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Editorial
Innovation, Creative Destruction, and Sustainable Governance: Theoretical Perspectives and Pathways toward COP30

Inovação, Destruição Criativa e Governança Sustentável: Perspectivas Teóricas e Caminhos rumo à COP30

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1. Introduction

The awarding of the 2025 Nobel Prize in Economics to Philippe Aghion, Peter Howitt, and Joel Mokyr enshrined one of the most transformative paradigms in contemporary economic thought: that sustained growth arises from cycles of innovation that destroy old structures and create new forms of productivity, value, and social organization. Originally formulated in the early 1990s and further developed in subsequent decades, this theory now offers a decisive interpretive framework for understanding the challenges of ecological transition, innovative public policies, and global governance oriented toward sustainability.

According to Aghion and Howitt (1992), innovation is an endogenous process, socially conditioned and institutionally mediated, in which each technological advance replaces the previous one, paving the way for new trajectories of growth and well-being. From this perspective, creative destruction is the driving force of economic progress, transforming obsolescence into opportunity and risk into learning.

Mokyr (2005, 2016) complements and deepens this view by demonstrating that progress is not explained merely by technical invention but by the consolidation of a *culture of growth*—an institutional and cognitive environment that values knowledge, experimentation, and continuous learning. For the author, modern growth emerges from a knowledge regime that connects propositional (scientific) knowledge to prescriptive (technical) knowledge, reducing access costs to information and multiplying its social applicability. Modern economies, therefore, rest not only on the accumulation of capital but on the accumulation of useful knowledge, legitimized by institutions that make it accessible, replicable, and cumulative.

This interpretation is reinforced by Begović (2017), who emphasizes that Mokyr's originality lies in identifying the culture of growth as an institutional and cognitive transformation that legitimized knowledge as the central productive force of modernity. According to the author, Europe pioneered the development of an open, competitive, and cumulative "market of ideas," in which intellectual contestability and merit-based recognition created the conditions for the emergence of Schumpeterian growth. Thus, modern progress resulted not only from economic or institutional incentives but also from the consolidation of an ethos of curiosity, experimentation, and trust in science as a vector of prosperity (Begović, 2017).

Mokyr (2005) further shows that the Industrial Revolution was preceded by an intellectual transformation, the Industrial Enlightenment, which institutionalized curiosity and belief in progress. This process gave rise to networks and institutions of knowledge such as scientific academies, universities, and technical societies, which facilitated the circulation of ideas and the legitimization of innovation as a public good. Such dynamics expand Aghion and Howitt's neo-Schumpeterian framework by revealing that innovation depends not only on research investment but also on ecosystems of knowledge and cognitive governance capable of connecting science, technology, and social values.

The theory of creative destruction, coined by Schumpeter (1934), serves as the direct antecedent to this neo-Schumpeterian and cognitive structure. For Schumpeter, economic development stems from “new combinations” introduced in the market—new products, processes, markets, and organizational forms that replace the previous ones and generate cycles of expansion and recession. This mechanism, far from representing collapse, constitutes the true engine of economic and social progress.

In the contemporary context, creative destruction is not limited to the business sphere; it also manifests itself in public administration, where digitalization, automation, and transparency reshape the ways of governing and producing public value (Schumpeter, 1934). Innovation, in this sense, ceases to be merely an economic vector and becomes a civilizational process of continuous reconstruction, in which knowledge, institutions, and culture become the foundations of sustainable and regenerative governance.

The Conferences of the Parties (COPs), under the United Nations Framework Convention on Climate Change (UNFCCC), now represent a concrete manifestation of this process of creative destruction on an institutional and planetary scale. In each negotiation cycle, old power structures, productive patterns, and governance models are questioned, reformulated, and replaced by new arrangements based on multisectoral cooperation and shared knowledge. As Aghion and Howitt demonstrate, innovation is endogenous and socially mediated; in the case of the COPs, it translates into the reconstruction of deliberative processes and the emergence of more inclusive and cognitive global governance.

A recent study by Bach, Keller, Müller, Schleussner, and Bolton (2025) confirms this transition by showing that the COPs have become spaces of institutional experimentation, where the participation of non-state actors, NGOs, universities, Indigenous peoples, youth movements, and companies has been redesigning the networks of influence and diffusion of climate ideas. The authors also identify that this new governance architecture remains strained by structural asymmetries, such as the significant presence of fossil fuel lobbies and the underrepresentation of Global South countries. Even so, the advance of citizen science, the proliferation of side events, and the strengthening of alliances for fossil fuel divestment reveal that institutional innovation is underway. The COPs thus become laboratories of global creative destruction, where old forms of governing and producing public value give way to new knowledge economies, climate justice, and sustainability as a civilizational principle.

The articulation between creative destruction and the culture of growth allows us to understand that the advancement of global sustainability depends both on the technological capacity to innovate and on the institutional willingness to reinvent itself. The knowledge economy and new forms of governance emerge as responses to the environmental, economic, and social crises that challenge traditional models of development. It is in this context that the Conferences of the Parties (COPs) assume a strategic role, as they materialize, on the plane of international politics, the same Schumpeterian principle of creative substitution by promoting the reconstruction of paradigms of production, consumption, and global cooperation. Each cycle of climate negotiations expresses a moment of institutional destruction and creation, in which new ideas, actors, and alliances reshape the mechanisms of governance and public value creation. The COPs, therefore, symbolize the point of convergence between theory and practice, serving as the space where innovation, science, and politics intersect to redesign the foundations of contemporary sustainable governance—the theme to be examined next.

2. The Conferences of the Parties and the Global Climate Governance Agenda

The Conferences of the Parties (COPs), held annually under the United Nations Framework Convention on Climate Change (UNFCCC), constitute the main international forum for deliberation on the climate crisis and global environmental governance. More than diplomatic meetings, the COPs have established themselves as arenas of institutional experimentation and political innovation, where consensus is built and the foundations of sustainable development are continuously reconfigured. The diversity of actors involved, including states, corporations, universities, civil society organizations, Indigenous peoples, and international agencies, reflects the multisectoral and inclusive nature of these negotiations, which aim to reconcile economic growth, social justice, and ecological balance under a logic of global cooperation.

The main themes discussed at the COPs are organized around eight interdependent axes of climate action, reflecting the complexity of the contemporary sustainability agenda:

1. Climate Change Mitigation – focused on reducing greenhouse gas (GHG) emissions and promoting just energy transitions based on renewable sources and the decarbonization of industry, transport, and agriculture.
2. Climate Adaptation – dedicated to strengthening the resilience of ecosystems and communities in the face of the observable impacts of global warming, emphasizing sustainable infrastructure, adaptive agriculture, and water and food security.
3. Climate Finance – aimed at mobilizing resources to support developing countries in the ecological transition through instruments such as the Green Climate Fund, the Loss and Damage Fund, and green bonds.
4. Carbon Market (Article 6 of the Paris Agreement) – focused on defining rules and standards for the international exchange of carbon credits between countries and companies, ensuring environmental integrity, traceability, and transparency.
5. Nature, Forests, and Biodiversity – committed to the protection of ecosystems and the promotion of zero-deforestation policies, recognizing the strategic role of Indigenous peoples and traditional communities in environmental conservation.
6. Climate Justice and Just Transition – ensuring that mitigation and adaptation measures occur equitably, respecting human rights, cultural diversity, social inclusion, and the generation of green jobs.
7. Climate Governance and Transparency – focused on strengthening accountability mechanisms and integrating climate goals into public budgets and corporate reports, in alignment with international standards such as IFRS S2, ISSB, and the Global Stocktake.
8. Science, Innovation, and Technology – dedicated to scientific cooperation, technology transfer, and the development of innovative solutions, such as climate-oriented artificial intelligence, green hydrogen, and the bioeconomy, capable of accelerating the transition to a low-carbon economy.

These axes express the collective effort of institutional and productive transformation that the COPs have been fostering since 1995. As Bach et al. (2025) emphasize, the conferences have evolved into laboratories of inclusive governance in which science, activism, and the private sector interact dynamically, albeit within contexts still permeated by tensions and power asymmetries. The research shows that, despite the persistent presence of fossil fuel groups, there is a growing influence of scientific and environmental networks that drive new coalitions toward the elimination of fossil fuels and the advancement of global climate justice.

Looking toward COP30, to be held in Belém do Pará, Brazil, in 2025, these transformations acquire symbolic and strategic meaning. In the Amazonian context, the conference invites Brazil and the world to rethink development through a regenerative paradigm, in which technological innovation, science, and culture consolidate as the pillars of sustainable and inclusive governance.

Understanding these axes and institutional dynamics provides the context for the papers gathered in this special issue, which address, from different perspectives, the challenges and opportunities of climate governance within a scenario of creative destruction and institutional renewal.

Over nearly three decades, the Conferences of the Parties have become a continuous process of institutional creative destruction, in which paradigms of governance, production, and international cooperation are successively reconfigured in response to global climate challenges. This dynamic reflects not only the search for technical solutions but also a broader cultural and political transformation, marked by the emergence of new forms of knowledge, participation, and environmental accountability.

Within this same horizon, RP3 – *Revista de Pesquisa em Políticas Públicas* – positions itself as a space for reflection and scientific co-production, in which academia dialogues with real processes of innovation and institutional reform observed in the COPs. The articles in this special issue reflect, across different scales and analytical perspectives, the effects of this transformation, discussing how sustainability, science, and public governance intertwine in the construction of new development models consistent with the ecological transition and the culture of sustainable growth that defines the twenty-first century.

4. COP30 Special Edition: Sustainable Governance, Science, and Creative Destruction

RP3 – *Revista de Pesquisa em Políticas Públicas* – launches its COP30 Special Edition, dedicated to reflecting, from multiple perspectives, on the pathways of sustainable governance, the integration of science and policy, and the valorization of environmental and social assets.

The articles gathered in this special issue illustrate how Brazilian science and public policy have responded creatively and critically to the challenges of sustainability. The study *"The Steps Model and Stakeholders to Observe the Intensity of Participation in the New Public Governance"*, by Antonia Danniele Jeska Torres de Oliveira and Rodrigo Santaella Gonçalves, presents an analytical model to measure the intensity of democratic participation in public policies, using social network mapping to understand the relationships among actors and the legitimacy of decision-making processes.

In *"Science and Politics in the Coproduction of Knowledge in the Policy Cycle: Epistemological Challenges and Evidence-Informed Dialogue in the Multilateral Governance of the COP30 Agenda"*, Fernando Antonio Hello analyzes the tensions between science and politics, advocating for the coproduction of knowledge and evidence-informed dialogue as central elements to strengthen multilateral governance and the effectiveness of climate public policies.

The article *"Integrating the SDGs into Brazil's Public Budget: Pathways for Sustainable Governance toward COP30"*, by Pedro de Morais Godinho and Diana Vaz de Lima, discusses the integration of the Sustainable Development Goals (SDGs) into federal planning and budgeting, focusing on the 2024–2027 Multi-Year Plan (PPA). It identifies methodological advances and challenges related to traceability and budgetary coherence in the transition toward green fiscal governance.

In *"Circular Economy: An Effective Response to Climate Change"*, Cláudia Aparecida Avelar Ferreira, Adriana Almeida do Carmo, Simone Costa Nunes, Renata Cristina Gomes Batista, and Armindo dos Santos de Sousa Teodósio analyze the role of the circular economy in climate change mitigation, highlighting the contribution of waste picker organizations to CO_2 emission reductions, social inclusion, and the creation of green jobs.

The study *"Environmental Economic Valuation and the System of National Accounts for Green Gross Domestic Product Calculation: A Bibliometric Analysis between 1945 and 2022"*, by Sérgio Saraiva Nazareno dos Anjos, Alexsandro Barreto Gois, Fátima de Souza Freire, and Jorge Madeira Nogueira, presents a bibliometric analysis of the evolution of environmental economic valuation and the integration of natural capital into the System of National Accounts. It discusses the conceptual and methodological foundations for calculating the Green Gross Domestic Product (Green GDP) and the role of the System of Environmental-Economic Accounting (SEEA).

The article *"The Impacts of the European Union Deforestation-Free Regulation (EUDR) on the Brazilian Agri-Food System: Global Governance, Regulatory Sovereignty, and Climate Justice"*, by Isadora Gomes da Silveira and Susan Elizabeth Martins Cesar de Oliveira, critically examines the effects of the European Union Deforestation-Free Regulation (EUDR) on the Brazilian agri-food system, discussing the tensions between global governance, regulatory sovereignty, and climate justice in the value chains of strategic commodities such as soy, beef, cocoa, and coffee.

In *"Just Transition and Low-Carbon Agriculture: Lessons from Brazilian Pig Farming for the COP30 Climate Agenda"*, Heris Coutinho Vieira investigates how integrated economic instruments — such as carbon pricing, green credit, payments for environmental services (PES), and technical assistance — can promote a just and low-carbon transition in Brazil's pig farming sector, balancing efficiency, equity, and environmental integrity.

Closing the collection, *"COP30 Challenges: Where Are Employment and Income in the Brazilian Bioeconomy (2011–2021)"*, by Edson Geraldo Nascimento da Paz and Jorge Madeira Nogueira, analyzes the Brazilian bioeconomy from the perspective of employment and income, using RAIS microdata to measure the participation of the 100% BIO core in formal employment and the wage bill between 2011 and 2021. The results show relative stability but reveal significant regional and sectoral reconfigurations, highlighting the role of agro-industrialization and value aggregation across territories.

Converging around the COP30 agenda, these works outline a comprehensive panorama of public governance and sustainable innovation, demonstrating how creative destruction manifests itself in science, the economy, and politics. Together, the articles reaffirm RP3's commitment to the production of applied and interdisciplinary knowledge, capable of inspiring new practices in public management, new metrics of socio-environmental value, and a regenerative and inclusive governance model for Brazil and the world.

5. Final Considerations

The analysis developed here shows that the global ecological transition is intrinsically linked to a process of institutional creative destruction, in which old productive, cognitive, and political structures give way to new ways of thinking, measuring, and governing development. Inspired by the contributions of Schumpeter (1934), Aghion and Howitt (1992), and Mokyr (2016), this transition reveals that sustainability is not limited to technological substitution but involves the emergence of a regenerative culture of growth guided by knowledge, cooperation, and social innovation.

The Conferences of the Parties (COPs), within the framework of the UNFCCC, represent the practical translation of this paradigm on a global scale. They constitute spaces of experimentation and collective learning, where science, politics, and society converge in the search for responses to contemporary climate dilemmas. In each cycle, the COPs reformulate concepts of value, transparency, and responsibility, driving the creation of instruments such as the carbon market, climate funds, and environmental governance and disclosure metrics. In these forums, creative destruction manifests not only through the substitution of technologies but also through the redefinition of principles of legitimacy and climate justice.

The studies gathered in RP3's COP30 Special Edition confirm that this transformation is neither linear nor homogeneous but plural and contextual. They demonstrate that sustainable governance is built simultaneously across multiple dimensions — institutional, economic, epistemological, and cultural — and depends on arrangements capable of integrating scientific knowledge, democratic participation, technological innovation, and environmental value metrics. Addressing topics such as participation and decision networks, SDG integration into public budgeting, circular economy, environmental valuation, regulatory sovereignty, and bioeconomy, the articles show that advancing sustainability requires both new analytical tools and new forms of cooperation and accountability.

The upcoming COP30 in Belém do Pará reinforces the symbolism of this agenda. Hosting a global conference in the heart of the Amazon signifies recognizing that the future of climate governance depends on listening to new actors, knowledges, and territories. Brazil has the opportunity to demonstrate in practice that it is possible to reconcile economic growth, social inclusion, and ecological integrity, consolidating a model of public and corporate governance grounded in evidence, participation, and innovation.

In sum, the convergence between theory and practice, between creative destruction and sustainability, and between science and politics outlines the contours of a new climate knowledge economy. In this new paradigm, creativity ceases to be merely a market attribute and becomes a civilizational foundation for a new era of prosperity — a prosperity measured not only by GDP but by the ability to regenerate systems, expand freedoms, and build shared futures. COP30, and the debates leading up to it, invite the world to rethink development through the lens of this creative regeneration, in which sustainability is no longer a constraint but the very condition for the continuity of life and innovation.

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The steps model and stakeholders to observe the intensity of participation in the new public governance

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Abstract
This article investigates the level of participation in public policies shaped by New Public Governance, focusing on assessing the democratic quality of decision-making processes in climate governance. The central question is: Can mapping decision-making across the phases of a public policy create a tool for measuring participation intensity through stakeholder analysis and social network mapping? The study hypothesizes that the steps model of public policy and the concept of "Participation Intensity" can serve as effective tools for monitoring democratic engagement within governance-based public policies. The theoretical framework applies public policy cycle theory to decision-making, enabling the development of a representative model that highlights participatory processes within public policy. Methodologically, the study combines bibliographic research with empirical applications, tracing the historical evolution of the public sector, divided into Classical and Contemporary periods. It applies the staged model of public policy cycle theory to elements of New Public Governance, focusing on consortia and public–private partnerships (PPPs) in solid waste management policy, with illustrative case studies in Brazil and Sweden. The results reveal varying levels of participation intensity across the cases, suggesting that the use of social network maps to analyze policy stages offers valuable insights into the context and challenges of democracy, decision-making processes, and participation in public policy. By delineating actors and mapping their relationships, this approach provides a practical framework for examining democratic processes in governance-based public policy.

keywords: Sustainability, Participation Intensity, Climate Justice.

Resumo
Este artigo investiga o nível de participação em políticas públicas moldadas pela Nova Governança Pública, com foco na avaliação da qualidade democrática dos processos decisórios para a governança climática. A questão central é: o mapeamento da tomada de decisão ao longo das fases de uma política pública pode criar uma ferramenta para medir a intensidade da participação por meio da análise de stakeholders e do mapeamento de redes sociais? O estudo levanta a hipótese de que o modelo das etapas em políticas públicas e o conceito de "Intensidade de Participação" podem servir como ferramentas eficazes para monitorar o engajamento democrático em políticas públicas baseadas em governança. O arcabouço teórico aplica a teoria do ciclo de políticas públicas à tomada de decisão, permitindo o desenvolvimento de um modelo representativo que destaca os processos participativos dentro das políticas públicas. Metodologicamente, o estudo combina pesquisa bibliográfica com aplicações empíricas, traçando a evolução histórica do setor público — dividido em períodos Clássico e Contemporâneo. Aplica o modelo em estágios da teoria do ciclo de políticas públicas a elementos da Nova Governança Pública, com foco em consórcios e parcerias público-privadas (PPPs) em políticas de gestão de resíduos sólidos, com estudos de caso ilustrativos no Brasil e na Suécia. Os resultados revelam níveis variados de intensidade de participação entre os casos, sugerindo que o uso de mapas de redes sociais para analisar os estágios das políticas oferece insights valiosos sobre o contexto e os desafios da democracia, dos processos decisórios e da participação em políticas públicas. Ao delinear atores e mapear seus relacionamentos, essa abordagem fornece uma estrutura prática para examinar processos democráticos em políticas públicas baseadas em governança.

Palavras-chave: Sustentabilidade, Intensidade de Participação, Justiça Climática.

1 Introduction

One of the major challenges in conducting public policy analyses stems from the choice of the scientific field that the researcher uses to achieve the proposed objectives. After all, the methods for observing and interpreting public policies are culturally and regionally diverse, constructed from various theories within different realities, societies, cultures, states, and types of capitalism.

This article reflects on the historical context of the development of public policy theories and assesses the various models used to observe the decision-making processes involved in this field of research. This discussion allows the researcher to situate the research problem within the multifaceted universe that constitutes public policy connecting and aligning concept democracy, energy transition with justice and equity.

The paths taken by a sustainability-oriented public policy are complex, multifaceted, and multidisciplinary. Observing this field through stages allows for the visualization of participatory processes, from agenda-setting (raising societal awareness of the conception of problems) and policy formulation to the implementation of governmental actions.

This study is situated within the context of the commitments assumed under the Paris Agreement (UNFCCC, 2015), which set the goal of limiting global warming by developing strategies to reduce high concentrations of carbon in the atmosphere. In the Brazilian case, the Nationally Determined Contributions (NDCs), specifically regarding waste, take on the mission of promoting adequate waste management policies and fostering the transition to a circular economy, with a focus on recycling and proper waste treatment. In this context, the policy for closing open-air dumpsites is linked to the green energy transition, digital transformation, and climate change mitigation

To understand the formation of the protagonism of institutional actors, the Stages Model is constructed. This approach presents the historical dimension of the development of public policy as a field and focuses on the observation of decision-making processes. The elements of this analysis are based on a thorough bibliographic review.

Intensity of Participation is perceived through decisions that are debated in a pluralistic manner and subsequently implemented through public services. Conducting this research provides a social orientation for instruments for defending democracy, allowing for the observation of the unequal distribution of decision-making power among institutions in the development and implementation of public policy.

The concept of Decision-Making Processes is discussed based on key authors in the field of public policy: Marques (2013), Cortes and Lima (2012), Sabatier and Schlager (2000), Farah (2018), Capella (2007), Vianna (1996), and Kingdon (2003).

The concept of Intensity of Participation involves continued and plural participation across consecutive stages, from problem definition (how the issue is treated by society, considering prior social and political contexts), agenda-setting (determining which political actors are capable of acting), development and formulation of services, implementation, and evaluation in terms of effectiveness and efficiency.

The concept of governance is built upon New Public Governance, Democratic Governance, Multi-level Governance, and Climate Governance, as presented in the IPCC reports and in the works of Balthasar, Schreurs, and Varone (2019); Jänicke, Schreurs, and Töpfer (2015); Silvestre (2017); Oliveira and Santaella (2022).

Justice and equity in relation to climate are presented in the IPCC reports. The concept of Inclusive Governance, which is addressed to develop solutions for climate justice aligned with the Paris Agreement, these principles indicates that justice and equity enable the creation of solutions to the climate emergency, as well as to economic and democratic crises, contributing to the reduction of inequalities and the eradication of poverty. However, it remains a challenge to engage people and to change their behavior in the face of the climate crisis (IPCC, 2021).

Observing a public policy through the perspective of action stages allows political science to overcome the bias that links *input* (political arena) to the contribution of administrative and bureaucratic factors that interact across different phases (*output*) of the political process (Werner; Wegrich, 2007). It also allows—and we aim to demonstrate in this article—that when participation occurs in one stage but is in some way ignored or annulled in the following stage, it may not be appropriate to speak of effective participation.

