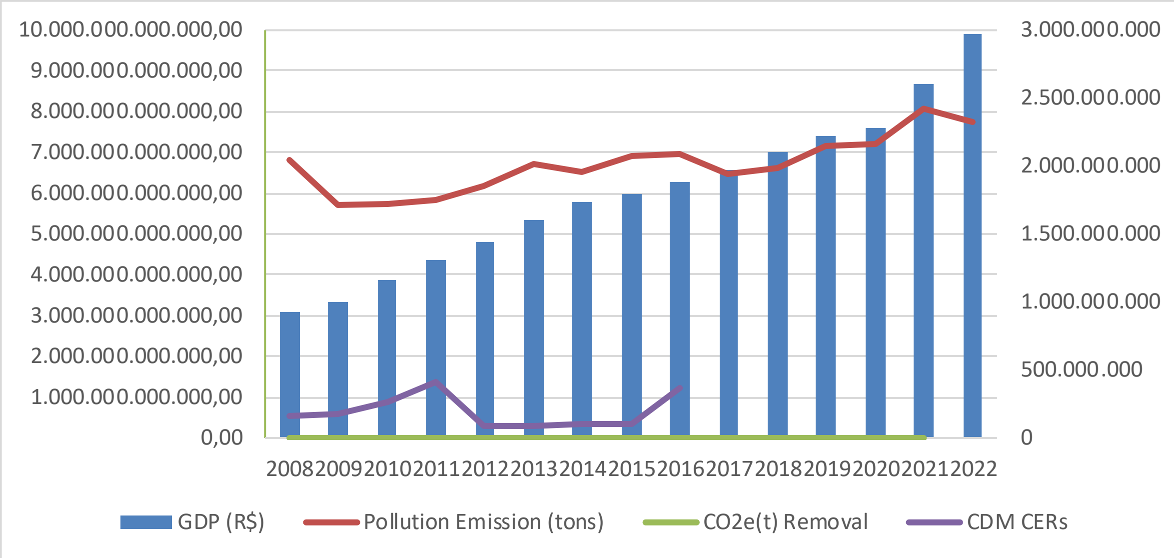
The share of GFCF in GDP is significant as it represents investments in the economy, indicating an increase in machinery and equipment use within production activities. This demonstrates advancements in innovation and modernization of production processes (OECD and EUROSTAT, 2018; Thakker and Bakshi, 2023). These investments are pivotal in implementing changes in products or processes, whether through new or improved methods.

Eco-innovation, in this context, introduces a set of innovations aimed at reducing environmental impacts (Haller et al., 2023). These innovations include products designed with environmentally responsible materials, processes, and designs to reduce pollution (Khaw et al., 2023).

Figure 3 provides an overview of GDP, carbon dioxide equivalent (CO2e) emissions (GWP-Ar5), CO2 reductions, and reductions achieved by companies certified under the Clean Development Mechanism (CDM) in Brazil. Emissions originate from industrial processes, waste, energy, agriculture, and land-use changes. CO2 reductions encompass soil organic carbon, protected areas, land-use changes, and secondary vegetation. Data were sourced from SEEG (2023) and MCTIC reports.

Periódico Eletrônico Fórum Ambiental da Alta Paulista
Electronic Journal Environmental Forum of Alta Paulista
ISSN 2966-2931 Suporte Online / *Online Support* - ISSN 1980-0827 Suporte CD-ROM / *CD-ROM Support*
Edição em Português e Inglês / *Edition in Portuguese and English* - v. 21, n. 1, 2025

Figure 3 - Gross Domestic Product, Pollution Emission, CO2e(t) Removal, and Emission Reduction Certificates of CDM Companies in Brazil



Source: Prepared by the authors, based on data from IBGE (2023), SEEG (2023), and the CDM Status Report from the Ministry of Science, Technology, Innovation, and Communication (MCTIC).

In Figure 3, an inverse relationship is observed, in just a few years of study, between Gross Domestic Product (GDP) and pollution, indicating that as GDP increases, pollution showed a 3% reduction from 2013 to 2014. In previous years, pollution was predominantly higher than Brazil's economic output. In 2016, an additional 7% decrease in emissions occurred in the country, while in the following years, small increases in pollution emissions were recorded, culminating in an 8% decrease in 2019 alone.