Methodologically, this study combines bibliographic research with empirical applications, tracing the historical evolution of the field of public policy, divided into the Classical and Contemporary Periods. These concepts are applied to the **Stages Model** within elements of New Public Governance (consortia and Public-Private Partnerships), using the Solid Waste Management Policy for empirical testing through case studies in Brazil and Sweden.

2 Decision-Making Processes: the connection between Public Policy and Political Science

The following section presents the concepts of Decision-Making Processes and Participation Intensity. It also discusses New Public Governance and the open dump closure policies.

Public policies (as part of the field of Political Science) are understood as a domain of study that analyzes the set of actions implemented by the State and governmental authorities. Their analysis seeks to extract meaning from the decision-making processes that guide governmental action. This field aims to understand why and how the State acts, given the surrounding conditions (Marques, 2013, p. 24).

The importance of this field is emphasized for political sociology, which focuses on the actors, processes, and structures that shape the relationship between the State and society (Cortes; Lima, 2012). Historically, two main phases can be identified in the construction of public policy theories: the so-called *"Classical Period"* and the *"Second Period."*

2.1 Decision-Making Processes during the Classical Period

The Classical Period is historically delimited up to the 1970s. Between 1930 and 1960, political theories were dominated by systemic approaches that focused on actors, interests, and institutions (Sabatier; Schlager, 2000). During this time, public policy was predominantly conceived as a rational process that could be developed scientifically and neutrally (Farah, 2018).

Harold Lasswell (1930–1970), a precursor in this field and a representative of the behavioralist tradition (which emphasizes the behavior of individuals in the realm of public policy), advocated the establishment of a scientific analysis of government—later termed *Policy Analysis*. His approach was centered on understanding the social and political contexts surrounding policies and on the rationality of decision-making processes.

In general, the authors of the Classical Period raised the question of *who makes decisions*. For instance, Herbert Simon and David Easton, both American scholars associated with this period and identified as behavioralists, focused on organizational theories.

Simon concentrated on organizational theory, applying insights from experimental psychology and economics. He argued that individual rationality in decision-making is limited by available information, cognition, time, and resources.

Simon's theories enabled the systematic development of knowledge on administrative behavior, such as the bureaucratic structures of public procurement.

David Easton, in turn, developed systems theory to explain the interactions among the various subsystems that make up a policy. He refined Lasswell's earlier ideas on policy cycles (Marques, 2013).

We incorporate this question from the Classical Period into our empirical analyses, examining through social network mapping the institutional actors who hold decision-making power, particularly when analyzing networks within the framework of New Public Governance.

From the perspective of political science, with a focus on decision-making processes, it is worth noting that the first critiques of the Classical Period challenged the excessive systematization and alleged neutrality within public policy studies. While decision-making was central, it did not occur in a single moment. Instead, it often unfolded simultaneously and incrementally, shaped by cost considerations.

Incrementalism in decision-making had already been defended by Etzioni (1967), who argued that fundamental decisions create new directions and developmental lines within a policy—a process he termed *"mixed scanning"* (Marques, 2013).

The Elitist Theory also stands out, drawing attention to both the decisions that are made and those that are deliberately not made, based on configurations of power and influence in policy-making (Bachrach; Baratz). Stephen Lukes, critiquing Elitist Theory, advanced the Marxist Theory of the State, which raises the discussion of how ideology may be used to conceal interests.

Equally noteworthy is the *"Garbage Can Model,"* which suggests that decision-making processes are conducted by administrators under budgetary constraints. The authors argue that frontline bureaucrats often reinterpret rules and act according to their own beliefs (Cohen; March; Olsen; Marques, 2013)—that is, the very actors directly involved in policy implementation.

During this period, the notion of an integrated environment had not yet emerged. It was at that time that the establishment of the United Nations (1945) laid the foundations for the global environmental governance system, which was primarily focused on natural resources.

2.2 Decision-Making Processes during the Second Period

The second period begins in the 1970s, when reflections emerged that focused on the distinction between the formulation and implementation of public policies. In parallel, it happened the emergence of global environmental governance following the Stockholm Conference (1972) marked the beginning of the concept of sustainable development.

This period is characterized by governmental practices based on the association between public and private institutions. It is also marked by the rise of neoliberalism, which introduced significant changes to the economic and ideological structures of the State and society, permeated by the central values of competition and individual freedom.

The cognitive approach to Public Policy and Political Science also emerged at this time. This perspective emphasizes the role of ideas, beliefs, and knowledge, suggesting that the choice of a policy solution is influenced by values and ideas—contrary to the classical model, which regarded decision-making as neutral and derived from instrumental rationality (Farah, 2018).

Decision-making is thus understood as ambiguous rather than rational. Factors such as the turnover of actors within decision-making arenas lead to fluid participation and to a lack of clear understanding of how decisions affect society. According to Kingdon (2003), the decision-making process consists of the convergence of three streams: problems, proposals, and politics. Policymakers' responses to societal problems depend on how they perceive and interpret reality (Capella, 2007).

During this period, new agreements emerged, such as the United Nations Conference on Environment and Development (Rio-92), the Kyoto Protocol, and the Paris Agreement, which institutionalized global environmental governance, established targets for reducing greenhouse gas emissions, and created the legal and economic foundations for environmental policy. Currently, global environmental governance is organized under the Paris Agreement and is based on cooperation, transparency, and shared responsibility

2.3 The Stages Model in Public Policy

Observing the decision-making processes of a public policy through the Stages Model involves combining classical and second-period concepts of decision-making. This makes it necessary to understand decision-making as encompassing all phases of a public policy.

This involves an extremely complex set of elements that interact over time, linked to hundreds of groups with potentially distinct values and interests, as well as different perceptions of situations and political preferences. Such processes are encompassed by a variety of programs, at multiple levels of government, operating in many localities. Most disputes involve deeply rooted values and interests, large sums of money, and, at times, authoritarian coercion (Sabatier, 2007).

To simplify this observation, we adopt the Stages Model, which focuses on the main moments of institutionalized decision-making. Our research concentrates on two specific stages: *Formulation* and *Implementation*.

The stages of public policies, as presented here, are understood within the theoretical framework of *policy cycles*, which are conceived as a sequence of distinct steps that together constitute the multifaceted complexity of a public policy. The cycle is also composed of governmental programs and actions aimed at addressing problems—problems that, in turn, are formulated and constructed as such through political and societal processes that supposedly involve public participation in agenda-setting.

2.4 The Intensity of Participation

The *Intensity of Participation* can be observed when there is diversity and continuity of interactions among institutional actors across successive stages. The success of governmental action depends on the relationship between the intentions of policymakers and the actions of implementers (Arretche, 2001).

The concept of intensity of participation is grounded in the stages of public policy, aligned with organizational theories, political science, and public administration. It marks the transition from the *input* to the *output* of public action, allowing political science to overcome the bias that separates these stages.

In participatory processes, there exists a chain of relationships between policymakers and implementers. These actors occupy different positions within the governmental apparatus, civil society, and private institutions. This implies the need for closer alignment between the intentions of policymakers and the actions of implementers, since the success of governmental action depends on this relationship (Arretche, 2001). The existence of such alignment ensures intensity of participation.

The formulation stage (its design) results from a broad process of negotiations and bargaining (agenda-setting). The final design is not necessarily the most adequate one, but rather the most widely accepted throughout the negotiation process (Arretche, 2001).

During the implementation stage, decisions tend to be modified. Observers must assess whether implementers adhere to the proposals, objectives, and methodologies of policymakers, especially because both policymakers and implementers tend to select implementation strategies based more on their potential acceptability than on their expected efficiency or effectiveness (Arretche, 2001).

Milani (2008) argues that the renewal of relationships between government and civil society enables participation, representation, and the promotion of protagonism. In this context, it is important to examine the profile of those who implement and those who formulate, and whether they participate in both stages, in order to analyze the continuity of policymakers in the implementation phase.

Attention must also be paid to State reform, which is grounded in public management and often inspired by the notion of *good governance*. This model, based on the parameters of minimalist democracy, emphasizes strategic rationality (Milani, 2008).

There is extensive criticism regarding the observation of public policies through heuristic models of cycles, stages, and processes. However, as we seek to demonstrate here, such observation is important and can make highly relevant contributions to understanding the incremental totality of policy-making. It is particularly useful for researchers examining the relationships among actors in public policy. Each stage involves a diversity of actors within arenas of negotiation shaped by conflicts of interest that evolve over time. Moreover, various models are employed in the analysis of implementation, especially those drawing on game theory.

The incongruence of objectives, interests, loyalties, and worldviews between policymaking agencies and the diverse range of implementers makes it unlikely that a program will fully achieve its objectives or be implemented exactly as designed (Arretche, 2001).

When observing the shift of protagonism across stages, the focus is on *Formulation* and *Implementation*—that is, on the translation of participatory decisions into concrete actions. Experienced public managers know they will ultimately be judged not by their good intentions, but by their ability to master the “art of making things happen.” Implementation is, above all, political. It often involves elements from all the earlier stages of policy creation, as well as the uncertainties and contingencies that these may entail (Wu; Ramesh; Howlett; Friyzen, 2004).

Arretche (2001) provides an evaluation of the implementation process of public programs, aiming to problematize the bias that separates implementation from formulation. She highlights that not all government agencies are capable of formulating policies, and that the implementation stage often becomes a new phase in the life of institutional action, particularly because of the discontinuity of participation: actors who influence formulation rarely remain involved in implementation.

In this context, bureaucracy—with its endemic intra- and inter-organizational conflicts—emerges as an important and decisive actor in public policy. Implementation by public agencies is often a costly, multi-year effort, and the continued funding of programs and projects is generally not guaranteed. In reality, it requires ongoing negotiations and discussions between the political and administrative branches of the State (Wu; Ramesh; Howlett; Friyzen, 2004).

The protagonism of actors across consecutive stages (formulation and implementation) should thus be seen as a field of uncertainty. It depends on how the policy was formulated, the federal design of the program, the actors involved, and their networked relations—where each institution has its own interests, where public–private relations intervene, and where the central authority of the program seeks to induce implementers to fulfill its objectives (Arretche, 2001).

2.6 New Public Governance and the Solid Waste Management Policy

The global system of multi-level climate governance was developed and consolidated globally beginning with ECO-92 and Agenda 21. This framework brought together a broad coalition of governmental, business, and civil society actors operating at all levels of the global multi-level climate governance system, allowing for wide access to and the development of technological solutions (Jänicke; Schreurs; Töpper, 2015).

Multi-level governance must be aligned across its institutional, legal, political, and strategic structures (global, federal, state, regional, and local levels) to expand cooperative and co-productive processes that aim at sustainable development (Balthasar; Schreurs; Varone , 2019).

The alignment of Multi-level governance is particularly important for access to energy transition and digital transformation policies related to climate change, as multi-level governance enables access to financing and technologies and the development of projects capable of achieving a fair and equitable energy transition. Such infrastructure is largely developed through public-private partnerships (PPPs) and consortium (Pan; Santaella; Paraná, 2025; Oliveira; Santaella, 2022), elements of the new public governance.

The Solid Waste Management Policy, which forms part of the tripod of Environmental Sanitation Policy (Water and Sewage, Stormwater Drainage, and Waste), is largely implemented on a regionalized basis through the mechanisms of New Public Governance: consortia and public–private partnerships (PPPs). These involve cooperation, co-production, coordination, and the circular economy. Today, the problem of waste management is embedded within broader policies addressing the climate crisis.

Oliveira and Santaella (2022) provide a critique of participatory processes in governance, connecting them with the three administrative reforms that took place in Brazil (Bureaucratic Reform, New Public Management, and New Public Governance). They highlight neoliberal influence and the role of the State in the formulation and implementation of public policies. The authors emphasize the following points:

Neoliberalism enters State structures through loans granted by international development agencies. In the form of mixed public–private economies, these actors engage in moderate coordination in the monetization of services. Governance can expand participatory processes, but there is also criticism of the neoliberal logic, which uses governance to implement privatizations and restructurings—establishing a new model of exercising power. Care must be taken not to reduce politics to mere management within this model, but rather to allow for the continued negotiation of divergent interests. Stakeholders become an important tool for observing both conflicting and convergent interests. Solidarity should be a central value of governance, while competition and individual freedom are central values of neoliberalism. In Brazil, neoliberal economic restructuring occurs through the promotion of fixed-variable income and credit expansion—a model currently in crisis due to widespread indebtedness (Oliveira; Santaella, 2022).

In the context of crises, governance plays a crucial role in addressing redistributive conflicts by opening new spaces for participatory processes. This is especially significant because governance integrates the State, the market, and civil society into the transformation of the public sector, seeking economic ventures as a means of providing public services (Oliveira; Santaella, 2022).

One of the main features of participatory processes under governance is the innovation and inclusion of non-governmental actors in all stages of public policy, along with the conceptualization of levels of participation (Silvestre, 2019).

This type of decision-making and institutional participation represents a connection between administrative mechanisms and the political and infrastructural dimensions of democratic political and institutional contexts (Filgueiras, 2018).

Thus emerges a new generation of administrative reforms aimed at joint action among diverse actors, with a focus on innovative solutions and sustainable development (Kissler; Heidemann, 2006). In this framework, multiple organizations interact in interdependent and complementary relationships, using a multiplicity of processes that enable a pluralist evolution of institutional participation.

Governance had its advent in Europe in the 1970s, which justifies the illustration of the European governance model through the example of the Swedish consortium. In Brazil, by contrast, the debate on governance in public management is relatively recent.

3 Methodology

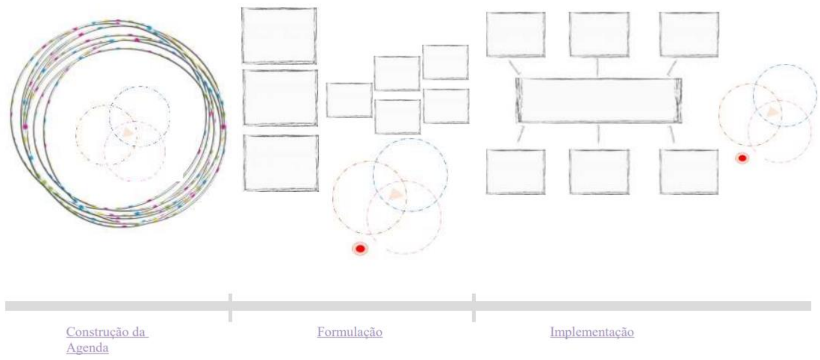
After presenting the Stages Model and discussing participatory processes and intensity of participation—connecting Public Policy and Political Science—we applied these concepts empirically through a Case Study in three units of analysis. These cases were selected because they represent different models of State and capitalism, as well as distinct forms of incorporating elements of New Public Governance, at various stages of formulation and implementation.

The units of analysis present diverse geopolitical and institutional characteristics: Codanorte Consortium (Brazil) – public management without concession; Conscensul Consortium (Brazil) – management model based on a Public-Private Partnership (PPP); VafabMiljö (Sweden) – illustrative case that followed an eight-year concession and currently operates under a PPP arrangement.

The data treatment and analysis consist of observing the institutions in networks and the solutions formulated in the Integrated Solid Waste Management Plans (PGIRS) and their implementation. Next, we mapped the institutional actors who participated in each stage of the policy cycle, classifying them by type of *stakeholders* and observing both their continuity across successive stages and whether the proposed solutions were effectively implemented.

Finally, Social Network Maps were constructed using the UCINET software, enabling us to visualize the continuity of relationships and the diversity of actors involved throughout the stages, thus providing a more robust analysis of governance and participation dynamics.

Figure 1: Stage Model



Source: Own Authorship, 2024

Figure 2: Legend to observe the classification of institutions and the diversity of actors

Source: Own Authorship, 2024.

4 Results

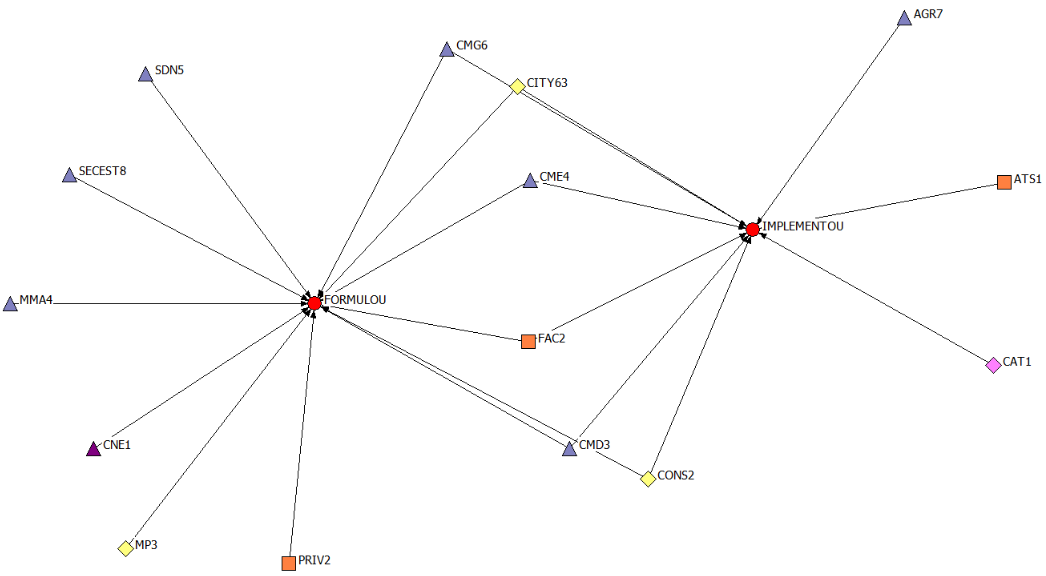
The results reveal different levels of intensity of participation across the cases, indicating that the use of social network maps to analyze the stages of policy provides valuable insights into the context and challenges of democratizing effective participation in governance-oriented public policies.

By delineating actors and mapping their relationships, this approach offers a practical framework to examine and evaluate democratic processes in governance-based public policies.

As previously mentioned, governance allows actors who participated in the formulation stage to develop strategies necessary to access the implementation of services, thereby constructing a multifaceted network of interests embedded in projects and programs coordinated by consortia and PPPs.

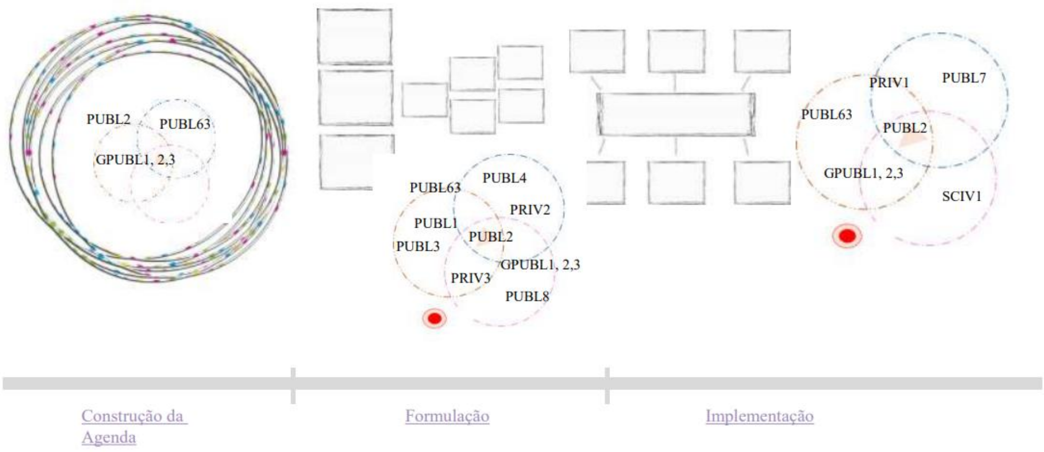
The stages of public policy are aligned with both planning and decision-making models, developed based on organizational theories, political science, and public administration. Within this context, formulation and implementation mark the transition from the *input* to the *output* of public action, enabling political science to overcome the bias that connects these stages.

Figure 3: Intensity of Participation of the CODANORTE Consortium



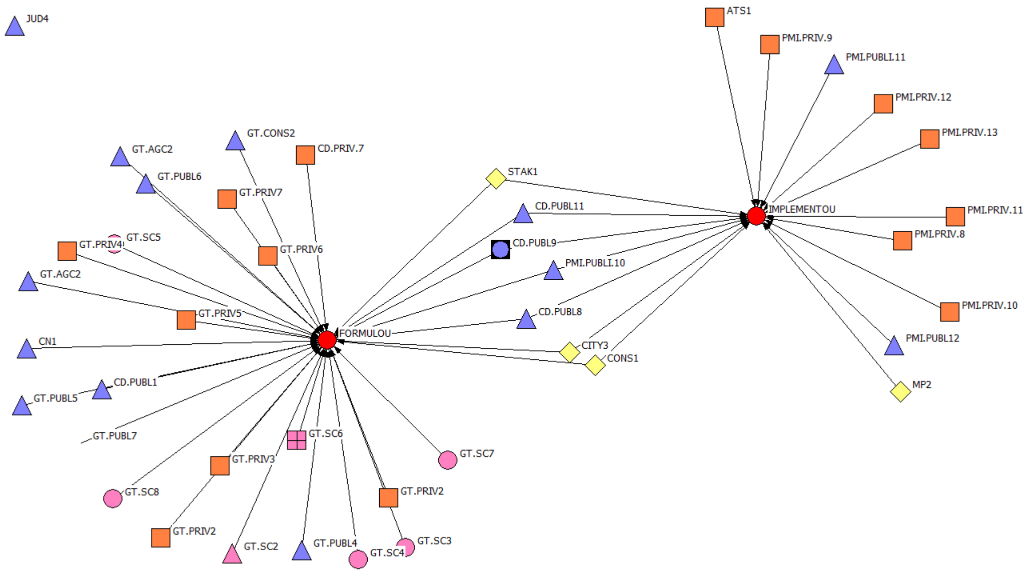
Source: Own Authorship, 2024.

Figure 4: Model of Stages and Continuity of Institutional Actors CODANORTE Consortium



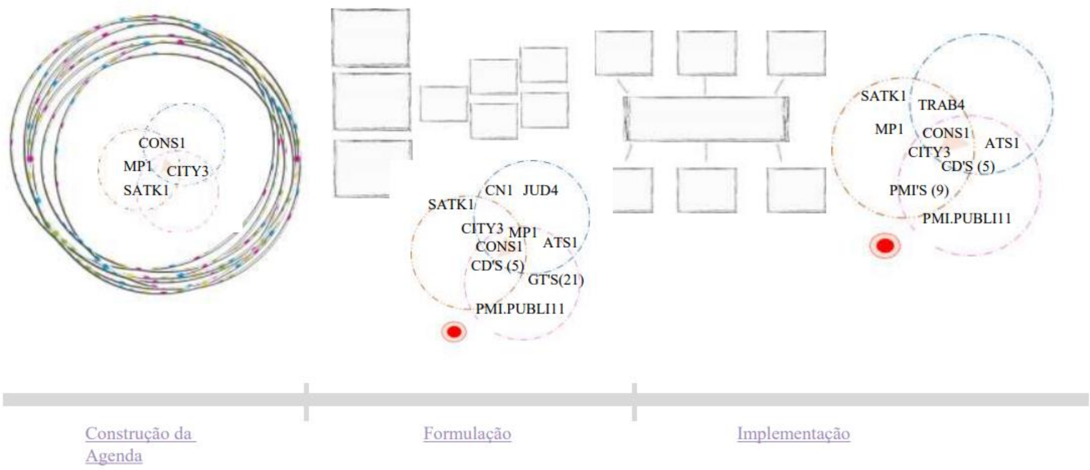
Source: Own Authorship, 2024.

Figure 5: Intensity of Participation of the CONSCENSUL Consortium



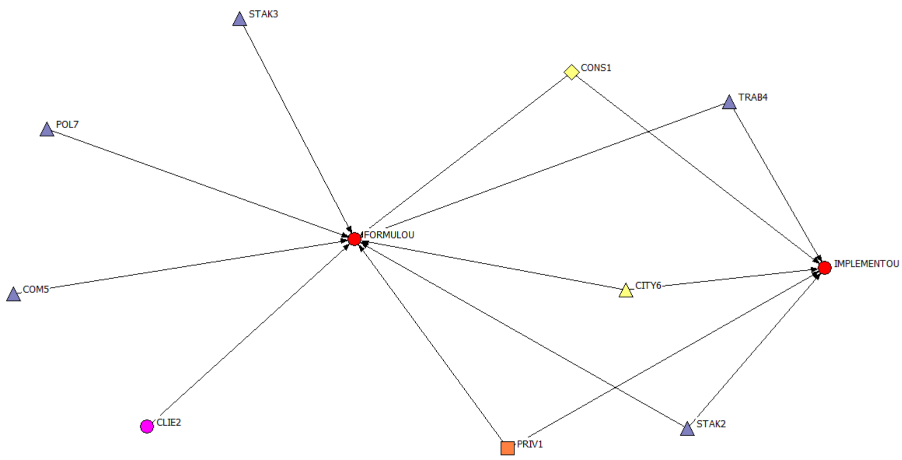
Source: Own Authorship, 2024.

Figure 6: Model of Stages and Continuity of Institutional Actors CONSCENSUL Consortium



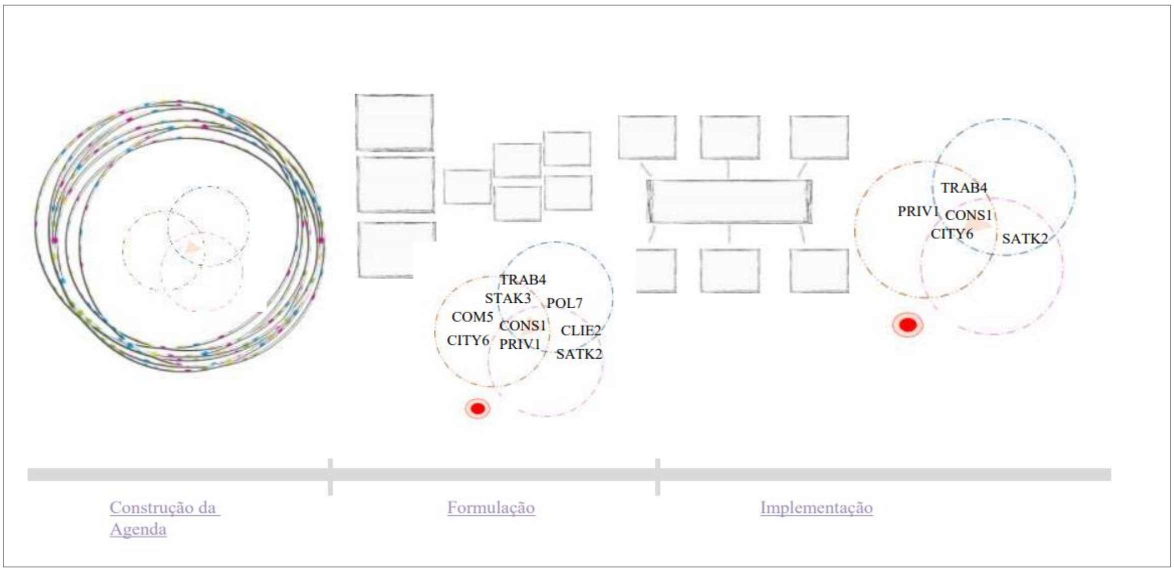
Source: Own Authorship, 2024.

Figura 8: Intensity of Participation of the VAFABMILJÖ Consortium



Source: Own Authorship, 2024.

Figura 8: Model of Stages and Continuity of Institutional Actors VAFABMILJÖ Consortium



Source: Own Authorship, 2024.

Social network maps show that consortia centralize power and legitimacy at key moments of decision-making, highlighting the capacity of governance elements to foster Intensity of Participation in decision-making processes and direct involvement in the implementation of public services.

When analyzing the social network maps, it becomes important to conduct a critical examination of the transitions of institutional managers across the stages. The theoretical perspective is confirmed, revealing that participation is being reconfigured. During the implementation stage, there is less diversity, and fewer institutions are involved.

In the Brazilian consortia, some actors serve as connectors across stages. This is not observed in the Swedish consortium, where all institutions participating in implementation also took part in the formulation of services. Additionally, the Swedish consortium plans its activities according to interest groups. In this context, decision-making is not centralized around institutional actors; rather, the model is based on congruent and conflicting interests.

It can be concluded that governance allows different groups to engage in dialogue over solutions; collective decision-making and control over implementation make it possible to observe the Intensity of Participation**.**

Different levels of intensity of participation are revealed across the cases, confirming that the use of social network maps to analyze the stages of policy provides valuable insights into participatory processes, actor diversity, and continuities and ruptures in participatory practices.

By delineating institutions and mapping their relationships, this approach provides a practical framework for examining democratic processes in public policies guided by elements of New Public Governance**.**

Finally, the unequal distribution of decision-making power among institutions can be observed in the development and implementation of public policies guided by the elements of New Public Governance (consortia and Public-Private Partnerships – PPPs).

In this context, the Stages Model can be considered an important instrument for researchers to highlight actors, participation, and democracy in public policy research. It characterizes and visualizes central actors, measures how the protagonism of actors changes across stages, and facilitates dialogue between theory and empirical evidence with regard to participatory processes within public policy.

5 Conclusion

Participation intensity demonstrates that there is a plurality of institutional actors in governance-driven participatory arrangements. However, Brazilian consortia do not promote effective democratic participation across all stages. In Sweden, stakeholder planning expands the capacity for democratic participation, reduces arenas of political conflict, and fosters cooperation and co-production by developing projects that promote the circular economy among stakeholders.

It can be concluded that the *Stages Model* with stakeholders can be considered a valuable tool for highlighting actors and participation, as well as for guiding the understanding of inclusion, continuity, exclusion, and/or marginalization of certain actors throughout decision-making processes across stages.

Using stakeholder mapping and social network analysis, we examined the dynamics of cooperation, coordination, and co-production among public authorities, private actors, and civil society. The results highlight both the democratic potential of governance arrangements and the risks of corporate governance prevailing over democratic participation.

Regarding actors, theory suggests that by segmenting decision-making processes into stages, it becomes possible to measure, classify, and categorize them according to various theoretical perspectives. To emphasize participation, theories in the field of public policy indicate a diversity of methods that allow for understanding strategic and power relationships involved in participatory and decision-making processes within public policies — for example, by applying insights from experimental psychology and economics, incorporating knowledge of administrative behavior, testing organizational theories, and observing configurations of power to understand how these are influenced by values and ideas. That is, after outlining the participation network, it becomes possible to deepen knowledge about decision-making processes.

By understanding the participation of institutional actors in the context of a public policy for climate emergency — developed through elements of *New Public Governance* — it becomes possible to examine dominant interest groups and assess the level of democratic capacity achieved by the public sector. By evaluating these concepts, parameters can be established to observe the inclusion and diversity of actors.

Furthermore, by correlating the network with the scope of implemented solutions, it is possible to determine whether the applied solutions meet the formulated objectives and whether, in this context, there is continuity in the participation of diverse actors. From these insights, we can identify and discuss participation intensity as a means to achieve inclusive governance for a fair and equitable energy transition.

It is concluded that the *Stages Model* and *Participation Intensity* framework can be extended to analyze climate and environmental policies, supporting decision-makers in implementing equitable and sustainable transitions aligned with COP 30 goals. The concept of participation intensity enables dialogue on the democracy of decision-making processes and connects this topic to processes of social, economic, and political transformation aimed at achieving sustainable societies with their sociobiodiversity protected.

In summary, through network-based participation analysis, it is possible to present the plurality of actors and examine the configuration of the State; provide a detailed account of participation; observe actors across all stages of a public policy; classify them as stakeholders; and identify neoliberal influences as well as points of resistance. In this way, the *Stages Model* and *Participation Intensity* framework allow researchers to reveal the configurations of democracy within a public policy.

Future work will introduce a *Participation Intensity (PI) Index* designed to capture the depth and influence of stakeholder engagement.

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Science and politics in the coproduction of knowledge in the *policy cycle*: epistemological challenges and evidence-informed dialogue in the multilateral governance of the COP 30 agenda

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Abstract
This article examines the growing gap between science and politics, their respective *ethos* and *modus operandi*, in public policymaking, within the *policy cycle*, and among decision-makers, especially in Brazil, where these dimensions interact problematically. Drawing on the specificities of the political and scientific fields, it is found that, although science is vital and objective in its pursuit of facts, decision-making in the political field is also influenced by diverse factors, revealing challenges in the application of scientific knowledge due to the epistemological differences between these two spheres of action and their institutions. Based on a structuralist approach and successive approaches to the issue, the need for innovative approaches that view science, policies, and society as "co-produced" is proposed. In this network of interfaces between actors, starting from a critique of the "Evidence-Based Policy" (EBP) approach, which has been superseded by "Evidence-Informed Policy" (EIP), the importance of dialogue between scientists, society, and decision-makers in the *policy cycle is highlighted*. In the particular case of COP 30 (Conference of the Parties to the United Nations Framework Convention on Climate Change), held in Belém, Pará, Brazil, in November 2025, incremental advances in better governance are proposed in these forums for complex global issues involving ethical values, legislation, negotiation, government strategies, multilateral agreements, and other policy commitments *informed* by scientific evidences.

Keywords: Policy Co-production; Climate Governance-COP 30; Evidence-Informed Policy (EIP); Epistemological Challenges; Policy Cycle.

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Resumo
Este artigo examina a distância crescente entre os discursos da ciência e da política, em seus respectivos *ethos* e *modus operandi*, na formulação de políticas públicas, no âmbito do *policy cycle*, junto aos tomadores de decisão, especialmente no Brasil, onde essas dimensões interagem de forma problemática. Partindo das especificidades do campo político e do campo científico, constata-se que, embora a ciência seja vital e objetiva em sua busca pelos fatos, a tomada de decisão no campo político também é influenciada por fatores diversos, revelando desafios na aplicação do conhecimento científico em função das diferenças epistemológicas entre essas duas esferas de atuação e suas instituições. Num percurso de base estruturalista e por aproximações sucessivas à questão, propõe-se a necessidade de novas abordagens que vejam a ciência, as políticas e a sociedade como "coproduzidas". Nessa rede de interfaces entre atores, partindo da crítica à abordagem da "Política Baseada em Evidências" (EBP), superada pela "Política Informada por Evidências" (IBP), destaca-se a importância do diálogo entre cientistas, sociedade e gestores tomadores de decisão no *policy cycle*. No caso particular da COP 30 (Conferência das Partes da Convenção-Quadro das Nações Unidas sobre Mudança do Clima), realizada em Belém (PA) Brasil, em novembro de 2025, são propostos avanços incrementais em melhor governança nesses fóruns para questões mundiais complexas, que envolvem valores éticos, legislação, negociação, estratégias de governo, para acordos multilaterais e demais compromissos em políticas (*policies*) informadas por evidências científicas.

Palavras-chave: Coprodução de políticas; Governança climática-COP 30; Política informada por evidências (PIE); Desafios epistemológicos; Ciclo de políticas.

I. Introduction

The literature presents the complex relationship between the field of science and that of public policy (PP) decision-makers. The separation of languages, discourses, temporalities, and the dynamics of their respective *ethos* and *modus operandi* suggests possible paths for reconciling these spheres of action, in an attempt to answer a central question: "How can we reconcile these two planes or spheres: that of science, in its paradigms, and that of politics and decision-makers?"

According to Carneiro *et al*. (2014, p. 2), "contemporary thinkers, such as Hannah Arendt, already drew attention to the 'progressively dug gap between the languages of science and politics'". According to the authors:

> [...] This distancing becomes particularly sensitive when seeking to support public policies with evidence from academic research, aiming to expand the range of choices for managers. The origin of this divorce dates back to the 17th century, with the institutionalization of modern science, which, in its search for legitimacy through reason and mathematization, specialized its language,

> moving away from the "common discourse, through which we still make—or should make—politics today." Science, in its "Holy Alliance with technology and industry" (Japiassu, 1977, p. 13), came to be seen as a production of knowledge that "only concerns the scientific community, possessing no moral or political significance" (Japiassu, 1977, p. 13). (Carneiro *et al*., 2014, p. 3)

This mismatch persists and manifests itself in several ways, whether in the overemphasis on technical-economic factors in policy or in arbitrary decisions that disregard or relativize evidence from scientific research. According to Carneiro, M. J. et al. (2014), the more reflective aspect of science, especially when it conflicts with developmental interests, tends to be left aside, largely due to the "inability to produce consensus and/or to translate into language that is timely appropriate to the temporality of political decisions" (Carneiro *et al*., 2014, p. 4).

From the outset, therefore, we add two important categories to our analysis: the differences in temporality for the spheres of science and politics, and the conflicts of interest between both spheres, which will become part of our approach to this issue and will be addressed later.

Still pointing out some dichotomies between these two dimensions, according to Carneiro and Rosa (2018), in Brazil, “the absence of institutionalized mechanisms to facilitate the interface between science and the State reveals a lack of understanding of the importance of scientific knowledge in the development of public policies” (Carneiro; Rosa, 2018, p. 332). According to the authors, in contrast to other countries where this bridge is more structured, here the use of knowledge occurs in a “casuistic manner, without following any systematic”, often through “personal initiatives of direct consultation with a recognized expert” or based on bibliographic material limited to what “is at hand”. This practice can lead to "total randomness" in the choice of consultants and objective evidence (Carneiro *et al*., 2014, p. 7).

Thus, at this Science-Politics interface, some authors point to a series of obstacles that perpetuate this divorce, as there are major differences:

a. Temporal: Science requires a long time for careful research, while "politics needs urgency and certainty" (Carneiro; Rosa, 2018, p. 335). Managers seek immediate answers, and the *timing* of each field is uncoordinated;
b. Epistemological, linguistic, and discourse-related: Science is guided by "doubts and uncertainties", while politics "demands more direct answers and assertions" (Carneiro *et al*., 2014, p. 10). Managers often complain that "scientists talk to themselves,

making their texts incomprehensible outside academic circles" (Carneiro *et al*., 2014, p. 11). Furthermore, there is a preference for quantitative data and "statistical information", seen as more objective, to the detriment of qualitative data, considered difficult to appropriate and/or understand;

c. In the logic of the decision-making process, political decision-making does not obey only scientific rationality. Factors such as the need to build political agreements, the influence of "lobbies, opinion crystallizations, pure arbitrariness", and the interference of hegemonic interests often override the objective evidence of science (Carneiro *et al*., 2014, p. 11; Sousa Aguiar; Delgrossi and Fornazier, 2024, p. 31). Brazilian politics itself, due to its specificity, "does not easily accept that science presents itself *a priori* as a legitimate instrument in decision-making processes" (Carneiro *et al*., 2014, p. 24).

As paths for a possible equation or reconciliation of the dichotomies of these two spheres, firstly, proposals for PP "based" on evidence emerge, and then, after long debates and criticisms, PP "informed" by evidence (Carneiro *et al*., 2014, p. 4), in the hope of reconciling these two dimensions.

In short, Evidence-Based Policy *(*EBP) argues that the effectiveness of policy can increase if it is based on sound scientific evidence. However, this methodology has been criticized for presupposing a technocratic vision and a "submission of policy to the instrumental rationality of science" (Carneiro; Rosa, 2018, p. 43), ignoring other forms of knowledge, experiences, and expertise of other actors, and the complexity of the political process itself.

In response to these criticisms, *Evidence-Informed Policy* (EIP) emerged, making the method more flexible, treating scientific knowledge as one of several factors to be considered, along with the practical experience of managers and the values of their respective beneficiaries. Science would not guide decisions but would participate "as an important factor in constructing a balance, together with a set of other factors and considerations" (Carneiro *et al*., 2014, p. 15), as summarized in Table 1 below:

Feature	Evidence-Based Policy (EBP)	Evidence-Informed Policy (EIP)
Core Philosophy	Seeks to base policy decisions directly on rigorous scientific evidence, aiming for maximum effectiveness.	Suggests that policy practices should be "informed" by evidence, which is one important factor among others.
Origin/ Prominence	More technocratic and inflexible approach.	A less technocratic, more flexible approach.
Relationship between Science & Policy	Assumes a linear, direct relationship where scientific knowledge dictates policy choice. Attempts to institutionalize the science-policy bridge.	Recognizes that scientific knowledge is just *one* field to be accessed in policy formulation.
Nature of Evidence Role	Guiding/Deterministic: Evidence should *guide* or *determine* decisions, with a focus on scientific rationality.	Informative/Contributory: Evidence participates as a key factor but should not guide practical decisions in absolute terms; values the co-production of knowledge.
Other Factors Considered	Often less explicit consideration of non-scientific factors (e.g., values, politics).	Explicitly acknowledges other fields/factors: scientific knowledge, practitioners' experience and expertise, and beneficiaries' values.
Assumptions about Science	Assumes neutrality and instrumental rationality of science.	Recognizes the limits of science and the political nature of decision-making and policy choices.
Critique/ Limitation	Criticized for assuming linearity between knowledge production and political decision-making, the technocratic vision.	Acknowledges the messy reality of policymaking, potentially risking insufficient weight given to robust evidence.
Practical Implication	Focus on producing and using the *best available evidence* (often randomized controlled trials or systematic reviews) to optimize policy design.	Focus on creating interfaces where policymakers consider scientific evidence alongside practical and ethical considerations for balanced decision-making.

TABLE 1 – Comparative Chart: Evidence-Based Policy (EBP) vs. Evidence-Informed Policy (EIP). Source: the author.

Thus, the effective reconciliation of these two dimensions, however, seems to require a deeper and more comprehensive transformation than the simple adoption of different methodologies. Highlighting the importance of rethinking the dualistic relationship between science and politics, some authors indicate the need to:

a. Recognizing the importance of co-production: authors such as Sheila Jasanoff (Carneiro; Rosa, 2018, p. 335) argue that science and society are co-produced, that is, they cannot be understood as separate entities, as they influence each other in a constant process. From this perspective, science is not immune to political disputes, and the very way of thinking about policies is already impregnated by a culture that values scientific rationality (Carneiro; Rosa, 2018, p. 335);
b. Building bridges and mediation: the role of a "translator" or mediator is essential to adapt scientific statements to policy demands. This role can be performed by managers with academic training, study centers within the government, or by scientists willing to direct their research toward public issues (Carneiro *et al*., 2014, p. 11; Carneiro; Rosa, 2018, p. 334);
c. Expanding dialogue and participation: the consolidation of an "extended peer community", as proposed by Funtowicz and Ravetz (Carneiro *et al*., 2014, p. 18), where new actors, in addition to scientists, participate in the debates, is a way to incorporate uncertainties and different knowledge into the decision-making processes. The implementation of forums, seminars, and management councils, where "conversations between different actors occur, in a productive tension between the parties" (Carneiro *et al*., 2014, p. 22), can constitute the embryos of this new way of doing science and politics;
d. Institutionalize evaluation and monitoring: The evaluation of public policies, conducted systematically and institutionally, is a privileged opportunity for mobilizing experts and fostering dialogue between different spheres. *Ex-post evaluation*, for example, is a "fundamental tool for guiding decision-making" and gathering "evidence on policy performance" (See BRASIL, 2018; IPEA, 2018, p. 2; Lassance, 2022). The Policy Cycle must *incorporate* evaluation as a step that feeds back into the formulation of new policies.

Ultimately, we realized that reconciling science and politics would not require a single solution, but rather a set of strategies that operate on different fronts. It would require, on the one hand, that institutionalized science become more accessible and willing to engage with the social demands of different actors, other forms of knowledge, and expertise. On the other hand, the political sphere institutionalizes channels and procedures for qualified access to knowledge, recognizing its value without submitting to a merely technocratic vision. The challenge would lie in making conflicts of interest transparent and allowing the political response to be "the result of a tense negotiation between systematic knowledge, other forms of knowledge, and the different actors involved" (Carneiro *et al*., 2014, p. 23).

II. The advisory-executive role of Science and Technology Institutions (STIs)

Amidst the tension between these two dimensions and their respective languages, discourses, temporalities, dynamisms, *ethos*, and *modus operandi*, lie the public Science and Technology Institutions (STIs). They have demonstrated their alignment with Brazil's efforts toward scientific and technological development, as promoters of scientific research and innovation nationally and internationally, pioneering technological frontiers with significant advances in knowledge and technology for gains in innovation and productivity. They are constantly challenged and even demanded in a variety of ways by the goals proposed by the government's incisive science, technology, and innovation (ST&I) agenda.

In this context, STIs become central actors in a critical analysis of their role as advisory-executive bodies for government public policies, in their attempt to align, support, and/or inform decision-making related to ST&I, the supposed basis and pathway for achieving broad national socioeconomic development. Their specificities and impacts will be felt in different and particular ways in the public sphere and management (Hello, 2024), challenging the understanding of how these public policies are created, produced, instructed, and evaluated pre- and post-evaluated for their impacts throughout the *policy cycle*.