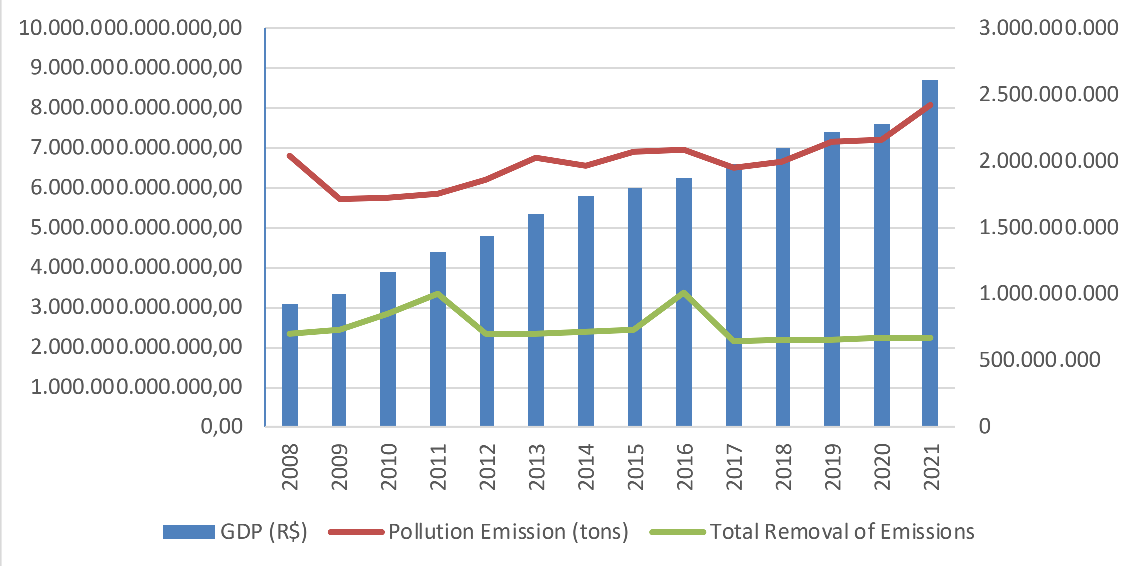
The study highlights the relevance of the Kyoto Protocol, established in 1997, which commits developed and developing countries to reduce their gas emissions by 5.2% based on 1990 emission levels during the period from 2008 to 2012 (KYOTO PROTOCOL, 1997). As shown in Figure 2, Brazil began to show responses starting in 2017, with the share of gross fixed capital formation (GFCF) in relation to GDP growing significantly in 2013, reaching 20.9%. This share fluctuated until 2017, with investments contributing 14.6% of GDP, as illustrated in Figure 2.

Regarding CO2e removals in tons, which reflect pollution, these are almost negligible compared to CO2e emissions in tons. On the other hand, removals from a set of companies certified by the Clean Development Mechanism (CDM) show a more significant contribution. They peaked at 421,197,677 tons of CO2 removed in 2011, with fluctuations throughout the study years, decreasing to 374,868,055 tons in 2017 in Brazil. Unfortunately, due to the lack of data and the suspension of CDM projects, the absence of CO2 removals is evident, which plays a fundamental role in mitigating greenhouse gases.

Figure 4 illustrates the scenario encompassing the sum of organic carbon removals from soil, removals in protected areas, removals by land-use change, and removals by secondary vegetation, along with removals by CDM-certified companies. This chart shows a trend line that stands out with the interrelationship between removals, pollution, and GDP.

Periódico Eletrônico Fórum Ambiental da Alta Paulista
Electronic Journal Environmental Forum of Alta Paulista
ISSN 2966-2931 Suporte Online / *Online Support* - ISSN 1980-0827 Suporte CD-ROM / *CD-ROM Support*
Edição em Português e Inglês / *Edition in Portuguese and English* - v. 21, n. 1, 2025

Figure 4 - Gross Domestic Product (GDP), Pollution Emissions, and Total Pollution Removal in Brazil



Source: Prepared by the authors, based on data from IBGE (2023), SEEG (2023), and the CDM Status Report from the Ministry of Science, Technology, Innovation, and Communication (MCTIC).

When considering the relationship between pollution emissions (CO2) in tons and total removals in tons, we highlight the mitigation of greenhouse gases in Brazil. Since 2018, pollution has been below the level of economic growth, reflecting technological changes in Brazil driven by innovation and eco-innovation, as evidenced by the increase in Gross Fixed Capital Formation (GFCF), with the aim of reducing greenhouse gas emissions. However, it is alarming that the lack of data and the suspension of the Brazilian Clean Development Mechanism (CDM) have impacted the ability of companies to adapt their processes through eco-innovation. This emphasizes the importance of eco-innovation as a crucial strategy for Brazil's sustainable economic growth, which faces challenges related to climate change.