The publication of the New Legal Framework for Science, Technology, and Innovation (NLFST&I) in 2018 introduces a series of structural innovations, fostering technological advancement based essentially on innovations arising from public scientific research. Anchored in robust previous legislation[2] that was developed as a legal framework for the national innovation process, and aiming to provide legal certainty for a series of new mechanisms proposed for national innovation and technological advancements, it more consistently supports the advisory-executive role of STIs in public

[2] See Law 10,973 (2004), Constitutional Amendment No. 85 (2015), Law 13,243 (2016), "National Strategy for Science, Technology and Innovation 2016-2022" (2016).

policies, enabling them to access the new benefits, advantages, instruments, and support, and/or induction, and/or incentive mechanisms now made available by the rules of the new Decree.

In this line, the current challenge refers to a strategic effort to understand and properly articulate the complex decision-making process involved within the scope of this broad *policy cycle*, in the planning and execution of structuring work related to the demands of innovation, the impacts of its discourse in the public sphere, and the design, implementation, dissemination and management related to the different PP (Hello, 2023; 2024).

In anticipation of this legislative structuring effort to disseminate and effectively implement innovative culture in the public sphere, the NLFST&I highlights public STIs in a way that is more aligned with its consultative-executive vocation in the area of knowledge production and productivity in ST&I, in the hope of going beyond a simple market, financial and competitiveness gain (Hello, 2024), seeking greater articulation with governments and decision-makers.

On the other hand, there is a strong expectation from production chains and society in general to create environments that promote what has been conventionally called "transformative" or "disruptive" innovation (See Schot; Steinmueller, 2018) in socio-productive inclusion and insertion, via social technologies, networks, environments, and more integrated innovation ecosystems, especially when it comes to international multilateral agreements involving the preservation of the planet and its diversity, and the urgent confrontation of climate change, as we will see later, in the context of COP 30.

To achieve this, there would be a need for innovation in scientific knowledge, processes, technologies, and innovative social artifacts developed, among other actors, especially by public STIs that, at the same time, can be evidenced in the future in their social reports as *outputs* and *outcomes* of the innovative effort in the public sphere; and the development of a new researcher profile that better dialogues through new narratives and interfaces with managers and decision-makers, for effectively transformative and more consistent results in production and productivity in ST&I aimed at society and the generation of innovative PP informed by scientific evidence.

To this end, it would be necessary to better understand the impacts produced by the cycle of formulation and implementation of these policies in the different spheres, public and private, and the role played by the discourse of innovation in public research, as a privileged path towards broad socioeconomic development (Hello, 2024).

However, it is important to note, as indicated by Rouen (2017) that, based on a system of objective scientific evidence, efforts to build a list of policies that encourage innovation in a broad sense, essential to obtaining better results in production and productivity indicators in ST&I, and socioeconomic development, although necessary, are not sufficient in themselves:

> Despite these efforts, the results of the most recent evaluation research have shown that the outcome indicators and impacts of these efforts have not improved at the same rate.
> Considering the current economic dynamics, which place a significant burden on technical change for productivity increases in a given economy, this low level of Brazilian innovation efforts contributes to hindering productivity gains essential for the international integration of Brazilian companies and the much-needed increase in the country's per capita income. In this sense, **technology and innovation policy itself need to be more innovative and bolder**. It also needs to be **bold in its objectives and, through intelligent government action, use all available tools — even those not readily apparent — to stimulate the development, introduction, and diffusion of innovation in the national economy**. (ROUEN, 2017, p. 11, our emphasis)

Among these tools, we list a systematic and permanent consultative process of feeding and informing through objective scientific evidence, which will subsidize, advise and innovate decision-makers in this cycle of formulation and implementation of different PP, more effectively connecting the findings of research in ST&I to the design of adopted strategic government lines, composing more consistent premises and guidelines aligned both with the scientific discourse and with the different government policies of broad development.

III. The specificity of decision-making processes in their interfaces

However, although this systematic feeding and information through objective evidence is necessary for better decision-making, what we perceive is a problematic distance between the knowledge constructed through scientific research institutionalized in and by STIs and the specificities of the political-decision-making process which, generally, will meet other requirements and particularities that, at times, are paradoxically and mutually strange and/or, even, opposed or conflicting.

This makes us perceive the world of scientific research, in its mission, vision, and values, as belonging to another sphere quite distant from public governmental and organizational decision-making systems and processes, where other variables are more relevant, which leads us to question the problematic articulation between their respective *ethos* and *modus operandi.*

This dichotomy is especially and paradoxically reflected in the organizational structure of STIs, whose mission as public institutions is, essentially, the production and advancement of scientific knowledge for technological innovation.

This fact is pointed out by Lopes (2018) about a possible reform in the structure of the state and its organizations, especially those of ST&I:

> It is, therefore, imperative that we seek to consolidate a transversal State model, with more distributed public management, focused on the search for and retention of talent with sufficient preparation and vision to minimize conflicts and confrontations and build agendas that span multiple organizations, **with shared goals and objectives and indicators that allow for monitoring and maximizing the delivery of results and impacts for society**. **An excellent example of the essentiality of such a model is in the field of innovation, which impacts almost everything that sustains developed nations**.
> Virtually all developed countries have **cross-cutting structures to stimulate innovation**, linked to the leadership of the executive branch, which recognizes that the issue is important enough and cross-cutting enough to deserve unified and pragmatic treatment by multiple **ministries, funding agencies, research organizations, universities, and companies**. (Lopes, 2018, our emphasis)

Thus, we problematize our underlying question that permeates the *ethos* and *modus operandi* of *policy cycles* for innovation projects and their respective impacts on the public sphere and research in this current context: why is scientific evidence produced by STIs generally underutilized, both in policymaking cycles themselves and, in parallel, in the decision-making processes that establish them? Would it be used in other formats or modalities, for example, via tacit knowledge? Are there other channels of scientific information that feed the *policy cycle* for decision-making and the formulation of government strategies?

Although we do not have a clear answer to these questions, we are moving forward with successive approaches to our subject of study, knowing that, today, science is immersed in society and is an important part of our daily lives. We also know that it is a tool for national and international development and that there is even a need for science for and about the political and decision-making process itself, given the explosion of knowledge and the frenetic pace of innovation as both opportunities and challenges for society and governments. In this context, it would be worth investigating the reasons for the difficulties of providing systematic and permanent scientific advice in forums with a diversity of stakeholders, both for instruction and for synthesis in supporting decision-making in the public sphere in general, and even within STIs in particular, as advisory-executive entities par excellence, in the development and formulation of PPs. As Packer *et al*. (2021) point out:

> Understanding the role of science in public policymaking is both thought-provoking and challenging, encompassing the interplay between knowledge and political action in an intricate process. To achieve this understanding, it is important to understand the role of scientists in the context of public policy without, however, falling into the temptation of technocratic thinking, which allows scientists to dominate the decision-making process, or of politicizing science, where political interest groups introduce biases into scientists' work (Miguel, 2014). From either perspective, science is not neutral, and the choice of one decision or another always involves diverse interests.
> Studies show that the participation of scientists in political decisions involves a process of intertwining experts and political actors, marked by disputes of diverse interests, in which the discourse of politicians is sometimes supported by scientific arguments (Jasanoff, 1990; Nowotny, 2000; Rifkin; Martin, 2005; Weingart, 2005; Wynne, 2003). (Packer *et al*., 2021, p. 8)

We thus perceive the need to translate science to inform policy, and vice versa, accurately, in operational syntheses of scientific evidence, if possible, without bias, providing valuable information for decision-makers in governance positions, without incurring the risk of "politicizing" the process, whether through biased *advocacy* or partisan *lobbying* by certain interest groups.

Given these challenges, therefore, at the governance level, there is a need to create a systematic and permanent advisory ecosystem, composed of well-trained scientists, or even a team of scientific advisors, a body of professionals and scientific societies, a robust university system, strengthened regulatory agencies, and a wide range of diverse and participatory advisory committees, which will perform the functions of modulating the political debate, influencing technical and political recommendations, informing strategies in resource allocation, and providing tacit and explicit knowledge as objective scientific evidence, both in the formulation and implementation phases of policies and their respective regulations, within the *policy cycle*.

Thus, given the central importance of innovation as a privileged route for broad national socioeconomic development, the proposal would be to move towards an innovation that is also transformative in socio-productive inclusion, for social insertion and inclusion and, in parallel, the consolidation of a transversal State model, with public management that is more distributed and informed by objective scientific evidence in evaluation to support the cycle of formulation, implementation and evaluation of impacts of PPs, to maximize the delivery of results (*outputs* and *outcomes*) for society (See Lassance Jr., 2004).

IV. A mutually possible advisory-executive ecosystem

To uncover the best system for the functioning of this mutually consultative-executive ecosystem for the PP construction system, which may, in the future, be extrapolated to more complex environments in other spheres of government, it is important to list some aspects to be studied or considered, according to Cairney *et al*. (2018):

a. The supply side *versus* the demand side of information or evidence: it is clear that there is a need to correctly decipher how the system of constructing a PP works with the participation of articulating political agents, experts and decision-making managers; what are the margins and limited flexibilities for maneuver; the possible short circuits and *by-passes* in the process; the incompleteness and ambiguity characteristic of science in its instruction to the process; the realization that *policy makers* are different from scientific arbitrators or influencers, acting in a specific and differentiated way in their context (Cairney *et al.*, 2018);
b. Furthermore, other relevant aspects involved in the political cycle: being able to identify who makes political decisions; being able to work with the expectation of informing policy, without "making" politics; bearing in mind that some relevant objective evidence will be ignored or misinterpreted; acting as a "promoter," not a "defender," of a given idea; the importance of maintaining scientific credibility with both politicians and scientists and experts; taking into account the difficulties in resolving value conflicts based solely on facts; keeping in mind the pressing need to work with interdisciplinary and transdisciplinary expertise; bearing in mind the fact that *policymakers* see scientific evidence as just another *input factor.* (Cairney *et al.*, 2018);

c. In this process, therefore, we must articulate categories such as: "policies" *versus* "*evidence*"; reactivity *versus* proactivity; the different views on what constitutes "good" evidence; the limitations of bounded rationality and heuristics in the process (Cairney *et al.*, 2018).
d. The importance of clearly identifying who controls and leads the political process as an agent (Cairney *et al.*, 2018).

In summary, the great challenge, therefore, is how to effectively, efficiently, and effectively instruct the decision-making process, through objective evidence arising from the advancement of scientific research and knowledge in ST&I, throughout the cycle of elaboration and management of PPs, to obtain more expressive, consistent, and sustainable results in "transformative innovation" and fewer mistakes in public management; bringing greater returns in social balances to public investments made in innovation in the sector, as well as benefits to society and the productive sector, generating a virtuous circle, overcoming the search for innovation guided only by competitiveness and financial and market gain, an objective foreign to the real vocation of the public sphere (Hello, 2024).

It is a fact that a large part of the success of intervention projects in the PP cycle and the effectiveness of their results ends up being a function of infinite political-administrative and pragmatic situations that, once favorable, allow for the synergistic reconciliation, over time, of the different agendas, expectations and tacit and explicit knowledge, both of the organizations and of the actors and other interest groups or institutions involved (Dutra, 2001).

Thus, with political intentionality and transformative potential, through successive approaches, we seek to perfect auxiliary tools for the *policy cycle* that enable a more collegial and participatory construction (Becker, 1992). As it develops responsibilities and commitments to activities and their results, it redefines and minimizes the need for extensive bureaucratic controls, once agreed upon, appropriated, and, accordingly, assimilated. In turn, this also favors the emergence of a new *ethos* and *modus operandi*, where *praxis* and discourses become more harmonious and consonant, creating a virtuous incremental circle in the management and continuous improvement of the *policy cycle* and its practical and concrete results (Hello, 2009). As ideas cannot be transformed into practice without the existence of, on the one hand, structuring movements and, on the other, structures that enable this practice, an essential point related to the instruction of the entire system by objective scientific evidence, including the process itself.

In this sense, the relevance of the structuralist discourse analysis function (Gregolin, 2001; Hello, 2009; 2022; 2023; 2024; Lemaire, 1979; Nogueira *et al.*, 2004; Orlandi, 2009) emerges as a fundamental multidimensional and multifunctional tool in the organization, as well as for rectifying and redefining the possibilities of instructing the political cycle of formulating PPs through new narratives based on their information by objective scientific evidence for decision-makers. It makes it possible to articulate the technical dimension with the political dimension of the processes, for the transformative construction of the common good represented, in this case, by the more effective, efficient and efficient management of public affairs, in the face of the new demands brought by the impacts of the innovation discourse in this sphere (Frey, 2009; Hello, 2009; 2024; Jobert; Muller, 1987; Lima Jr.; Santos, 1976; Santos, 1998; Nonaka, 1997; Trevisan; Van Bellen, 2008).

Or as Capella (2006) indicates, referring to "governments", but which could be perfectly applied to the guidelines and premises of management in the public sphere, which we aim to be "transformative", and to technological advancement:

> In *Agendas, Alternatives, and Public Policies*, Kingdon seeks to answer the following question: why do some issues become important to a government? How does an idea fit into the set of concerns of policymakers, becoming a public policy? Kingdon considers public policy as a set of four processes: the establishment of a public policy agenda; the consideration of alternatives for public policy formulation, from which choices will be made; the dominant choice among the set of available alternatives; and, finally, the implementation of the decision. (Kingdon, 1984 *apud* Capella, 2006, p. 25)

Our expectation, therefore, is to build new possibilities capable of instructing and informing, in a transformative, systematic and permanent way, informed by objective scientific evidence, the decision-making processes of managers in the formulation of PPs in the *policy cycle*, based on a new philosophy of political governance that is capable of taking into account, benefiting from and systematically feeding on the findings and discoveries of ST&I.

V. The Field of COPs (Conference of the Parties to the United Nations Framework Convention on Climate Change)

In the particular case of the COPs, this conflict between the *ethos* and *modus operandi* of science with its objective evidence, that of politics and policy, and that of decision-makers in government bodies is evident.

The central principles that guide COP 30, held in Belém (PA) in November 2025, as well as all other COPs already held, were established by the "United Nations Framework Convention on Climate Change" (UNFCCC) and reinforced by the Paris Agreement, in general terms they deal with "common but differentiated responsibilities (CBDR)" and "maintaining global temperature" (Lee *et al.*, 2023; Brasil, 2025a; b; c; d; e).

The CDBR is the most important principle, recognizing that all nations have an obligation to combat climate change, but the level of action and commitments differ depending on national circumstances, capabilities, and respective historical roles in emissions. In this sense, more developed countries should take the lead, providing financial, technological, and capacity-building support to developing countries.
As for "global temperature control," broadly speaking, efforts should be aimed at keeping the increase in global average temperature well below pre-industrial levels, and at limiting the increase to 1.5°C.

The major challenge of COP 30, therefore, will be to present a new round of "Nationally Determined Contributions" (NDCs), which are each nation's climate action plans, and which are more ambitious than the 1.5°C target. To this end, it is essential to strengthen cooperation between governments, the private sector, civil society, and traditional peoples for a unified and accelerated global response to the climate crisis, promoting the energy transition from fossil fuels to renewable sources and low-carbon technologies.

Furthermore, another COP 30 guideline relates to increasing the capacity of the most vulnerable countries and communities to adapt to the inevitable impacts of climate change, ensuring that adaptation and mitigation plans consider equity and social justice, benefiting Indigenous peoples, traditional communities, and other vulnerable populations. This will certainly require intensified efforts to ensure that developed countries fulfill their commitments to climate finance and the provision of technology and capacity building to other developing countries.

COP 30 will also review and evaluate previous agreements, verifying and validating the compatibility of ongoing actions with the current state of the environment and climate goals, reinforcing the transparency regime so that each country's actions and progress in relation to its NDCs are clearly monitored.

Also being held in the Amazon, it will highlight the role of nature and forests in global climate solutions, placing biomes and traditional communities at the center of the debate.

To be achieved, all these somewhat ambitious goals and expectations articulate the conflict between the *ethos* and *modus operandi* of science, with its objective evidence, and the politics and policy of decision-makers at the negotiating table. The interface between the production of objective scientific knowledge and political decision-making in global governance, particularly in the context of COPs, constitutes an intrinsically complex field of tension that is fundamental to the effectiveness of consensual responses to the climate crisis.

The *ethos* of science and its *modus operandi*, characterized by the pursuit of robust evidence, quantified uncertainty, and an iterative, interactive, and cumulative process aimed at describing and predicting reality, aims to produce objective and politically neutral assessments of risks and response options, focusing on empirical validity and theoretical coherence, using a language of probabilities and confidence intervals. On the one hand, climate science, for example, deals with timescales spanning decades or centuries, in very long-term preventive actions. On the other hand, the implementation of scientific evidence almost always clashes with the allocation of scarce resources, where the costs of mitigation and adaptation compete with other social and economic priorities.

In contrast, politics and decision-making, as seen previously, are governed by a distinct logic, focused on pragmatic action and the maintenance of stability, in this case, within a system of sovereignty and state and government strategies. Their *modus operandi* is more characterized by short cycles involving electoral cycles, whose temporal discontinuity ultimately favors and pressures short-term solutions. Their decisions are also filtered primarily by national interests and the maintenance of sovereignty, to the detriment of broader global imperatives. Commitments are much more guided by economic capacity and "diplomatic" concessions, losses, and gains than by the evidence and facts of the problem at hand. Decision-makers often demand "certainties" from their advisors, or simplify complex scientific messages, replete with uncertainties and probabilities, to create political narratives that justify the option of inaction, or more gradual action, or even the prioritization of certain economic sectors, according to the objective and certainly very well-calculated strategy.

The conflict between these two distinct dimensions arises at the moment of transition from the domain of evidence to the domain of values, and even between moral and ethical counter-values of action, such as respect for human dignity, solidarity, cooperation or competition, merit or favoritism; autocracy or participation, among many others. Thus, when science presents objective evidence, most of the time, through its actors, it is making a "descriptive" statement, based on or informed by evidence.

However, the decision to implement a given action or not is a "prescriptive" statement that cannot be resolved by science alone, requiring a political value judgment regarding ethical values, equity, shared responsibilities, economic viability, acceptable social impacts of the transition, conflicts of interest, among many others. They present themselves, therefore, as opposed "discourses" in an arena where statements (what is spoken) and enunciations (the act of speaking what is spoken) (Gregolin, 2001; Hello, 2024; Lemaire, 1979; Orlandi, 2009; Vallejo; Magalhães, 1981) they alternate dynamically according to the mutual and relative movements of each of the other actors, in collegial decision-making, especially in these forums.

Furthermore, residual scientific uncertainty, an integral part of the scientific method, is often exploited, or even subverted or manipulated, as a strategic or advantageous political uncertainty, serving as a justification for this or that position in collegial democratic decisions. The *ethos* of "organized" political skepticism thus clashes with the *modus operandi* of a political movement that prioritizes maintaining the *status quo* or, conversely, the consensual adoption of incremental actions, or even inaction. Thus, we could say that science establishes a kind of "biophysical limit to action," and politics defines the social and economic limits of "possible action".

Overcoming this dichotomy would therefore require not only more effective scientific communication and discourse in these forums, but the development of more advanced mechanisms of global governance that would understand the long-term imperatives of science within the framework of short-, medium-, and long-term arrangements, incentives, negotiations, and strategies of global politics.

VI. Final considerations

By exploring successive structuralist approaches to our questions, we highlight the fact that science and politics *operate* in distinct and, at times, opposed and contradictory dimensions. These findings renew demands for new research on the specificities and dynamics characteristic of these two spheres of action, in their respective discourses, often with opposed frameworks, in the hope of conciliation, mutual benefit, and synergy.

This conflict largely demands a better analysis and understanding of these discourses, their statements, and enunciations in defense of their positions, structurally related to the negotiating table, in dynamic movements of interaction and/or iteration. International forums such as COP 30 emblematically highlight the clashes between these two distinct discourses, where statements and enunciations will decide different relative strategies and positions, taking into account values and counter-values, interests, trade-offs, and costs/benefits of each option, in the construction of short-, medium-, and long-term agreements and consensus.

The expectation is that this better understanding of these two reference points of speech, that of science and that of politics, will certainly result in better decision-making, better informed and qualified, even if sometimes tending to one side or the other in relation to the objective evidence in question.

It is a fact that decision-makers operate under different pressures in the dynamism of political times, both from public STIs and from national and even international government frameworks.

To advance our understanding of these processes, critical discourse analysis can help us establish a permanent consultative-executive system among these actors, aligning discourses, needs, demands, and desires.

In the field of ST&I, STIs position themselves as privileged executive-advisory actors in the production and communication of scientific evidence, which, in turn, will inform various decision-makers, provided there is room for a systematic practice of both supply and demand for information, knowledge, and evidence. And for this to happen, the political dimension will necessarily have to consider the specificities and rites of the scientific dimension, mutually respecting their respective *ethos* and *modus operandi*, benefiting from the best of each field.

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Integrating the SDGs into Brazil's Public Budget: Pathways for Sustainable Governance toward COP30

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Abstract
This article examines Brazil's recent efforts to integrate the Sustainable Development Goals (SDGs) into its federal planning and budgetary systems, with emphasis on the 2024–2027 Multi-Year Plan (PPA). Through qualitative and exploratory documentary analysis, it assesses the methodological design adopted to associate government programs with the SDGs, identifying advances, limitations, and opportunities for improvement. The study argues that the PPA represents an important innovation in policy coherence but remains limited in its translation to the Budget Guidelines Law (LDO) and the Annual Budget Law (LOA), where resource allocation and execution occur. As contextual evidence, the article also notes Brazil's broader convergence with international sustainability standards, such as the national adaptation of IFRS S1 and S2 principles through NBC TDS 01 and 02, reflecting institutional alignment with global governance trends. By linking the discussion to the emerging agenda of climate finance and the Brazilian Emissions Trading System (SBCE), the paper highlights how sustainable budgeting can interact with mechanisms of carbon pricing and fiscal transparency. The findings point to methodological gaps in traceability, quantification, and standardization, and propose a unified coding model to enhance monitoring and accountability within Brazil's federal budget, an essential step as the country prepares to host COP30 and strengthen its leadership in sustainable fiscal governance.

Keywords: Public Budget; Sustainable Development Goals; Fiscal Governance; Policy Coherence; Sustainable Budgeting.