When analyzing the relationship between economic growth and the amount of pollution emitted, it becomes evident that pollution increases as a result of economic growth. The search for pollution mitigation aims to reverse this trend by promoting innovations such as eco-innovation. In this context, Table 1 provides a quantitative view of economic growth in relation to pollution, expressed in monetary values over the years of the study. It is possible to observe how the value of economic growth behaves in relation to pollution levels.

It is important to note that the real cost of pollution goes beyond the values presented in Table 1, as it does not encompass the impacts on human health. These costs are not reflected in the results presented, being limited to the productive sectors of the economy. It is imperative to consider these additional costs when assessing the true economic and social impact of pollution, highlighting the importance of sustainable approaches for mitigation and prevention.

Table 1 - Cost of Economic Growth by Pollution (CO2e) in Tons

Year	Cost of Pollution in (t)
2008	R$ 1.525,01
2009	R$ 1.944,42
2010	R$ 2.257,43
2011	R$ 2.493,60
2012	R$ 2.590,39
2013	R$ 2.640,74
2014	R$ 2.945,26
2015	R$ 2.8889,29
2016	R$ 2.999,70
2017	R$ 3.384,23
2018	R$ 3.520,71
2019	R$ 3.440,79
2020	R$ 3.522,86
2021	R$ 3.591,15

Source: Prepared by the authors, based on available data from IBGE (2023) and SEEG (2024).

When analyzing the graphs representing the evolution of economic growth over time and the corresponding trend in pollution, as shown in Figures 2, 3, and 4, Table 1 clearly demonstrates the progressive increase in the value of economic growth in relation to pollution, in monetary terms. This phenomenon arises from a series of factors, one of which is environmental regulation resulting from public policies, including taxes that can influence whether or not Gross Domestic Product (GDP) increases, as indicated by Formula 1, through government action (G), among others.

In 2021, the cost of growth due to pollution, as shown in Table 1, reached R$3,591.15 per ton, a value that, although it may seem insignificant at first glance, does not fully capture the damage caused to health, social well-being, and the environment. It is crucial to recognize that this figure does not comprehensively reflect the adverse impacts on these aspects. However, it provides an initial perspective on how political authorities can establish values to penalize companies that emit pollution on a large scale. This understanding is fundamental for the implementation of policies and practices aimed not only at economic measurement but also at a comprehensive consideration of the social and environmental costs associated with pollution.

It is important to emphasize that as technological changes become innovative through eco-innovation, with considerable investments and long-term returns (Khaw et al., 2023), social well-being is strengthened and sustainability gains ground over time. Countries, including those in development, have the opportunity to promote sustainable economic development through eco-innovation (Khan and Idrees, 2023). Assessing eco-innovation is a complex challenge, as it involves a series of product innovations, technological advancements, innovations in production processes, and market adaptation to changes in production (Mavi et al., 2022).

5 CONCLUSION

In the current scenario, eco-innovation emerges as a central element in reducing negative environmental impacts and promoting social well-being. To fully leverage the benefits of eco-innovation, it is essential for political authorities to uphold economic and environmental sustainability guidelines in collaboration with society, demonstrating a strong commitment to stringent environmental policies and concrete actions to combat climate change. It is urgent that Brazil reconsiders its involvement in Clean Development Mechanism (CDM) activities, as highlighted in Figures 2, 3, and 4.

The presented data reveal relationships between economic growth, measured by Gross Domestic Product (GDP), Gross Fixed Capital Formation (GFCF)—represented by machinery, equipment, and labor—carbon dioxide (CO2) emissions (a reflection of pollution), and CO2 reduction efforts. Although GDP increased, the share of GFCF grew at a smaller proportion, contributing to a 12.6% rise in CO2 emissions, increasing from 2,165,003 tons in 2020 to 2,422,625,065 tons in 2021. Furthermore, between 2019 and 2020, pollution emissions (CO2e in tons) rose by only 0.58%, demonstrating that innovation, including eco-innovation, is closely tied to Brazil's economic growth rate during the studied years.

These numbers highlight the urgent need to raise awareness among the population and productive sectors about the importance of pollution mitigation in Brazil. Eco-innovation proves to be a vital strategic tool for the Brazilian economy. Only through continuous commitment and coordinated action among the government, society, and the private sector can Brazil aspire to a more sustainable and equitable future.

The figures, alongside Table 1, show that the rising cost of economic growth relative to pollution reached R$3,591.15 per ton in 2021. This phenomenon stems from a combination of factors, including environmental regulation and externalities. Although this value may seem modest at first glance, it fails to adequately capture the damage caused to health, social well-being, and the environment. This serves as a wake-up call for public policymakers, underscoring the need for effective measures to mitigate greenhouse gas emissions.

It is crucial to acknowledge that this value does not fully reflect the adverse impacts across the aforementioned domains. However, this discussion serves as an important indication of how political authorities could impose financial penalties on companies that emit pollution on a large scale. Penalizing environmental negative externalities could encourage more sustainable and responsible corporate practices. These insights should form the basis for implementing stricter environmental policies and fostering greater awareness about the importance of pollution reduction. Only through such measures can negative environmental impacts be minimized while ensuring enhanced well-being for society and future generations.

As a direction for future research, expanding data collection specifically related to innovation and eco-innovation aimed at reducing CO2 emissions in Brazil is crucial. Moreover, conducting an in-depth analysis of the costs of pollution and its social and environmental impacts is imperative. Additionally, further investigation into the strategies adopted by companies to implement eco-innovation, including costs and investments, will provide valuable insights. These studies will enable a more comprehensive understanding of trends and practices related to greenhouse gas emission reductions in Brazil. By carefully analyzing corporate strategies, it will be possible to identify the most effective approaches and the challenges faced in adopting eco-innovation, paving the way for more targeted and impactful future studies.

6 BIBLIOGRAPHICAL REFERENCE

ANDERHOFSTADT, B.; SPINLER, S. Factors affecting the purchasing decision and operation of alternative fuel-powered heavy-duty trucks in Germany – A Delphi study. **Transportation Research Part D: Transport and Environment**. Elsevier Ltd, 2019. Available at: https://doi.org/10.1016/j.trd.2019.06.003. Accessed: 20 set. 2024.

BARBIERI, J. C. **Desenvolvimento e meio ambiente: as estratégias de mudanças da agenda 21**. Petrópolis, RJ: Vozes, 1997.

BOCKEN, N. M. P.; ALLWOOD, J. M.; WILLEY, A. R.; KING, J. M. H. Development of a tool for rapidly assessing the implementation difficulty and emissions benefits of innovations. **Technovation**, 2012. Available at: https://doi.org/10.1016/j.technovation.2011.09.005. Accessed: 20 set. 2024.

BOROWSKI, P. F. Management of energy enterprises in zero-emission conditions: Bamboo as an innovative biomass for the production of green energy by power plants. **Energies**, MDPI, 2022. DOI 10.3390/en15051928. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85127433627&doi=10.3390%2fen15051928&partnerID=40&md5=7329d23383c40a9d2520563d17ae84df. Accessed: 20 set. 2024.

COUTINHO, S. M. V.; CEZARE, J. P.; PHILIPPI Jr., A. Desafio da gestão ambiental pública urbana na América Latina no contexto das mudanças climáticas. In: PHILIPPI Jr., A. (Org.). **Mudanças climáticas: do global ao local**. Barueri: Manole, 2014.

CHIEN, F.; CHAU, K. Y.; SADIQ, M. The effect of energy transition technologies on greenhouse gas emissions: New evidence from ASEAN countries. **Sustainable Energy Technologies and Assessments**, v. 58, 2023. DOI 10.1016/j.seta.2023.103354. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85164223224&doi=10.1016%2fj.seta.2023.103354&partnerID=40&md5=ade64a0db5e2bf77d9871787f8e8a00f. Accessed: 20 set. 2024.

CHIEN, F. S.; PARAMAIAH, C.; JOSEPH, R.; PHAM, H.; PHAN, T.; NGO, T. The impact of eco-innovation, trade openness, financial development, green energy and government governance on sustainable development in ASEAN countries. **Renewable Energy**, v. 211, p. 259–268, jul. 2023. Available at: https://doi.org/10.1016/j.renene.2023.04.109. Accessed: 20 set. 2024.

ETHOS Ambiental. COP 22 - Os resultados da primeira COP pós Paris. 2016. Available at: https://www3.ethos.org.br/cedoc/cop-22-os-resultados-da-primeira-cop-pos-paris/. Accessed: 05 dez. 2017.