Resumo
Este artigo analisa os avanços e limitações do esforço brasileiro para integrar os Objetivos de Desenvolvimento Sustentável (ODS) ao orçamento público federal, no contexto da preparação do país para sediar a COP30. Com base em análise documental do PPA 2024 - 2027 e da LOA 2024, o estudo avalia a coerência metodológica da vinculação ODS - programas orçamentários e propõe aperfeiçoamentos para fortalecer a governança fiscal sustentável. Os resultados mostram que o PPA representa um avanço relevante na coerência de políticas, mas sua aplicação orçamentária ainda é limitada, dificultando o monitoramento e a rastreabilidade dos gastos voltados aos ODS. O artigo propõe um modelo de codificação unificada aplicável aos sistemas SIAFI e SIOP, que permitiria identificar e acompanhar despesas associadas a cada ODS sem alterar a estrutura legal do orçamento. Ao relacionar essa proposta à agenda de finanças climáticas e ao Sistema Brasileiro de Comércio de Emissões (SBCE), o estudo demonstra o potencial de integrar políticas fiscais, ambientais e sociais em um mesmo arcabouço analítico. Conclui-se que o fortalecimento dessa integração é essencial para que o Brasil consolide sua liderança em governança fiscal sustentável e amplie sua credibilidade internacional na COP30.

Palavras-chave: Orçamento Público; Objetivos de Desenvolvimento Sustentável; Governança Fiscal; Coerência de Políticas; Orçamento Sustentável

1. Introduction

The 30th Conference of the Parties (COP30), to be held in Belém, Pará, in 2025, marks the first time a United Nations Climate Change Conference will take place in the Brazilian Amazon. Beyond its symbolic importance, the event positions Brazil and Latin America at the forefront of global discussions on climate governance and sustainable development (GovBR, 2024; Chatham House, 2025; S&P Global Ratings, 2025). As both a major emerging economy and the host country, Brazil faces the challenge of demonstrating how sustainability principles are effectively incorporated into its institutional and fiscal architecture. Within this framework, the public budget assumes a strategic role: once designed primarily for financial control, it has evolved into a governance instrument capable of linking policy priorities, performance management, and accountability (Schick, 1998; Allen, 2009; Rezende, 2017).

COP30 therefore provides an opportunity to assess how fiscal governance can be aligned with environmental and social objectives, particularly through mechanisms such as sustainable budgeting and climate finance integration. Brazil's recent initiatives in these areas, such as the incorporation of the Sustainable Development Goals (SDGs) into federal planning and the adoption of sustainability disclosure standards, illustrate an ongoing institutional effort that may inform similar transitions across emerging economies (OECD, 2020; UNDP, 2021; IFRS Foundation, 2023).

In the framework of the 2030 Agenda for Sustainable Development, budgets are no longer neutral or purely accounting devices, they are strategic tools for implementing global commitments at the domestic level (UN, 2015; OECD, 2020). By aligning fiscal planning and execution with the Sustainable Development Goals (SDGs), governments can make resource allocation more transparent, traceable, and responsive to long-term sustainability objectives (World Bank, 2021). This approach, however, demands methodological innovation and institutional coordination to ensure that budget structures reflect policy coherence rather than symbolic alignment.

Recent discussions on green fiscal governance and climate finance highlight the growing recognition that fiscal policy must integrate environmental and social objectives. In Latin America, CEPAL (2023) stresses the need for investment and fiscal frameworks consistent with climate and sustainability goals, emphasizing that fiscal systems play a critical role in mobilizing resources for the transition to low-carbon development. Empirical evidence compiled by the Inter-American Development Bank (Delgado, 2021) shows that the introduction of green budget classifications or tags can help governments identify and measure expenditures that contribute to climate-related actions. In parallel, the Common Framework of Sustainable Finance Taxonomies developed by UNEP and UNDP (2023) provides regional guidance for defining eligibility criteria for sustainable investments, promoting coherence among national financing strategies.

Reports by the UNEP Finance Initiative (2023), produced with support from institutions such as the Development Bank of Latin America (CAF), note that within national public budgets, allocating and tracking resources for climate adaptation remains challenging, since many expenditures pursue multiple development purposes and lack systematic monitoring mechanisms. This diagnostic underscores the importance of developing fiscal instruments, such as SDG tagging, green budget tagging, and climate-finance tracking, to improve the visibility, classification, and reporting of public expenditures related to sustainability and adaptation. Collectively, these initiatives illustrate a gradual regional movement toward more transparent and accountable approaches to linking budgets with climate and development objectives.

Brazil's 2024 - 2027 Multi-Year Plan (PPA) marks the first comprehensive effort to align federal planning with the Sustainable Development Goals (SDGs). For the first time, 88 finalistic programs were explicitly associated with the SDGs, reflecting a structural innovation in policy coherence (MPO, 2023a; MPO, 2023b). While this initiative represents a major step forward, its implementation remains largely conceptual and has yet to be translated into the instruments that guide fiscal execution, the Budget Guidelines Law (LDO) and the Annual Budget Law (LOA) (MPO, 2024).

Parallel to this, Brazil has also moved toward international convergence in sustainability governance. The country's recent regulatory reforms demonstrate an effort to align fiscal and accounting practices with global standards of transparency and sustainability disclosure (IFRS Foundation, 2023; CFC, 2023). However, while progress in corporate reporting has been significant, methodological advances in public budgeting remain limited, particularly in linking fiscal data to the Sustainable Development Goals (SDGs).

Against this background, this article aims to analyze the advances achieved by Brazil's 2024 - 2027 PPA in integrating the SDGs into the federal budget, identify the methodological and institutional limitations of this process, and propose theoretical and operational improvements to strengthen sustainable fiscal governance. Specifically, the study seeks to examine whether the PPA's SDG-linked programs provide a consistent basis for monitoring budgetary allocations, and to suggest how mechanisms such as SDG coding and quantitative indicators could enhance traceability and accountability. By combining documentary analysis with a comparative perspective, the article contributes to ongoing debates on how developing countries can move from declaratory commitments to evidence-based sustainable budget governance, an essential agenda in the lead-up to COP30.

2. Theoretical Framework

The role of public budgeting has evolved from a mechanism of financial control to a key instrument of governance and strategic management. This transformation reflects broader shifts in public administration theory, in which budgeting ceased to be viewed merely as a technical procedure for expenditure control and became a central process for articulating government priorities and coordinating policies. As Wildavsky (1979) argues, the budgetary process is inherently political, as it represents the arena where competing interests negotiate and decide "who gets what, when, and how much." Schick (1998) reinforces that modern fiscal systems must move beyond procedural compliance to adopt managerial and performance-based approaches that connect financial resources to outcomes. Similarly, Allen (2009) and Wehner (2008) emphasize that effective fiscal governance depends on institutional mechanisms that ensure consistency between financial management and policy objectives, strengthening transparency and accountability. In the Brazilian context, Rezende (2017) interprets the budget as both a political and technical arena in which governance decisions materialize through the allocation of resources and the coordination of collective action.

This evolution reflects a broader movement from formal accountability, focused on compliance with legal and procedural rules, to results-based accountability, which emphasizes measurable performance and outcomes. The shift toward Performance Budgeting redefines the purpose of public budgets from merely ensuring legality and fiscal control to demonstrating how resources generate social, economic, and environmental results (Allen, 2009; Wehner, 2008). Within this perspective, the principle of Policy Coherence gains operational meaning: while associating programs with SDGs satisfies the formal dimension of coherence, establishing a standardized SDG coding structure would enable a shift toward performance-oriented governance.

The adoption of the 2030 Agenda for Sustainable Development, established by the United Nations (UN, 2015), reinforced this conception of budgeting as an integrated governance tool. The agenda's 17 Sustainable Development Goals (SDGs) call for governments to align planning, budgeting, and evaluation processes in pursuit of economic, social, and environmental objectives. Under this approach, the budget becomes an instrument of policy coherence and accountability, capable of demonstrating whether resource allocation effectively supports sustainable outcomes. The OECD (2020) and the World Bank (2021) highlight that linking budgets to the SDGs enables governments to identify expenditure gaps, coordinate multisectoral action, and improve transparency and accountability in public finance.

To operationalize this integration, several methodological innovations have emerged, particularly SDG budgeting and budget tagging. The UNDP (2021) defines *budgeting for the SDGs* as the process of incorporating the 2030 Agenda into national budget frameworks through explicit tagging or classification of expenditures that support specific SDGs. This approach allows countries to identify and track how public resources contribute to sustainability targets. Similarly, the OECD (2021), in its *Green Budget Tagging: Introductory Guidance and Principles*, describes budget tagging as a methodology to systematically identify, assess, and prioritize expenditures and revenues that contribute to environmental and sustainable development goals. Both organizations emphasize that such mechanisms strengthen fiscal transparency and support evidence-based policymaking by linking financial data to policy outcomes. Taken together, these approaches form part of a broader framework in which budgeting serves not only as an allocation tool but also as a mechanism for measuring, reporting, and improving progress toward long-term development goals.

International experiences illustrate how SDG-oriented budgeting can be institutionalized through different mechanisms and degrees of complexity. In Mexico, the *Sistema de Información de los ODS (SIODS)* integrates planning and budgetary data, allowing the Ministry of Finance to identify, monitor, and report on expenditures contributing to each SDG (UNDP, 2021). The system functions as a comprehensive tagging tool embedded in the national planning framework, ensuring transparency in how federal resources align with the 2030 Agenda. In France, the *Budget Vert*, coordinated by the Ministry of Finance and the Ministry of Ecological Transition, assesses the environmental impact of the State budget and classifies expenditures as positive, neutral, or negative relative to environmental objectives (Boutron, 2023).

This initiative stands as a pioneering example of green budgeting within the European Union. Similarly, under the OECD's Green Budget Tagging Framework (2021), countries such as Ghana and Portugal have developed tagging systems that categorize budgetary programs according to their degree of contribution, direct, indirect, or marginal, to the SDGs. These cases demonstrate that the institutionalization of SDG-oriented budgeting depends on two critical elements: a consistent classification system integrated into the budget law and quantitative indicators that enable the monitoring of results over time.

In Latin America, regional development institutions have increasingly emphasized the fiscal dimension of sustainability. Reports by CEPAL (2023) and the Development Bank of Latin America (CAF, 2023) highlight that sustainable fiscal governance requires not only transparent reporting but also the alignment of tax, spending, and investment policies with climate objectives. These discussions have influenced national strategies across the region, including Brazil, where sustainable budgeting and SDG tagging are seen as mechanisms to bridge environmental, fiscal, and social agendas.

In Brazil, the discussion on SDG-oriented budgeting gained institutional relevance with the 2024 - 2027 Multi-Year Plan (PPA), which, for the first time, formally linked 88 finalistic programs to the Sustainable Development Goals (MPO, 2023a; MPO, 2023b). This initiative represents a significant advance in policy coherence, establishing a conceptual bridge between long-term planning and the principles of the 2030 Agenda. However, this integration remains limited to the planning stage and has not yet been systematically extended to the Budget Guidelines Law (LDO) or the Annual Budget Law (LOA), instruments that guide fiscal execution. In the absence of standardized classification codes and clear quantitative indicators, it remains difficult to trace how public expenditures effectively contribute to specific SDGs. This limitation weakens the evaluative potential of the initiative and constrains its capacity to serve as an accountability mechanism.

At the same time, Brazil has advanced in broader aspects of sustainability governance, particularly through the adoption of international transparency and reporting standards. The publication of the NBC TDS 01 and NBC TDS 02, based on the IFRS S1 and S2 standards developed by the International Sustainability Standards Board (ISSB), reflects the country's alignment with global practices in sustainability disclosure (CFC, 2023; IFRS Foundation, 2023). Although these standards were designed primarily for the private sector, they promote principles of materiality, comparability, and transparency that can indirectly influence public sector governance. Their adoption in Brazil's institutional environment demonstrates a growing culture of disclosure and data standardization, prerequisites for integrating sustainability principles into fiscal policy.

Nevertheless, as Rezende (2017) and the OECD (2021) emphasize, regulatory convergence alone is insufficient to guarantee effective governance. The real challenge lies in translating normative progress into operational capacity, the ability to link planning, budgeting, and evaluation through coherent methodologies and reliable information systems. From this perspective, Brazil's experience can be seen as an intermediate stage of institutional innovation: one in which normative alignment with international sustainability frameworks coexists with persistent operational fragmentation.

Achieving sustainable budget governance, therefore, requires moving beyond declaratory commitments to develop instruments capable of measuring and demonstrating how fiscal resources contribute to the SDGs. As highlighted by the World Bank (2021), such integration depends on transparent information systems, standardized indicators, and interministerial coordination. The consolidation of these elements would allow Brazil to evolve from symbolic alignment to verifiable integration, transforming its planning and budgeting systems into effective instruments for implementing the 2030 Agenda.

The global transition toward low-carbon economies has expanded the scope of fiscal governance to encompass climate-related financial mechanisms. In Brazil, this agenda has gained renewed momentum with the implementation of the Sistema Brasileiro de Comércio de Emissões (SBCE), which aims to regulate carbon markets and establish a transparent system of emission caps and tradable allowances (MMA, 2024). The integration of such mechanisms into fiscal planning creates new interfaces between sustainable budgeting and climate finance, enabling the government to link budgetary allocations with measurable environmental outcomes. As CEPAL (2023) and UNEP FI (2023) indicate, the alignment of national budgets with carbon pricing frameworks enhances the capacity of governments to mobilize and track resources directed toward mitigation and adaptation. In this context, Brazil's approach to SDG tagging and budgetary coding represents a critical step toward consolidating a coherent framework that connects the fiscal system with the broader architecture of climate finance and green investment.

3. Methodology

This study adopts a qualitative and exploratory design based on documentary analysis of Brazil's federal planning and budgetary instruments. It focuses on how the Sustainable Development Goals (SDGs) were integrated into the 2024 - 2027 Multi-Year Plan (PPA) and how this integration is reflected in the 2024 Annual Budget Law (LOA). The objective is to assess the methodological coherence of the SDG-budget linkage proposed in the PPA, identify its main limitations, and propose refinements to strengthen the alignment between planning, budgeting, and evaluation within the framework of sustainable fiscal governance.

The research relies on three official sources. The first is the **PPA 2024 - 2027**, particularly its annex *Planejamento Orientado à Agenda 2030*, which associates 88 finalistic programs with specific SDGs (MPO, 2023a; MPO, 2023b). The second is the **LOA 2024**, which authorizes expenditures and establishes the legal framework for fiscal execution (MPO, 2024). The third comprises technical notes issued by the **Ministry of Planning and Budget (MPO)** that describe the criteria adopted to associate programs with SDGs. Together, these documents provide the empirical basis for evaluating how sustainability objectives are embedded in Brazil's planning and budgetary structure.

The methodological procedure consisted of a systematic comparison between the classifications presented in the PPA and their corresponding entries in the LOA. Each of the 88 programs associated with the SDGs was traced to its equivalent in the 2024 budget to verify whether the linkages established during planning were preserved in fiscal execution. The analysis also evaluated the presence or absence of quantitative indicators capable of measuring the degree of budgetary commitment to each SDG, following the recommendations of the UNDP (2021), OECD (2021), and World Bank (2021), which emphasize the importance of measurable parameters for transforming policy coherence into fiscal accountability.

To explore the operational implications of the observed gaps, the **Program 5118 – Atenção Especializada à Saúde** was selected as a representative case. This program, linked to **SDG 3 (Good Health and Well-Being)** and **SDG 5 (Gender Equality)**, was used to simulate the introduction of a **unified four-digit coding system** that allows identification of SDG-related expenditures without altering the legal or structural configuration of the federal budget. The proposed model combines the identifiers of the program and the SDG into a single analytical field, maintaining the hierarchy of Brazil's functional-programmatic classification. For instance:

- 51A3 → Program 5118 *(Atenção Especializada à Saúde)* + SDG 3 (Good Health and Well-Being);
- 51A5 → Program 5118 *(Atenção Especializada à Saúde)* + SDG 5 (Gender Equality).

This model enables tagging and aggregation of expenditures by SDG within systems such as SIAFI and SIOP, facilitating monitoring across fiscal years. To evaluate its analytical potential, three quantitative indicators were conceptually defined:

- Health Commitment Ratio (51A3): proportion of Program 5118 resources allocated to actions that expand access to specialized care and strengthen universal health coverage (aligned with SDG 3).
- Gender Equality Allocation Share (51A5): percentage of the program's budget directed toward initiatives promoting equitable access to health services for women (aligned with SDG 5).
- Execution Efficiency Index: ratio between executed and authorized expenditures under each unified code, measured annually to assess efficiency and resource absorption capacity.

Finally, international experiences in SDG-oriented budgeting and tagging were reviewed to contextualize the Brazilian case. Examples from Mexico, France, Ghana, and Portugal (UNDP, 2021; Boutron, 2023; OECD, 2021) were analyzed as benchmarks for identifying institutional and methodological conditions conducive to successful implementation.

4. Findings and Discussion

The analysis of Brazil's 2024–2027 Multi-Year Plan (PPA) reveals a significant institutional effort to integrate the Sustainable Development Goals (SDGs) into federal planning. For the first time, 88 finalistic programs were formally linked to the 17 SDGs, representing a structural innovation in policy coherence (MPO, 2023a; MPO, 2023b). However, comparison with the 2024 Annual Budget Law (LOA) shows that this integration remains largely conceptual. The associations established in the PPA are not systematically reproduced in the LOA, where expenditure authorization and execution control take place (MPO, 2024). In practice, the absence of standardized SDG tagging within the LOA prevents detailed appropriations, by project or activity, from being aggregated or analyzed according to sustainability targets. This methodological gap restricts the operational linkage between planning (at the program level) and execution (at the action level), limiting fiscal traceability and the ability to evaluate outcomes.

A key finding is the aggregation bias resulting from program-level associations. Because each federal program encompasses multiple projects and activities, linking entire programs to multiple SDGs dilutes analytical precision. In some cases, a single program was associated with up to nine goals, obscuring the actual share of resources contributing to each objective. This methodological overextension, also observed in early international experiences, demonstrates the risk of adopting broad classifications without standardized coding or contribution levels (UNDP, 2020; OECD, 2021). The absence of quantitative indicators compounds these limitations: neither the PPA nor the LOA defines financial baselines or measurable targets for SDG-related expenditures. As emphasized by the OECD (2021) and the World Bank (2021), quantitative tagging mechanisms and fiscal indicators are essential for transforming formal alignment into operational governance.

To address these challenges, the study tested a unified four-digit coding model using Program 5118 – *Atenção Especializada à Saúde* as a case study. Under this model, expenditures related to SDG 3 (51A3), such as hospital expansion and universal health initiatives, and those related to SDG 5 (51A5), such as maternal health programs, could be distinctly recorded and monitored within existing budgetary systems. This framework allows data disaggregation by SDG while preserving the legal and institutional integrity of Brazil's budget structure. The model also enables the creation of quantitative indicators, such as the *Health Commitment Ratio*, *Gender Equality Allocation Share*, and *Execution Efficiency Index*, which convert descriptive linkages into measurable fiscal commitments.

The proposed coding would function as a tag integrated into existing information systems (SIAFI and SIOP). It would not modify the functional-programmatic structure or legal classifications (e.g., *Natureza da Despesa*, *Fonte de Recursos*) but would add an analytical field allowing expenditures to be tagged, aggregated, and monitored across fiscal years. Such interoperability would improve traceability, enhance fiscal transparency, and facilitate the production of sustainability reports linking financial and policy data. This configuration aligns with international practices of SDG tagging, providing a technically feasible and low-cost mechanism for integrating sustainability considerations into fiscal management while ensuring compliance with Brazil's budgetary framework.

When compared internationally, this proposed mechanism aligns with successful budget-tagging practices in Mexico, where the *Sistema de Información de los ODS (SIODS)* connects planning and budgetary data for SDG monitoring (UNDP, 2021); in France, where the *Budget Vert* classifies expenditures by environmental contribution (Boutron, 2023); and in Ghana and Portugal, which, according to the OECD (2021), employ tagging frameworks distinguishing between direct, indirect, and marginal contributions. These cases highlight that the institutionalization of SDG-oriented budgeting depends on classification consistency and quantitative indicators for tracking outcomes over time.

The Brazilian case remains at an intermediate stage. The PPA offers a conceptual foundation for linking programs to the SDGs, but its operational translation into the LOA lacks methodological rigor and standardized coding. This fragmentation prevents intertemporal comparability and limits the capacity for accountability and evaluation. As Rezende (2017) notes, governance reforms in Brazil often face implementation barriers that result in institutional discontinuity, a dynamic also reflected in the current SDG-budget integration process.

Despite these challenges, the PPA 2024 - 2027 represents an important step toward sustainable budget governance. By incorporating sustainability discourse and aligning with international transparency standards, such as the NBC TDS 01 and NBC TDS 02 (CFC, 2023; IFRS Foundation, 2023), Brazil has established regulatory and informational conditions to advance toward a data-driven fiscal model. The proposed coding and indicator system would strengthen this framework by enabling verifiable tracking of fiscal commitments to the SDGs.

Ultimately, the findings indicate that achieving effective SDG integration requires moving beyond declaratory commitments toward operational mechanisms supported by standardized data and interministerial coordination. Implementing a unified coding system, such as the one exemplified by codes 51A3 and 51A5, would allow Brazil to consolidate a sustainable fiscal governance model that combines policy coherence, methodological rigor, and accountability. This transformation would not only enhance national planning capacity but also reinforce Brazil's leadership in sustainable governance as host of COP30.

5. Conclusion

The analysis of Brazil's recent initiatives demonstrates that the country has made significant progress in aligning its planning and accounting frameworks with the Sustainable Development Goals (SDGs) and international standards of sustainability reporting. The 2024-2027 Multi-Year Plan (PPA) marked the first systematic effort to integrate the 2030 Agenda into federal planning by linking 88 finalistic programs to specific goals (MPO, 2023a; MPO, 2023b). In parallel, the adoption of the ISSB's IFRS S1 and S2 standards, translated domestically into NBC TDS 01 and NBC TDS 02, positioned Brazil at the forefront of sustainability disclosure in Latin America (CFC, 2023; IFRS Foundation, 2023). Together, these initiatives indicate a growing institutional awareness of the need to incorporate sustainability principles into fiscal governance and reflect Brazil's commitment in the context of COP30 (UN, 2015).

Nevertheless, the comparative analysis between the PPA 2024 - 2027 and the Annual Budget Law (LOA) 2024 reveals that the integration between planning and budgeting remains primarily normative. The associations established in the PPA are not systematically reproduced in the LOA, restricting the traceability of expenditures (MPO, 2024; World Bank, 2021). The current approach generates aggregation bias, since entire programs are often linked to multiple SDGs without disaggregating resources by activity or objective. As highlighted by the UNDP (2020) and OECD (2021), this methodological limitation undermines the analytical precision necessary for effective SDG budgeting and weakens the evaluative potential of fiscal monitoring.