FEIJÓ; RAMOS (Orgs.). **Contabilidade social: referência atualizada das contas nacionais do Brasil**. 5. ed. Rio de Janeiro: Elsevier, 2017.

FETHI, S.; RAHUMA, A. The impact of eco-innovation on CO2 emission reductions: Evidence from selected petroleum companies. **Structural Change and Economic Dynamics**, v. 53, p. 108–115, jun. 2020. Available at: https://doi.org/10.1016/j.strueco.2020.01.008. Accessed: 20 set. 2024.

FUCHSOVÁ, E. Environmental tax reform scenarios analysis. **E a M: Ekonomie a Management**, v. 16, n. 3, p. 47–56, 2013.

HALLER, H. et al. Climate neutrality through economic growth, digitalisation, eco-innovation and renewable energy in European countries. **Kybernetes**, Emerald Publishing, 2023. DOI 10.1108/K-09-2022-1254. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85145375334&doi=10.1108%2fK-09-2022-1254&partnerID=40&md5=d0d4c99f3a59b248482e95caeb83845e. Accessed: 20 set. 2024.
IBGE. **Formação Bruta de Capital Fixo**. Notas Metodológicas, v. 1, 2020.

KHAN, A.; IDREES, A. S. Environmental impact of multidimensional eco-innovation adoption: an empirical evidence from European Union. **Journal of Environmental Economics and Policy**, 2023. DOI 10.1080/21606544.2023.2197626. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85152444599&doi=10.1080%2f21606544.2023.2197626&partnerID=40&md5=7e8b67b76a7bc0c7b0057ab37d6563b2. Accessed: 20 set. 2024.

KHAW, K. W. et al. Benchmarking electric power companies' sustainability and circular economy behaviors: using a hybrid PLS-SEM and MCDM approach. **Environment, Development and Sustainability**, 2023. DOI 10.1007/s10668-023-02975-x. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85147948998&doi=10.1007%2fs10668-023-02975-x&partnerID=40&md5=fcb394644034933acf1fb53e46cccc37. Accessed: 20 set. 2024.

KOELLER, P. et al. Ecoinovação: revisitando o conceito. In: **IV ENCONTRO NACIONAL DE ECONOMIA INDUSTRIAL E INOVAÇÃO**, ago. 2019, Campinas. Blucher Engineering Proceedings. Campinas: Editora Blucher, ago. 2019. p. 695–712. DOI 10.5151/iv-enei-2019-5.3-026. Available at: http://www.proceedings.blucher.com.br/article-details/33173. Accessed: 12 ago. 2023.

LOPES, L. M.; VASCONCELOS, M. A. S. D. **Manual de macroeconomia: básico e intermediário**. Atlas, 2000.
LU, Y. Modelling the role of eco innovation, renewable energy, and environmental taxes in carbon emissions reduction in E-7 economies: Evidence from advance panel estimations. **Renewable Energy**, v. 190, p. 309–318, maio 2022. Available at: https://doi.org/10.1016/j.renene.2022.03.119. Accessed: 20 set. 2024.

MASIERO, É.; MENEGALDO, V.; TAVARES, S. G. Análise crítica dos planos municipais de adaptação e mitigação às mudanças climáticas. **Periódico Eletrônico Fórum Ambiental da Alta Paulista**, v. 19, n. 4, 15 nov. 2023. DOI 10.17271/1980082719420234328. Available at: https://publicacoes.amigosdanatureza.org.br/index.php/forum_ambiental/article/view/4328. Accessed: 27 dez. 2024.

MAVI, R. et al. Eco-innovation analysis of OECD countries with common weight analysis in data envelopment analysis. **Supply Chain Management - an International Journal**, v. 27, n. 2, p. 162–181, 17 fev. 2022. Available at: https://doi.org/10.1108/SCM-01-2021-0038. Accessed: 20 set. 2024.

MCTI - Ministério da Ciência Tecnologia e Inovação. **Atividades de Projetos de MDL Aprovados nos Termos da Resolução Nº1**. Brasília, 2014.

MCTI - Ministério da Ciência Tecnologia e Inovação. **Mecanismo de Desenvolvimento Limpo (MDL)**. Available at: https://antigo.mctic.gov.br/mctic/opencms/ciencia/SEPED/clima/mecanismo_de_desenvolvimento_limpo/Mecanismo_de_Desenvolvimento_Limpo.html. Accessed: out. 2023.

NAÇÕES UNIDAS BRASIL. **Objetivos de Desenvolvimento Sustentável**. 2016. Available at: https://brasil.un.org/pt-br/sdgs. Accessed: 10 jun. 2024.

PADHAN, H.; GHOSH, S.; HAMMOUDEH, S. **Renewable energy, forest cover, export diversification, and ecological footprint: a machine learning application in moderating eco-innovations on agriculture in the BRICS-T economies**. Environmental Science and Pollution Research, 2023. DOI 10.1007/s11356-023-27973-4. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85162691745&doi=10.1007%2fs11356-023-27973-4&partnerID=40&md5=14b9bb17b9db5b629041a929874d0d38. Accessed: 12 ago. 2023.

PROTOCOLO DE QUIOTO. **Protocolo de Quioto**. 1997. Accessed: 2 out. 2023.

OECD; EUROSTAT. **Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation**, 4th Edition. OECD, 2018. (The Measurement of Scientific, Technological and Innovation Activities). DOI 10.1787/9789264304604-en. Available at: https://www.oecd-ilibrary.org/science-and-technology/oslo-manual-2018_9789264304604-en. Accessed: 12 ago. 2023.

PADHAN, H.; GHOSH, S.; HAMMOUDEH, S. **Renewable energy, forest cover, export diversification, and ecological footprint: a machine learning application in moderating eco-innovations on agriculture in the BRICS-T economies**. Environmental Science and Pollution Research. Springer Science and Business Media Deutschland GmbH, 2023. DOI 10.1007/s11356-023-27973-4. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85162691745&doi=10.1007%2fs11356-023-27973-4&partnerID=40&md5=14b9bb17b9db5b629041a929874d0d38. Accessed: 12 ago. 2023.

PUERTAS, R.; MARTI, L. **Eco-innovation and determinants of GHG emissions in OECD countries**. Journal of Cleaner Production, v. 319, 15 out. 2021. DOI 10.1016/j.jclepro.2021.128739. Available at: https://doi.org/10.1016/j.jclepro.2021.128739. Accessed: 12 ago. 2023.

SATURNINO NETO, A.; JABBOUR, C. J. C.; JABBOUR, A. B. L. S. **Green training supporting eco-innovation in three Brazilian companies: practices and levels of integration**. Industrial and Commercial Training, v. 46, n. 7, p. 387–392, 1 jan. 2014. DOI 10.1108/ICT-02-2014-0010. Available at: https://doi.org/10.1108/ICT-02-2014-0010. Accessed: 4 fev. 2024.

SCOLARI, B. S.; STRAUHS, F. D. R. Contribuições da Geração Fotovoltaica no Alcance dos Objetivos de Desenvolvimento Sustentável. **Periódico Eletrônico Fórum Ambiental da Alta Paulista**, v. 20, n. 2, 28 abr. 2024. DOI 10.17271/1980082720220244195. Available at: https://publicacoes.amigosdanatureza.org.br/index.php/forum_ambiental/article/view/4195. Accessed: 27 dez. 2024.

SEEG. **Análise das Emissões de Gases de Efeito Estufa: e suas implicações para as metas climáticas do Brasil**. Observatório do Clima, 2023. Accessed: 4 fev. 2024.

SIERZCHULA, W.; BAKKER, S.; MAAT, K.; VAN WEE, B. **The influence of financial incentives and other socio-economic factors on electric vehicle adoption**. Energy Policy, v. 68, p. 183–194, maio 2014. DOI 10.1016/j.enpol.2014.01.043. Available at: https://doi.org/10.1016/j.enpol.2014.01.043. Accessed: 12 ago. 2023.

THAKKER, V.; BAKSHI, B. R. **Ranking Eco-Innovations to Enable a Sustainable Circular Economy with Net-Zero Emissions**. ACS Sustainable Chemistry and Engineering. American Chemical Society, 2023. DOI 10.1021/acssuschemeng.2c05732. Available at: https://doi.org/10.1021/acssuschemeng.2c05732. Accessed: 12 ago. 2023.

VEUGELERS, R. **Which policy instruments to induce clean innovating?** Research Policy, v. 41, n. 10, p. 1770–1778, dez. 2012. DOI 10.1016/j.respol.2012.06.012. Available at: https://doi.org/10.1016/j.respol.2012.06.012. Accessed: 12 ago. 2023.