Taken together, these findings suggest that Brazil's integration efforts remain partial and inconsistent, oscillating between declaratory commitments and operational limitations. To address these challenges, international experiences-such as those of Mexico, France, and Ghana, demonstrate the importance of adopting structured *budget tagging* systems with codified taxonomies, defined contribution levels (primary, secondary, marginal), and quantitative indicators to measure impact (UNDP, 2021; OECD, 2021; Boutron, 2023). Incorporating such practices into the Brazilian context would enhance transparency, improve comparability, and strengthen accountability in sustainable fiscal governance.

In light of these results, this article proposes three key methodological innovations. First, the implementation of a unified four-digit coding mechanism within the LOA that explicitly links programs, actions, and projects to the SDGs, ensuring traceability throughout the budget cycle (Schick, 1998; Wehner, 2008). For example, under this model, Program 5118 – Atenção Especializada à Saúde could be coded as 51A3 when contributing to *SDG 3 (Good Health and Well-Being)* and 51A5 when contributing to *SDG 5 (Gender Equality)*, allowing expenditures to be monitored by sustainability objective without altering the legal budget structure.

Second, the establishment of quantitative indicators and financial baselines capable of measuring the proportion of budget resources allocated and executed for each SDG, thus enabling longitudinal monitoring of fiscal commitments (UNDP, 2020; OECD, 2021; World Bank, 2021).Third, the creation of standardized classification criteria, coordinated by the Ministry of Planning and Budget, to ensure consistency, comparability, and coherence across federal programs (Rezende, 2017).

By consolidating these methodological refinements, Brazil could move beyond symbolic alignment and achieve operational integration between planning and budgeting. Such an evolution would equip the fiscal governance system with tools to ensure that public resources are allocated transparently and effectively in support of sustainable development. Hosting COP30 in Belém do Pará reinforces Brazil's responsibility to translate its normative commitments into measurable fiscal outcomes. By advancing mechanisms of sustainable budget governance, the country can demonstrate institutional leadership in the intersection of climate finance, fiscal transparency, and social development, offering a model for the region and the Global South. Beyond its national implications, the Brazilian experience holds significant relevance for the Global South.

As one of the largest emerging economies, Brazil illustrates how countries with rigid and highly codified budget structures can adapt existing systems to meet the demands of the 2030 Agenda and climate finance frameworks. The proposed SDG tagging model demonstrates that it is possible to advance sustainability governance through managerial innovation rather than structural overhaul, offering an adaptable framework for other developing nations seeking to reconcile fiscal responsibility with environmental and social commitments. More broadly, it would position the Brazilian case as a reference in SDG-oriented budgeting, reinforcing its institutional credibility and leadership as host of COP30.

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Circular Economy: an effective response to climate change

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Abstract

Climate change has affected all countries, generating great losses for the economy, the environment, and human lives. The circular economy is an effective way to address climate change, contributing to the potential reduction of carbon dioxide emissions. The objective of the study is to analyze the potential relationship between the reduction of carbon dioxide emissions and the recycling of urban solid waste by waste pickers' organizations. Quantitative and documentary research was developed based on data from the Recycling Yearbook (2020-2024). The results point to a positive relationship between potential CO2 reduction as the number of organizations increases, from 1,829 in 2020 to 3,028 in 2024, associated with the expansion of the collection and correct disposal of recyclable materials, especially plastics, metals, and paper/cardboard, which together account for most of the reduction in carbon emissions. As contributions, it is highlight that waste pickers' organizations are the axis for the social inclusion of people in social vulnerabilities, women's empowerment, in addition to contributing to the reduction of water and energy consumption and lower impacts on the environment.

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Keywords: Circular economy. Solid Waste**.** Carbon Dioxide Gas**.** COP30. Climate Governance.

Resumo
As mudanças climáticas têm atingido todos os países gerando grandes perdas para a economia, meio ambiente e vidas humanas. A economia circular é o caminho efetivo para as mudanças climáticas, contribuindo para redução potencial de emissão de gás carbônico. O objetivo do estudo é analisar a relação potencial de diminuição das emissões de dióxido de carbono e a reciclagem de resíduos sólidos urbanos pelas organizações de catadoras e catadores. Foi desenvolvida uma pesquisa quantitativa e documental a partir dos dados do Anuário da Reciclagem (2020-2024). Os resultados apontam uma relação positiva entre potencial diminuição de CO2 à medida que aumenta o número de organizações, de 1.829 em 2020 para 3.028 em 2024, associada à ampliação da coleta e destinação correta de materiais recicláveis, especialmente plásticos, metais e papel/papelão, que juntos respondem pela maior parte da diminuição das emissões de carbono. Como contribuições destaca-se que as organizações de catadoras e catadores são o eixo para inclusão social das pessoas em vulnerabilidades sociais, empoderamento das mulheres, além de contribuir para redução do consumo de água e energia e menores impactos ao meio ambiente.

Palavras-chave: Economia circular. Resíduos Sólidos. Gás dióxido de carbono. COP 30. Governança Climática.

1 Introduction

Sustainability is not a fad, but a complex action that depends on the involvement of all stakeholders (the public, civil society, governments, and business leaders) and is grounded in intergenerational ethics. This means that environmental and economic actions taken by people today should not reduce the chances of future generations enjoying equivalent levels of wealth, utility, or well-being (Meadowcroft, 2022).

Nature, as well as people and the structures that sustain nations, have been impacted by the COVID-19 pandemic (Soares; Pinto, 2020), in some cases irreversibly. The environment continues to undergo changes resulting from human intervention, whether direct or indirect, which creates additional challenges for achieving the 17 Sustainable Development Goals (SDGs). The 2030 Agenda is an initiative of the United Nations (UNESCO, 2019) that proposes a global pact for sustainable development. It aims to ensure human progress and meet the basic needs of individuals through economic, political, and social processes that respect the environment and the principles of sustainability.

Climate change is one of the most relevant global challenges, gradually highlighting inequalities between North and South and resulting in increasingly intense impacts. The Paris Agreement, signed on December 12, 2015, represents a milestone in the multilateral process by establishing a treaty that encompasses all nations, intending to combat climate change and promote adaptation to its effects (United Nations Climate Change, 2015). International cooperation provides a global reach by imposing uniform core obligations through a minimum agreement, in addition to stimulating debates on inequalities related to vulnerability and the capacity for equitable coping (Oliveira, 2019). The Paris Agreement seeks to reach consensus on the stabilization of carbon dioxide in the atmosphere, aiming to keep the global average temperature at 1.5°C and reduce CO_2 emissions by 43% by 2030, contributing to the social and economic transformation of countries (United Nations Climate Change, 2015).

The 30th United Nations Climate Change Conference 2025, called COP30, will take place from November 10 to 21, 2025, in the city of Belém, Brazil, to mobilize the action agenda consisting of voluntary climate actions by civil society, companies, investors, cities, states and nations to more prominently support the reduction of emissions, adaptation to climate change and the transition towards sustainable economies in accordance with the Paris Agreement (COP30 Brazil).

Massuga *et al.* (2022) warn of the increased generation of plastic waste in coastal regions during the pandemic, especially from personal protective equipment. This scenario poses a prolonged environmental and social challenge due to the disruption of sustainable practices and the increased use of disposable plastics, requiring structural and behavioral responses to promote sustainability.

Consequently, solid waste generation has increased in recent years due to changes in people's lifestyles. However, without recycling these materials, carbon emissions into nature and greater impacts on the climate and health would increase (Bordim *et al*., 2022). However, this increase in waste consumption generates income for people in social inequalities (Tizziani *et al*., 2025) through the collection and selection of materials, in addition to expanding the cooperatives responsible for sorting (Carvalho *et al*., 2025).

As a way of reducing the harm caused by environmental impacts and preserving lives, and the need to solve immediate social problems, it justifies the transformation of the economy with the concept of social innovation (Avelino *et al*., 2019), emerging circular, creative, collaborative, shared, and multi-currency economies (Schinaider *et al*., 2025).

In this study, we adopted circular economy as a production model that aims to recover the value of tangible commodities through a closed cycle, using resource reuse and restoration techniques to determine the performance of production systems (Ashby, 2018), such as the recycling process (Ribeiro *et al*., 2014).

The circular economy has three dimensions: a) preserving and increasing natural capital, aiming to control finite stocks and balance the use of renewable resources; b) optimizing resource use in production, focusing on circulating products and materials with maximum use (technical cycle and biological cycle); and c) stimulating system efficiency by identifying and eliminating negative externalities in processes (Berardi; Dias, 2018). For full effectiveness, intersectoral collaboration is required, with the involvement of various private and public stakeholders to minimize energy consumption and reduce CO2 emissions.

Solid waste recycling is one of the pillars of smart and sustainable cities, as it guarantees income for the marginalized and social protection for cooperative members (Carvalho *et al*., 2025), reduces environmental pollution and climate-related tragedies (Bordim *et al*., 2022), and generates economic development and profits for companies through the carbon market (Zong *et al*., 2019). Environmental disasters constitute an obstacle to economic growth and highlight the difficulties in reconciling economics with environmental conservation and health quality for people in certain areas (Pott; Estrela, 2017).

Considering the global impact scenario and its implications for the environment, the economy, human lives, and public health, the question arises: Can the circular economy contribute to the potential reduction of CO2 emissions? The objective of this study was to analyze the potential relationship between carbon dioxide (CO2) emissions reduction and the recycling of urban solid waste by waste picker organizations. A descriptive, quantitative, and documentary study was developed using data from the Recycling Yearbook (2020-2024).

To this end, quantitative and documentary research was conducted (Sá-Silva *et al*., 2009), using secondary data from the yearbook. The theoretical framework adopted was based on studies on social innovation (Avelino *et al.,* 2019). The article's relevance is highlighted by its adherence to Sustainable Development Goal number eleven (SDG 11 - sustainable cities and SDG 13 - climate action) and, in the academic context, by its contribution to the field of administration, evidenced by the fact that there are only twenty articles mentioning carbon in the article titles in the Scientific Periodicals Electronic Library (Spell) database, as of September 20, 2025. This study presents the direct relationship between urban solid waste circularity, waste picker organizations, and potential CO2 emission reduction.

This article is divided into five sections, the first being the introduction, the second a literature review addressing the environment and the circular economy, the third the methodology, the fourth presenting the results, analysis, and discussion, the fifth the conclusions, and finally the references.

2 Literature review

2.1 Environment and the circular economy

According to Sena *et al*. (2016), environmental and climate change have a direct impact on public health, often going unnoticed and hindering action on the various determinants of health. These changes significantly influence the population's living conditions, especially regarding access to water, both in quality and quantity. For municipalities, adequate management of the effects of drought and its relationship with achieving the SDG targets requires the formation of strategic partnerships and investments in territorial infrastructure, aiming to mitigate processes related to health and disease (Sena *et al*., 2016).

Azevedo and Resende (2025) add that sanitation is a human right that is the responsibility of governments, and that many governments do not consolidate public policies that guide universalization and equity of access to sewage, generating more inequalities in addition to impacting the environment.

Therefore, building a sustainable world requires a broader vision, recognizing ecosystems in balance and prioritizing collective well-being through collaboration between people, organizations, and governments. Partnerships and behavioral transformations are essential to underpin a new development paradigm (Berardi; Dias, 2018; Sena *et al.*, 2016), where changes in business dynamics, especially in the steel, chemical, and port industries, are crucial.

One of the challenges of climate change is energy consumption and CO2 emissions, particularly for the steel industry. In China's case, the potential for carbon dioxide reduction in 2020 will be 541.75 million tons and 856.68 million tons in the long term (Wang; Lin, 2016). Another area that contributes to high CO2 emissions is port activities, but some ports are already aware of their carbon footprint and how they replicate it, in addition to the need to consider emissions from waste treatment operations and employee commuting (Azarkamand *et al*., 2020).

The steel industry needs to adopt resource-saving practices, such as reverse logistics and material reuse. This not only extends product lifespans and reduces costs, but also expands companies' reach and boosts profitability. Decarbonizing the sector, recognized as one of the largest emitters of CO2, proves strategic for ensuring business sustainability while also contributing to mitigating environmental impacts and advancing toward a low-carbon economy (Circular Economy of the Brazilian Steel Sector, 2025).

Akiama and Spers (2024) point out that the circular economy in the steel industry in Brazil is linked to global circularity trends in the steel chain but still needs to improve in some areas to meet Agenda 2030, such as increasing the reduction of CO2 emissions, having good waste management, and financial and regulatory incentives aiming at a more efficient circular economy.

In this context, the circular economy emerges as an innovative model that permeates the entire production chain, proposing new ways of thinking and acting. According to the Organization for Economic Cooperation and Development (OECD), the five main circular business models are: product as a service, circular inputs, resource recovery, life extension, and sharing (Ekins *et al*., 2019). These models point out the way to overcoming the multiple forms of violence against people, animals, and the climate itself, promoting a virtuous cycle of environmental protection and social justice (Ekins *et al*., 2019).

Figueiredo (2024) argues that adapting the chemical industry to sustainability challenges involves replacing oil, coal, and natural gas with renewable raw materials, fostering the concept of biorefineries with the production of synthetic fuels from biomass, and providing platform molecules that replace traditional base chemicals such as fossil fuels. Plastic recycling is not only about reducing environmental contamination and CO2 emissions from plastic incineration, because non-recyclable plastics constitute a waste of valuable material. Recycling can be mechanical, the best known, but other methods include chemical recycling, such as thermochemistry and depolymerization.

Circularity in the chemical industry, focused on carbon dioxide gas, refers to the application of carbon as a raw material and transformed into methanol and liquid hydrocarbons, generating hydrogen from water through electrolysis and renewable electricity, resulting in green hydrogen (Figueiredo, 2024).

Luiz and Suski (2019) state that there is a direct influence between urban solid waste management and global warming due to the reduction of carbon dioxide gas through waste decomposition and the reuse of materials, thus preventing some significant parts of the production processes from (in)directly emitting gases that favor the increase in the greenhouse effect. Maia (2020) demonstrates that the recovery and recycling of solid waste from an association of waste pickers in Montes Claros achieved savings of enough water and energy to supply a population of 4,434 inhabitants for 20 days. Carvalho *et al*. (2025) warn about the increase in household solid waste generation in Minas Gerais, especially paper and cardboard, which reinforces the need for systemic interventions for waste management.

Vital (2018) emphasizes that the Paris Agreement imposed a condition for reducing greenhouse gas emissions, thus creating a global market for carbon trading. At the same time, the Chinese experience described by Zong *et al.* (2019) shows that efficient carbon emissions management can be a powerful tool for competitiveness and sustainability by creating tradable credits, encouraging clean development, and expanding the use of renewable energy in the global context.

Therefore, building smart and sustainable cities based on the premises of the circular economy depends on the coordination of public policies, governments at the micro, meso, and macro levels, business engagement, and the active participation of civil society. The circular economy, as a social innovation, is an effective response to climate change. Only through this joint effort will it be possible to advance toward SDG11 and its intersections with all the other SDGs, promoting prosperity, inclusion, and environmental balance for present and future generations.

We highlights that the Brazil has high potential in the role of transition to a low-carbon circular economy through global mobilization, with commitment, action and political initiatives such as the National Circular Economy Policy according to Bill No. 1,874 of 2022 (Brasil, 2022) and the National Circular Economy Plan that was approved on May 8, 2025 to establish goals and actions for the implementation of circularity in the economy over the next 10 years (Mont'Alverne; Holanda, 2025) with five axes: normative environment, innovation and education, waste reduction, financial instruments and interfederative articulation (Brasil, 2025).

3 Methodology

Quantitative and documentary research adopted (Sá-Silva *et al*., 2009; Sousa *et al*., 2007). Quantitative research involves the analysis of numbers to answer the research questions or hypotheses (Sousa *et al*., 2007). Documentary research allows the analysis of primary and secondary data according to the following narrative and is based on extracting data and making interrelations with other data and literature:

> The use of documents in research must be appreciated and valued. The wealth of information that we can extract and retrieve from them justifies their use in various areas of the human and social sciences because it makes it possible to broaden the understanding of objects whose understanding requires historical and sociocultural contextualization (Sá-Silva *et al*., 2009, p.2 tradução nossa).

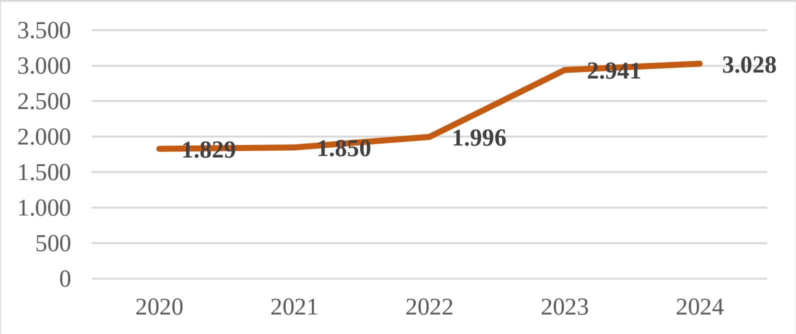
This method was chosen to analyze secondary data from a socioeconomic and environmental perspective, providing a broad and organized approach to the recycling process across Brazil. The data source used was the Recycling Yearbooks (2020 to 2024), which contain updated information on the recycling sector in Brazil.

Data extracted from the Recycling Yearbooks for the years 2020 to 2024 refers to the years 2019 to 2023. Quantitative data is presented in tables and graphs and tabulated using Excel software. The variables analyzed were: number of organizations, number of waste pickers in the organizations, quantity collected and destined for recycling by the organizations (in tons) and potential for carbon (CO_2) reduction in thousands of tons by type of material, energy savings by type of material (in millions of MWh), and virgin raw material savings by type of material, according to the availability of annual numerical data.

4 Results: analysis and discussion

Figure 1 shows the number of waste picker organizations in Brazil in absolute numbers from 2020 to 2024. There is exponential growth in the number of organizations above 65%, rising from 1,829 in 2020 to 3,028 in 2024. The average participation rate during this period was 2,329. This increase not only reveals greater waste collection capacity in urban areas, covering households, businesses, and public agencies, but also results in reduced environmental contamination and reduced disasters. Furthermore, it reflects greater opportunities for waste pickers to be included in organizations, accompanied by greater social protection (Carvalho *et al.*, 2025; Bordim *et al.*, 2022), a gradual reduction in social inequality (Tizziani *et al.*, 2025), and for companies contributing to better financial performance by contaminating the environment less (Vital, 2018; Zong *et al.*, 2019).

Figure 1 - Number of waste picker organizations in Brazil (2020 to 2024)



Source: Recycling Yearbook (2020 to 2024).

Table 1 shows the number of waste pickers in the organizations that agreed to participate in the annual survey. The variation in the number of recycling workers over these five years is evident. Women predominate in recycling organizations. In 2020, they had a total of 10,413 waste pickers. The COVID-19 pandemic saw a reduction in the number of waste pickers. In 2023, participation was high (86,878 waste pickers) and decreased in 2024 (70,608).

This does not mean that the number of waste pickers has decreased, but fewer organizations agreed to participate in the survey. The year 2023 refers to 2022 data, and there was a reduction in paper and cardboard disposal in the metal industries due to COVID-19, bringing other implications for the environment (Massuga *et al.*, 2022; Soares; Pinto, 2020). The predominance of female waste pickers is due to sexism and racism in Brazilian society, creating social inequalities and hindering their entry into the formal labor market. Another factor is that this activity corresponds to a social role, as it leads to social inclusion and empowerment for these women. Most are heads of households, and this role is a way to ensure family food security (Deiga Ferreira *et al.*, 2023). They are the group most affected by the effects of climate change and its impact on health (Sena *et al*., 2016).

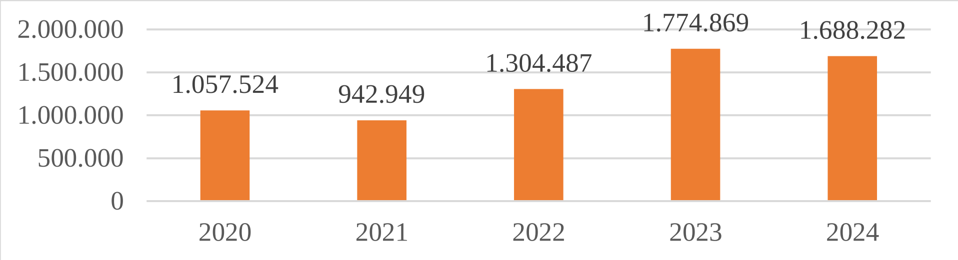
Table 1 - Number of waste pickers by gender from 2020 to 2024

Nº (%) of collectors by gender/Year	**2020**	**2021**	**2022**	**2023**	**2024**
Women	5.719 (55%)	5.287 (54%)	5.483 (54%)	46.519 (53,5%)	38.280 (54,2%)
Men	4.694 (45%)	4.467 (46%)	4.371 (44%)	40.359 (46,5%)	32.328 (45,8%)
Total	10.413	9.754	9.854	86.878	70.608

Source: Recycling Yearbook (2020 to 2024).

Figure 2 shows the quantity collected and destined for recycling by organizations, in tons (2020 to 2024), and the year 2023 stands out with the largest quantity of tons of materials for recycling and a potential estimate of a greater reduction in CO_2 emissions when compared to the year 2021. This also reflects greater adherence to the National Solid Waste Policy post-pandemic and the importance of mitigating damage to nature (Carvalho *et al*., 2025; Ribeiro *et al.*, 2014; Luiz; Suski, 2019) with the potential circular economy (Ekins *et al*., 2019; Figueiredo, 2024; Maia, 2020).

Figure 2- Quantity collected and destined for recycling by organizations, in tons (2020 to 2024)



Source: Recycling Yearbook (2020 to 2024).

Table 2 shows the potential for Carbon (CO_2) reduction in thousands of tons by material type over the last 5 years.

Table 2 - Carbon (CO_2) reduction potential in thousands of tons by type of material

Materials	**CO2 reduction potential (thousands of tons)**					**Total per year**	**% by material type**
By yearbook type/year	**2020**	**2021**	**2022**	**2023**	**2024**		

Paper/cardboard	22,8	20,5	23,4	108,6	71,70	247,0	8,6
Plastic	87,8	77,2	112,8	472,3	660,00	1.410,1	48,9
Glasses	1,2	0,5	0,9	2,3	351,8	356,7	12,4
Metals (aluminum and other metals)	63,0	55,0	145,3	293,1	313,00	868,9	30,1
Total	174,3	153,2	282,4	876,3	1.396,5	2.882,7	100

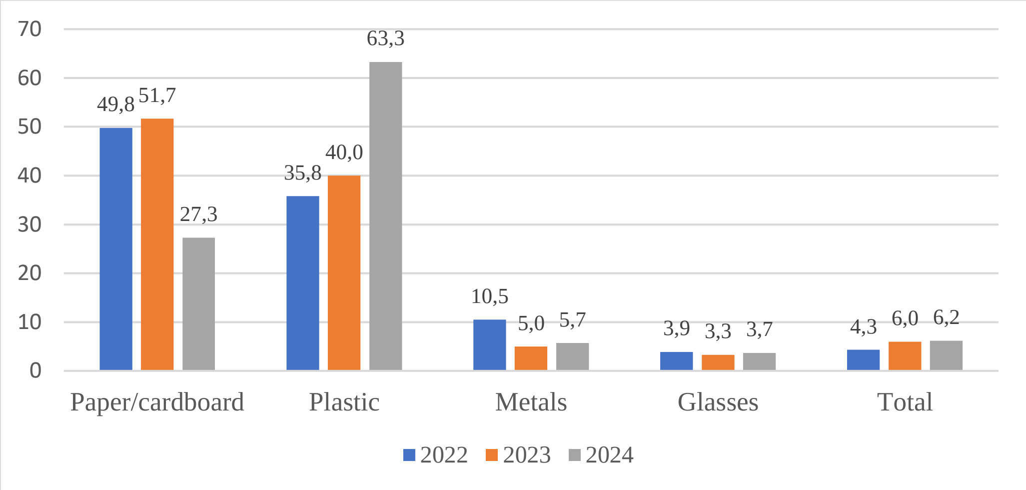
Source: Recycling Yearbook (2020 to 2024).

The material that contributed most to the potential for emissions reduction was plastic (48.9% fewer emissions into the atmosphere) due to the amount collected. As Figueredo (2024) states, plastic recycling prevents the waste of valuable material, reduces environmental contamination, and lowers CO2 emissions caused by incineration. The second material that contributed the least CO2 to nature was metal waste (30.1%), due to the high energy level expended in the production of virgin raw materials. In total, almost three million tons of materials were prevented from contaminating the environment and offset the generation of gases naturally emitted during the decomposition of solid waste, in this case, paper/cardboard and metals. Consequently, there was a lower production of virgin materials (plastics, metals, and glass) (Carvalho *et al*., 2025; Ribeiro *et al*., 2014).

There is a direct relationship between organizations, waste pickers, and recycled production that enables CO2 emissions to be reduced. Therefore, this marginalized political group needs to be valued, because without their involvement in the circular economy, climate change would be more severe and solar warming would increase.

Figure 3 shows the energy savings by material type, in millions of MWh, between 2022 and 2024. There was a percentage increase in plastics in the total materials collected and sold by waste picker organizations, triggering an increase in energy savings in 2024 compared to 2023. There was a decrease in the total amount of materials collected and sold, except for paper/cardboard. The recovery and recycling of solid waste leads to savings not only in energy but also in water, as Maia (2020) points out, the reduction in energy and water consumption was enough to supply 4,434 people for 20 days.

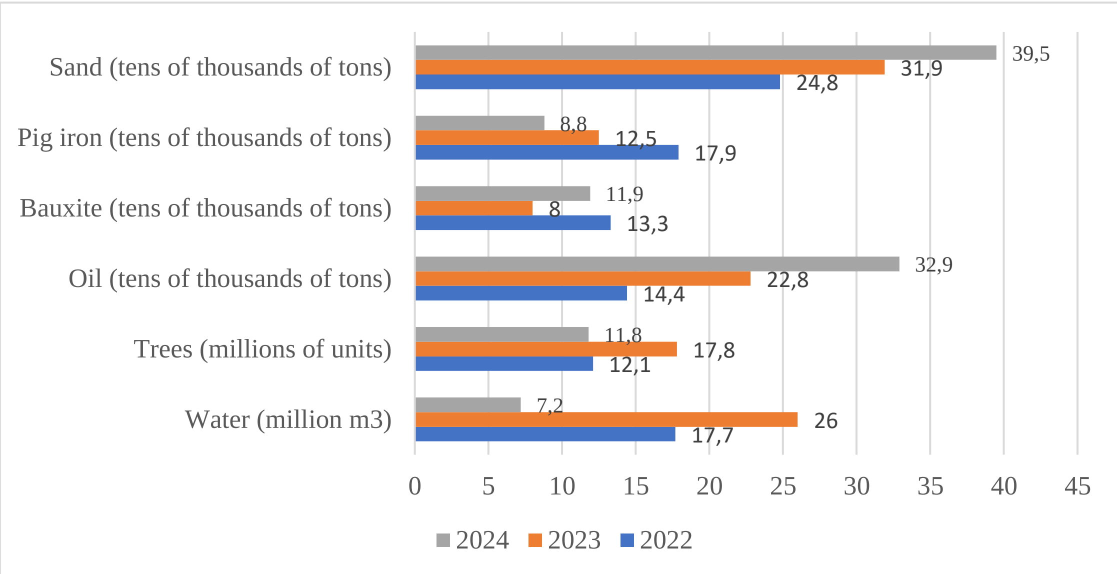
Figure 3 - Energy savings by material type, in millions of MWh, between 2022 and 2024



Source: Recycling Yearbook (2024).

Figure 4 shows the savings in virgin raw materials by type of material during the period from 2022 to 2024.

Figure 4- Savings in virgin raw materials by type of material, between 2022 and 2024



Source: Recycling Yearbook (2024).

The actions of waste picker organizations influenced the amount of raw material savings. There was an increase in the savings of oil (32.9) and sand (39.5) in 2024, and in 2023, the savings of sand (31.9), oil (22.8), trees (17.8), and water (26.0) increased. The growth in the oil economy was due to the increase in plastic in the total materials and the reduction in its role in saving water and trees. These data, despite the low participation of waste picker organizations, demonstrate that Brazil is committed to reducing CO2 and the environmental impacts resulting from climate change, and the chemical and steel industries and the population have contributed to this savings in raw materials (Akiama; Spers, 2024; Circular Economy of the Brazilian Steel Sector, 2025; Ekins *et al.*, 2019; Figueiredo, 2024).

5 Conclusions

Analysis of data from the Recycling Yearbook (2020-2024) highlights a direct relationship between the growth in the number of waste picker organizations and the increased potential for reducing CO2 emissions from urban solid waste recycling. The expansion of these organizations, which jumped from 1,829 in 2020 to 3,028 in 2024, is associated with the increased collection and proper disposal of recyclable materials, especially plastics, metals, and paper/cardboard, which together account for more than half of the reduction in carbon emissions.

Plastics stand out, representing 48.9% of the potential for emission reduction, followed by metals (30.1%) and paper/cardboard, reinforcing the strategic role of these materials in mitigating environmental impacts. Strengthening associations and the circular economy, in addition to promoting environmental gains, contributes to reducing social inequalities, especially by guaranteeing income and prominence to women waste pickers, who make up more than half of these organizations. On the other hand, simply trading carbon credits can discourage the effective adoption of circular practices by creating a false sense of environmental commitment without addressing the underlying causes of the problem. It is essential to prioritize policies that value the closed material cycle and the leading role of cooperatives in a sustainable urban context. On the other hand, the carbon market favors economic growth.

Among their contributions, it is worth highlighting that waste picker organizations are a key driver for the social inclusion of socially vulnerable people, the empowerment of women, and the reduction of water and energy consumption, which reduces environmental impacts.

Climate change affects women and men differently, with women being more impacted due to being more vulnerable due to low access to resources, education, land, technology, and participation in political and economic decisions resulting from historical patriarchy. Therefore, it is necessary to promote gender equality, making it possible to obtain greater effectiveness of climate change mitigation and adaptation strategies, as women and men play diversified roles and responsibilities in relation to the environment and their needs. To face the complexity of climate challenges, plural and transversal solutions are urgent (Matos *et al*., 2023).

The patriarchal consequences in Brazil still guarantee the subordination of women in the domestic space and exclusion in the formal labor market that mainly requires education, mastery of technologies, making it impossible for women, especially black women, who suffer the intersectionality of sexism, racism, classism, generating social and racial inequalities and imputing to black women survival at the base of the social pyramid, because poverty is a black female stronghold (Ferreira; Carvalho, 2025).

It is necessary to reduce gender and race inequalities in the circular economy by a criterion of social and climate justice, and for this, public policies for the empowerment of women, especially black women, who are the majority because of the crossing of oppressors of race, gender, and social class, are fundamental. Matos *et al*. (2023) point out the need to promote a symbolic relationship between climate justice and social justice, as one contributes to the other, because climate effects are increasingly intense and affect the most vulnerable populations and those on the margins of society. This group has no active voice in decision-making and faces low opportunities and basic resources that can guarantee protection and the ability to react in the face of severe weather events.

The limitations lie in the fact that this is secondary data and corresponds to the organizations that agreed to participate in the survey. To provide a more realistic picture of recycling, all registered organizations should be encouraged to participate, enabling the identification of barriers and challenges to the circular economy.

Suggestions for future research include investigating why organizations do not participate in the surveys, whether they have difficulty understanding the terms for investing in training and development for all interested parties, and having public financial action that can encourage participation and show how much Brazil has the potential to reduce CO2 emissions to the world and thus increase credits to boost other SDGs such as SDG 1 (no poverty), SDG 2 (fighting hunger), SDG 3 (health and well-being), SDG 4 (quality education), SDG 9 (industry, innovation, infrastructure), SDG 10 (reduction of inequalities), SDG 11 (sustainable cities and communities), SDG 13 (climate action) and SDG 17 (partnerships for the means of implementation) (UNESCO, 2019).

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Environmental Economic Valuation and the System of National Accounts for Green Gross Domestic Product calculation: a bibliometric analysis between 1945 and 2022

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Abstract
This article is a theoretical essay that presents the state-of-the-art relationship between Environmental Economic Valuation and the System of National Accounts (SNA), unifying accounting, and economic elements to develop future indicators for Green Gross Domestic Product (Green GDP) calculation. Several studies have emerged to define, classify, and measure ecosystem services in recent decades. Nevertheless, there are still gaps in the quantification and disclosure of natural capital. The quantification of natural capital is essential in the System of Environmental-Economic Accounting (SEEA). By including environmental information in the traditional SNA, the SEEA makes it possible to estimate macroeconomic aggregates more rigorously for the Green GDP. Methods and procedures are needed to make these estimates viable that allow monetary assessment of ecosystem goods and services that do not have a market price and the depletion or depreciation of the stock of resources that make up the national ecological heritage. This paper is exploratory and quantitative research based on a bibliometric analysis of scientific publications on GDP, Green GDP, and economic valuation from 1945 to 2022, prospected on the Web of Science database. There are publications on the proposed theme on all continents, emphasizing Europe, Asia, North America, and Africa, and the low representation of South America. There are a predominance of universities and Research and Development (R&D) organizations among the institutions. Some retrieved documents are papers published by institutions that do not develop R&D activities like the

financial system, showing interest in the subject aiming for competitiveness in its market. There is a need for further research to develop and validate indicators to obtain Green GDP, including the natural capital. The ratification of several international agreements and protocols related to the environment also can stimulate the application of economic valuation methods to guarantee the adequate inclusion of environmental assets in the calculation of national wealth.

Keywords: Environmental Accounting; Natural Capital; System of Environmental-Economic Accounting.

Resumo
Este artigo é um ensaio teórico que apresenta o estado da arte da relação entre a Valoração Econômica Ambiental e o Sistema de Contas Nacionais (SCN), unificando elementos contábeis e econômicos para desenvolver indicadores futuros para o cálculo do Produto Interno Bruto Verde (PIB Verde). Diversos estudos surgiram para definir, classificar e mensurar os serviços ecossistêmicos nas últimas décadas. No entanto, ainda existem lacunas na quantificação e divulgação do capital natural. A quantificação do capital natural é essencial no Sistema de Contas Econômicas Ambientais (SEEA). Ao incluir informações ambientais no SCN tradicional, o SEEA possibilita estimar agregados macroeconômicos com mais rigor para o PIB Verde. Métodos e procedimentos são necessários para viabilizar essas estimativas que permitam a avaliação monetária de bens e serviços ecossistêmicos que não possuem preço de mercado e o esgotamento ou depreciação do estoque de recursos que compõem o patrimônio ecológico nacional. Este artigo é uma pesquisa exploratória e quantitativa baseada em uma análise bibliométrica de publicações científicas sobre PIB, PIB Verde e valoração econômica de 1945 a 2022, prospectadas na base de dados *Web of Science*. Há publicações sobre o tema proposto em todos os continentes, com ênfase na Europa, Ásia, América do Norte e África, e a baixa representatividade da América do Sul. Há predominância de universidades e organizações de Pesquisa e Desenvolvimento (P&D) entre as instituições. Alguns documentos recuperados são artigos publicados por instituições que não desenvolvem atividades de P&D como o sistema financeiro, demonstrando interesse no tema visando competitividade em seu mercado. Há necessidade de mais pesquisas para desenvolver e validar indicadores para a obtenção do PIB Verde, incluindo o capital natural. A ratificação de diversos acordos e protocolos internacionais relacionados ao meio ambiente também pode estimular a aplicação de métodos de valoração econômica para garantir a inclusão adequada dos ativos ambientais no cálculo da riqueza nacional.

Palavras-chave: Contabilidade Ambiental; Capital Natural; Sistema de Contabilidade Ambiental-Econômica.

1. Introduction

In the last forty decades, several publications have sought to define, classify, and measure ecosystem services to highlight the importance of natural capital. The aim is to encourage the conservation of goods and services considered significant for humanity and relevant to social and economic well-being. The definitions, classifications, and measurements of ecosystem services follow the 17th Convention for the Protection of World, Cultural, and

Natural Heritage precepts held in 1972 by the General Conference of the United Nations Educational, Scientific and Cultural Organization (UNESCO).

The Millennium Ecosystem Assessment (MEA, 2005) presented the relationship between ecosystem services and social well-being to support decision-making by political and economic agents. However, Cruz-Garcia et al. (2017) emphasize that there are studies that present the relationship between ecosystem services and social well-being, but without robust results and linked to some economic models. This fact brings up the reflection that there still needs to be more consensus on the limits a model should apply to quantify and disclose natural capital (Eigenraam; Obst, 2018).

Criteria such as spatial limits, connections with other systems, and the fundamental boundaries and links between ecosystem services and human well-being can be considered essential for developing a conceptual framework that addresses the relationship between ecosystem services and social welfare (Eigenraam; Obst, 2018). Despite its relevance, the result of a conceptual framework is beyond the scope of this article. Our focus here is to highlight the state-of-the-art relationship between the Economic Valuation of the Environment and the System of National Accounts (SNA) from a bibliometric analysis.

The SNA has limitations that have been widely analyzed by several economists, emphasizing the referenced study by Stiglitz, Sen and Fitoussi (2009) for the French government. One of them is the inability to integrate economic flows and variations in the stock of natural capital (environment). For example, in a first analysis, the Gross Domestic Product (GDP) measures the final goods and services produced in an economy at a specific time, characterized as a flow indicator. However, to generate wealth flows, we can degrade wealth stocks (an area of natural vegetation), reducing their economic value. Thus, one of the issues that limit the disclosure of socioeconomic-environmental information is the non-inclusion of the environmental system, evidencing the degradation and preservation of the environment, such as depollution and decontamination activities, forest recovery, and soil regeneration, in the calculations of a socioeconomic indicator (King et al., 2021).

To overcome or minimize these limitations, the System of Environmental-Economic Accounting (SEEA) was developed. SEEA is a National Accounting standard for the interconnection of economic and environmental data. For example, the Green GDP must quantify and qualify the natural ecological heritage, that is, measure the wealth of a nation's natural capital, thus being an indicator of stock. Realizing this distinction, the SEEA must consider this particularity for possible integration with the SNA.

The SEEA uses the principles adopted in measuring the standardization of the economic system in all countries. However, validated methodologies are scarce for including natural capital in calculating national wealth. Evidencing this scarcity is the north for the execution of this study. For this, the objective of this article is to present the state-of-the-art relationship between Environmental Economic Valuation and the SNA in scientific publications for further comprehension of the points of progress that will favor the calculations of the Green GDP.

The results of this study can be data-driven to identify scientific gaps to further development and implementation of efficient policies towards economic growth and environment preservation. This combination is also an important path for expansion of the SEEA worldwide implementation.

2. Theoretical foundation

The Convention on Biological Diversity (CBD), established at the United Nations Conference on Environment and Development (UNCTAD), also called "Rio-92" and that took place in Rio de Janeiro in June 1992 has three fundamental pillars: the conservation of biological diversity, the sustainable use of biodiversity, and the fair and equitable sharing of benefits arising from the use of genetic resources (UN, 1992). In this context, the CBD also incorporates social issues with traditional communities[1] (Thorstensen; Mota, 2021). As a result, the convention is considered one of the most important international environmental instruments and the first legal framework for biodiversity in some countries (Chandra; Idrisova, 2011).

The integration of ecosystems in the planned actions of the public and private sectors meets the goals established both in the Convention on Biological Diversity (CBD) and in the Sustainable Development Goals (SDGs) of the 2030 Agenda, in particular SDGs 2 (zero hunger), SDG 9 (industry, innovation, and infrastructure), SDG 11 (sustainable cities and communities), SDG 12 (responsible consumption and production), SDG 13 (climate action), SDG 14 (life below water) and SDG 15 (life on land). The mentioned SDGs allow us to verify

[1] According to item I of paragraph 3 of Decree No. 6,040, of February 7th, 2007, traditional communities are culturally differentiated groups that are recognized as such, that have their own forms of social organization, that occupy and use territories and natural resources as a condition for their cultural, social, religious, ancestral, and economic reproduction, using knowledge, innovations and practices generated and transmitted by tradition (Brazil, 2007).

that the goals involved link ecosystems (SDG 13, SDG 14, SDG 15) to society (SDG 2) and the economy (SDG 9, SDG 11, SDG 12) that are funneled in SDG 17 (partnerships and means of implementation) (Gois; Issifou; Anjos, 2022).

2.1 Natural Capital

An asset is a right that can produce economic benefits from past events expressed in the present currency for future profit. Environmental assets refer to the ecosystems, their biodiversity, live or dead, and their services to provide human well-being and survival (*e.g.*, plant pollination by bees and leisure). Therefore, these assets have unique characteristics whose accounting recognition procedures raise doubts (Anjos; Issifou, 2022).

With the continuation of scientific research to provide better concepts and methods for better accounting recognition of environmental assets, the term "natural capital" was created. It is based on the principles of economics, being a recent and emerging concept of the environment, which develops in systems (ecosystems) and does not fit into a marginal analysis; this requires metrics and evaluation methods that reflect their actual condition in economic systems, and extrapolate the measurability of flows of ecosystem services (Barbier, 2019; Helm, 2019; Mace, 2019). Thus, the monetary value attributed to natural capital can generate reserves and industrial applications for the future (Nogueira; Medeiros; Arruda, 2000). However, Martins (2021) highlights that the concept of natural capital only as raw material for industrial processes neglects its indirect use, quasi-option, and existence values, generating the need for a better definition of methods for financial measurement.

The link between biodiversity and different ecosystems, in various stages of conservation and with the socioeconomic variety found worldwide, constitutes a great challenge that requires a complex integration process. This link aims to achieve efficient management of ecosystems, aligning economic development with the rational use of natural capital; this is because ecosystem management aims to sustain the flow of services provided to society and is aligned with the sovereignty of the country in its natural capital, according to the CBD and the Nagoya Protocol, a supplementary document to the CBD that reinforces such sovereignty (Thorstensen; Mota, 2021).

This work proposes the connection between the conservation of biological diversity and the sustainable use of biodiversity, associated with the pillars of the convention, as both are fundamental for maintaining human life on Earth. Assuming that only what is quantified is measured, the quantification and disclosure of natural capital are necessary to achieve the proposal of this work, including considering the depletion of natural capital to support the calculation of the Green GDP. Ratifying Boyd (2007), possibly for this, one of the most important instruments that the economic literature makes available is the economic valuation of the environment.

2.2 Economic Valuation of the Environment (VEMA)

The economic valuation of environmental assets reflects ecosystem services and biodiversity in monetary value. Doing so is a strategic and necessary mechanism to show the relevance of the environment to society and the consumer market (Baveye; Baveye; Gowdy, 2013), contributing to its preservation and rational use (Nogueira; Medeiros; Arruda, 2000). Therefore, natural capital becomes a measurable asset and can be included in national accounts (Dasgupta, 2021).

Smesaert, Missemer and Levrel (2020) include valuation as a process of commoditization and conversion of goods and services into marketable products. Hahn et al. (2015) reinforces this concept by pointing out that there was an expansion in the use of economic tools that allowed the scaling up of funding for biodiversity. The signing of the CBD in 1992 and the publication of legal frameworks such as Law # 13,123/2015 in Brazil reinforce the inclusion of economic exploitation and the applicability of methods that allow obtaining monetary values of intermediate or final products from access to native genetic heritage. In his study, Anjos (2020) detected the importance of valuing and pricing biodiversity assets to subsidize conservation regulation and undo market distortions; this represents a paradigm shift from predatory use to a sustainable model (Andrade, 2017).

The pricing of biodiversity and ecosystem services is a challenge for world science as it is outside official foreign trade statistics (there are no codes that promote the distinction of biodiversity assets from fossil assets, for example) (Silva; Pereira; Martins, 2018). This fact causes a mistaken and subjugated perception of the economic importance of biodiversity. Therefore, it induces market failures by imputing values with empirical methods and concepts that do not apply to reality (Nogueira; Medeiros; Arruda, 2000), in addition to enabling a better measurement of abiotic impacts (rain, drought, cold, heat, for example) with economic indicators of biodiversity (King et al. 2021).

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In this context, the economic valuation of the environment tends to be necessary to include the environmental perspective in the SNA, in other words, to adjust the GDP that we currently know into the Environmental Economic Accounts integration. Thus, through the economic valuation of the environment, it is possible to attribute qualitative and quantitative value to environmental resources, contributing to the calculation of the Green GDP (Gois; Nogueira, 2020). Also, the depletion (or depreciation) of the natural capital must be valued to be considered in the System of Environmental-Economic Accounting (SEEA) calculation as a reducer of the natural ecological heritage.

2.3 National Accounts System and System of Environmental-Economic Accounting

The SNA was established under the leadership of the UN and adopted for calculating macroeconomic aggregates, including GDP. As a result, the SNA generates several indicators that can guide, assess, and manage the economic growth of a nation (Mueller, 2012). In particular, the GDP calculation is used by all countries to measure the production of goods and services in a given place in a fiscal year, as national accounts were developed to provide an overview of the state of the economy over a while.

The essence of the SNA procedures is based on a Keynesian macroeconomic model, including elements of the microeconomic theories of general equilibrium and well-being (Mueller, 2012). Thus, national accounts have limitations, such as the fact that the assessment of a nation's economic and social well-being must consider not only activities that have a market value but must consider activities without market value.

According to Mueller (2012), although the SNA provides a consolidated set of aggregated indicators with consistency and solidity, it must be considered that there is a significant deficiency (or omission) of the system in recording the impacts of the economic system on the environment. In a complementary way, regarding the macroeconomic aggregates considered for the measurement of GDP, Feijó and Ramos (2017) go into greater detail concerning this criticism and mark that the national accounts omit or fail to include several activities that do not have a market value, including depletion of natural resources and that reiterate the explanation of Nogueira, Medeiros and Arruda (2000) in the last section. Feijó and Ramos (2017) also comment that the GDP calculation includes things that do not make a country more prosperous. For example, it increases with polluting activities that deplete the stock of natural resources.

Young, Pimenteira and Almeida (2018) comment that one of the alternatives to solve the absence of the calculation of activities that do not have a market value, such as the depletion of natural resources, would be the construction of satellite accounts. In doing so, the conventional GDP calculation metric would remain unchanged, adding environmental information on the depletion of natural resources as a form of GDP adjustment. An alternative would be the complete formulation of new information on aggregation systems that would not be restricted to transactions of an economic nature.

In this sense, returning to the criticism of GDP, it is a macroeconomic indicator that measures the productivity of economic activity. Nevertheless, it does not measure the wealth of natural ecological heritage through quantifying and disclosing natural capital. The GDP reflects, in its composition, the degradation of this heritage, considering that to produce goods and services, it is necessary to use natural capital, which causes the depletion of the natural ecological heritage (Mueller, 2012; Young; Pimenteira; Almeida, 2018).

With the development of GDP analysis, it became evident that macroeconomic aggregates hide costs and treat expenditures associated with environmental regeneration, protecting individuals and families from the effects of environmental degradation as income, therefore, as an indicator of well-being. Furthermore, the asymmetric treatment given to elements of a country's heritage, such as built capital (factories, machines, vehicles, buildings), whose variation is carefully monitored by the SNA, and natural capital (natural resources such as soils, mineral reserves), whose variation is not registered by the system (Mueller, 2012).

Considering that the SNA treats the economy as an isolated system in which transactions do not interact with the environment, ignoring the impacts of production and consumption activities. Because of this, it generates indicators and aggregates that provide a distorted view of what happens in the economic system, with deficiencies and omissions in the system, as Mueller (2012) relates:

1. The SNA ignores the depreciation of the economy's natural capital stock.
2. The SNA does not consider the costs of environmental degradation.
3. The expenses resulting from environmental degradation are included in the economy's GDP.

The deficiencies above reduce the importance of macroeconomic aggregates, which do not show the impact of the economic system on the environment. Therefore, different actions were initiated to review the methodologies and practices of the current SNA to correct these flaws.

In the mid-1980s, studies were carried out to reform the SNA to include aspects of the environmental dimension, developed jointly with the United Nations Statistical Office, the World Bank, and statistical organizations in some countries. In these studies, it is concluded that an auxiliary system should be developed, with a set of environmental satellite accounts, to be coupled to the central core of the SNA, which allows the generation of aggregate indicators that capture aspects of the relations of the economic system with the environment. In this way, the System of Economic-Environmental Accounting (SEEA) emerged, which brought some discussions on the main aspects of this system:

1. treatment of depletion (depreciation) of natural capital.
2. treatment of the costs of environmental degradation generated by the economy.
3. costs of preventing and defending against the effects of environmental degradation.

In this sense, as a response to the deficiency of the SNA, due to the limitations of information only from the economic system, in an isolated way, the SEEA aims to include data and environmental information in the SNA through the environmental satellite accounts, integrating the economic and environmental systems.

From the discussions held by the World Commission on Environment and Development in 1987 (UN; WCED, 1987), studies were carried out and brought proposals that were approved and adopted, such as the creation of the Integrated System of Economic and Environmental Accounting (SICEA) of the UN in 1993. It was updated in 2003, and the last version of this methodology was published in 2012, known as SEEA, which generated a UN framework that integrates economic and environmental data to provide a more comprehensive and multifunctional view of the interrelationships between the economy, the environment and stocks and changes in stocks of environmental assets, contributing benefits to humanity (Barcellos; Carvalho, 2018).

2.4 Application of VEMA in SEEA development

The biggest challenge for developing the SEEA is identifying the most appropriate methodology, integrating ecosystem resources into the SNA, and identifying and recognizing biodiversity, ecosystems, and ecosystem services as the country's natural capital. For example, Joly et al. (2011) pointed out the necessary relationship between biodiversity and ecological processes to valuation mechanisms and valorization of ecosystem services as a form of preservation and rational use.

King et al. (2021) reinforce the issue by pointing out the importance of considering gamma diversity and extrapolating changes in the occurrence of species in different places and times in the development and application of indicators that will encourage the calculation of the Green GDP in addition to allowing the inclusion of social indicators. Therefore, new production boundaries to balance environmental processes with human or economic processes must be reconsidered to integrate ecosystem services to SNA and extrapolate the production boundary of GDP to obtain the Green GDP (Obst; Hein; Edens, 2016).

The ecosystem services and the impact on human well-being are the standards of the SEEA. Therefore, the first step is quantifying physical flows from environmental assets to its clients and beneficiaries (Pelletier; Heagney; Kovač, 2021). At this point, economic valuation techniques can insert biodiversity into economic systems, generate data for application in SEEA, and obtain monetary values consistent with SNA principles (King et al., 2021; Pelletier; Heagney; Kovač, 2021). In addition, economic valuation allows the articulation of biodiversity, ecosystem services, and benefits generated in a broad view, such as that of an invasive species that can enhance pollination in an ecosystem (King et al., 2021).

The advantages of the economic valuation methods of the environment are evident. However, deficiencies and limitations still reduce their application in the calculation of the Green GDP with the inclusion of environmental indicators in the calculation of GDP (Hoff et al., 2021). At this point, Daly and Cobb (1989), mentioned by Li and Fang (2014), comment that the current SNA treats ecosystems as a "business in liquidation." As a result, the usual methods of calculating the Green GDP do not incorporate environmental sustainability as they ignore the benefits generated by ecosystem services to society, and successful experiences are specific and regional in scope (Li; Fang, 2014).

Yuan, Lo and Yang (2017) confirm the indication by King et al. (2021) when stating that the valuation of ecosystem services would generate essential proxies for calculating the Green GDP. However, Li and Fang (2014) point out the low number of scientific studies that relate the integration of the valuation of environmental assets with the usual economic and accounting precepts, which generates gaps due to the lack of reliable data and measures. Therefore, the development of a dashboard of indicators is important to encourage countries to adopt valuation techniques to obtain the real monetary value of ecosystems for a better calculation of Green GDP, to engage public policies, and to develop economic and accounting definitions of sustainability (Comte et al., 2022).

3. Methodology

The research is bibliographic and documentary using scientific publications retrieved on the Web of Science database (WoS) by Clarivate Analytics and accessible through the site "Periódicos da CAPES"[2] on April 21st, 2022. The temporality of the research execution was between 1945 and April 21st, 2022, and the indicators used were: years of publication, WoS categories (scientific areas), countries, institutions, authors, journals, and citations. The scientific areas refer to the WoS indexing areas for each publication inserted in the database, which can facilitate the necessary filtering and assess some degree of multidisciplinarity in the search. The WoS option for the search was made because it is the oldest database, with publications from 1945 onwards, for having a *template* that favors the detailing of the indicators to be used and for creating extra keywords that increase the retrieval of scientific publications.

The search was performed by combining keywords in English that encompass GDP, valuation, and accounting in the "Topic" field, which allows combining searches in titles, abstracts, authors' keywords, and extra keywords that WoS inserts. Each search term was combined using the Boolean operators "AND" to search for documents that integrate the search words and "OR" to search for variations in GDP indexing, and the wildcard character "asterisk" (*) was also used to include spelling variations in search terms and increase the number of documents retrieved. The search was then redone, changing the term GDP to "Green GDP" to compare this result with the macro search. In both searches, grey literature, such as institutional reports, working papers, government documents, dissertations, theses, and proceedings of technical-scientific events, were excluded from the corpus to mitigate potential biases of the possible lack of scientific accuracy (Cui; Zhang, 2024) (Figure 1)

[2] Foundation linked to the Brazilian Ministry of Education, whose initials means "*Coordenação de Aperfeiçoamento de Pessoal de Nível Superior*, or "Coordination for the Improvement of Higher Education Personnel" in English.

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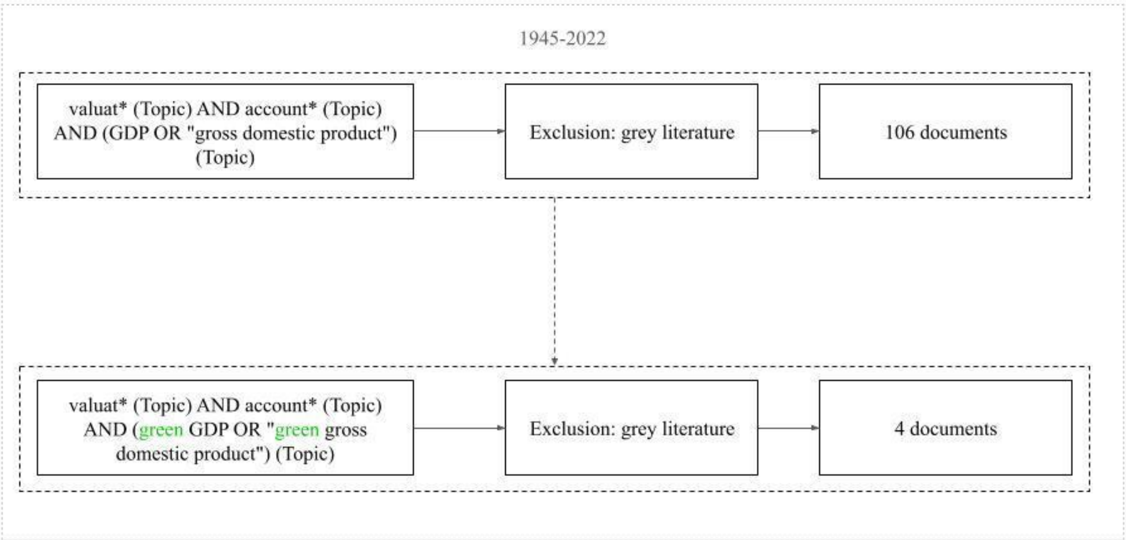

Figure 1: Search protocol. Source: Own elaboration.

One of the advantages of WoS is the compatibility of recovered data with VantagePoint (Search Technology) and VOS Viewer (Leiden University) softwares for mining and processing bibliometric data. Raw data were extracted and processed in VantagePoint, which allows mining, cleaning bibliometric data extracted from databases such as WoS, crossing, and decomposing data to allow better visualization and interpretation (Miles; Saritas; Sokolov, 2016). VOS Viewer analyzes raw data extracted from databases and uses algorithms that organize the information into clusters by the distance between the data and the size of the figure corresponding to the numerical representation of each data (Miles; Saritas; Sokolov, 2016; Smesaert; Missemer; Levrel, 2020).

4. Results and discussion

The results of searches for scientific publications are described in Table 1.

Table 1: Result of the bibliometric search

Search strategy	Temporality	Number of documents retrieved
valuat* (Topic) AND account* (Topic) AND (GDP OR "gross domestic product") (Topic)	1945-2022	106

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valuat* (Topic) AND account* (Topic) AND ("green GDP OR "green gross domestic product") (Topic)	1945-2022	4

Source: Own elaboration.

The number of documents that refer to the Green GDP represents only 3.77% of the total documents retrieved in the broader search, where the four publications are contained (Table 2):

Table 2: Result of the bibliometric search using "green GDP" or "green gross domestic product" in the search strategy

Authors	**Institutions**	**Country**	**Title**	**Periodical**	**Year of Publication**
Hans Werner Holub, Gottfried Tappeiner, Ulrike Tappeiner (Holub; Tappeiner; Tappeiner, 1999)	University of Innsbruck	Austria	Some remarks on the System of Integrated Environmental and Economic Accounting of the United Nations	Ecological Economics	1999
James Boyd (Boyd, 2007)	Resources for the Future	USA	Nonmarket benefits of nature: What should be counted in green GDP?	Ecological Economics	2007
Guangdong Li, Chuanglin Fang (Li; Fang, 2014)	Chinese Academy of Sciences; University of Chinese Academy of Sciences	China	Global mapping and estimation of ecosystem services values and gross domestic product: A spatially explicit integration of national 'green GDP' accounting	Ecological Indicators	2014

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Mei-Hua Yuan, Shang-Lien Lo, Chih-Kai Yang (Yuan; Lo; Yang, 2017)	National Taiwan University	Taiwan	Integrating ecosystem services in terrestrial conservation planning	Environmental Science and Pollution Research	2017

Source: Own elaboration.

Baveye, Baveye and Gowdy (2013) reported the development of works that refer to the economic valuation of ecosystem services from Ancient Greece, with Plato's perceptions about the relationship between deforestation of forests, soil erosion, and drier springs. From the end of the 1940s onwards, works were published that proved human dependence on the environment, and market distortions, such as those by the Romanian economist Nicholas Georgescu-Roegen.

Even with the temporality of the search starting in 1945, the first article retrieved was published in 1993. Ivanov et al. (1993) described the deployment of the SNA in the Commonwealth of Independent States republics. Between 1993 and 2006, some publications and numbers increased from 2007 onwards (Figure 2). According to Baveye, Baveye and Gowdy (2013), the theme "monetization of ecosystem services" was officially launched in 1997, which is similar to the findings of this study and confirms that the use of economic valuation methods for ecosystems and their services is recent and there are few positive experiences in the calculation of Green GDP, as pointed out by Li and Fang (2014).

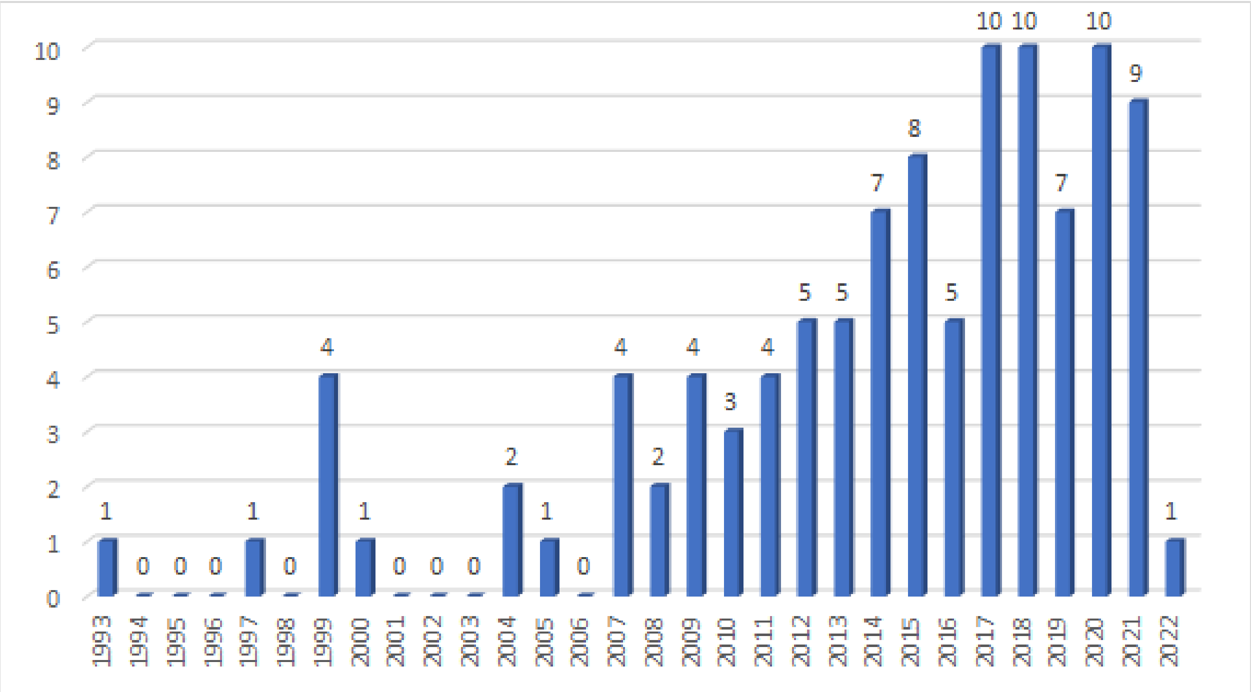

Figure 2: Years of publication of the 106 retrieved documents. Source: Own elaboration.

Table 3 presents the scientific areas with more than one occurrence on the retrieved documents. These areas are WoS categories divided into five groups (Arts & Humanities, Life Sciences & Biomedicine, Physical Sciences, Social Sciences, and Technology) that index and

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categorize the documents on the database important for further analysis (CLARIVATE ANALYTICS, 2025).

Table 3: Web of Science categories of the documents retrieved

Ranking	**# Records**	**Web of Science Category**
1	49	Environmental Sciences
2	43	Economics
3	13	Ecology
4	11	Business, Finance
5	5	Engineering, Environmental
6	5	Forestry
7	5	Green & Sustainable Science & Technology
8	5	Public, Environmental & Occupational Health
9	4	Business
10	4	Multidisciplinary Sciences
11	3	Agricultural Economics & Policy
12	3	Meteorology & Atmospheric Sciences
13	2	Biodiversity Conservation
14	2	Energy & Fuels
15	2	Health Policy & Services
16	2	International Relations
17	2	Management
18	2	Oceanography
19	2	Social Sciences, Interdisciplinary
20	2	Urban Studies
21	1	Critical Care Medicine
22	1	Development Studies

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Ranking	# Records	Web of Science Category
23	1	Engineering, Chemical
24	1	Entomology
25	1	Ergonomics
26	1	Food Science & Technology
27	1	Health Care Sciences & Services
28	1	Infectious Diseases
29	1	Marine & Freshwater Biology
30	1	Materials Science, Multidisciplinary
31	1	Neurosciences
32	1	Nursing
33	1	Obstetrics & Gynecology
34	1	Parasitology
35	1	Pediatrics
36	1	Political Science
37	1	Psychiatry
38	1	Regional & Urban Planning
39	1	Respiratory System
40	1	Social Issues
41	1	Transportation
42	1	Tropical Medicine
43	1	Water Resources

Source: Own elaboration.

Figure 3 presents the autocorrelation map between the WoS categories with more than one occurrence (1st to 20th positions on Table 3's ranking). This map presents the correlations between scientific areas of the documents retrieved in the search. The size of each circle

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represents the number of documents, and the thickness of the lines represents the degree of correlation.

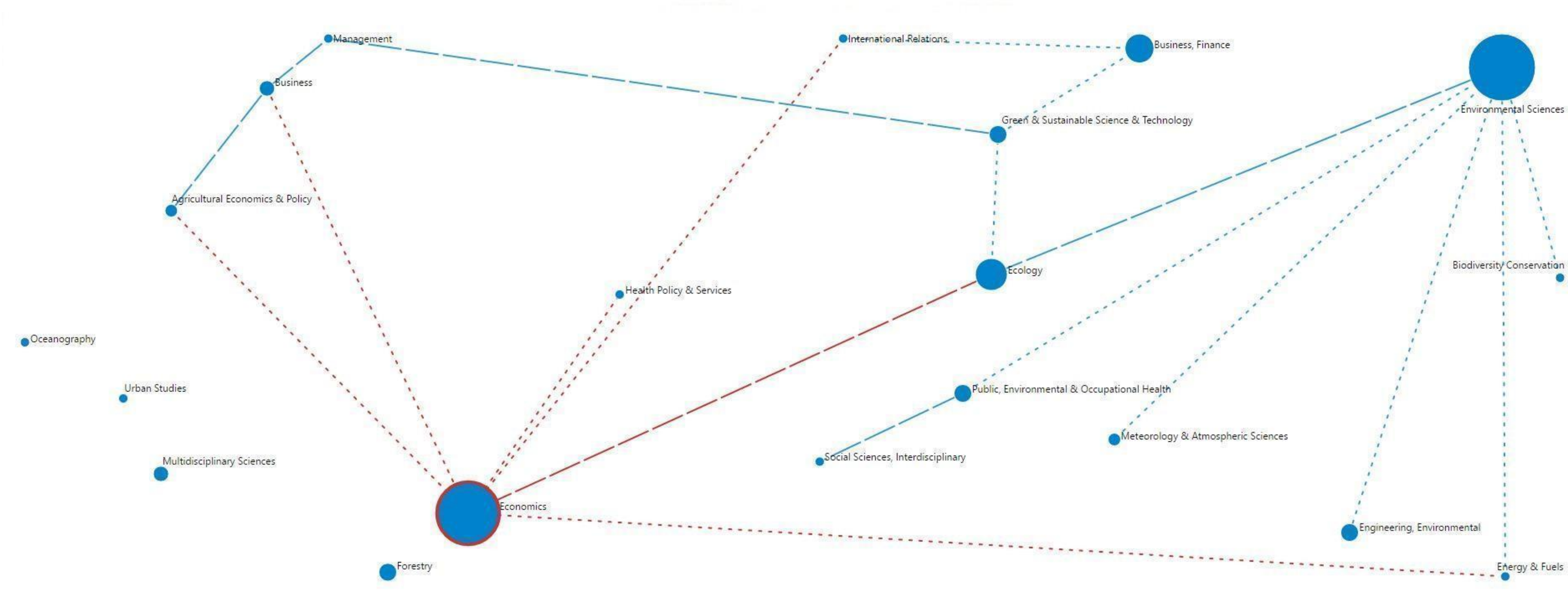

Figure 3: Autocorrelation map constructed on VantagePoint software between Web of Science categories on Table 3, with highlights on the Economics scientific subject. Source: Own elaboration

Economics and Environmental Sciences have equal importance and powerfully connect to Ecology. This information confirms what Boyd (2007) reinforced: ecosystem services, which Ecology can represent, are a consistent point of contact between Economics and Environmental Sciences.

Other essential connections include Business, Management, Agricultural Economics & Policy, and Management and Green & Sustainable Science & Technology. These connections make part of the theoretical basis for Green GDP calculation. Oceanography, Urban Studies, and Forestry do not have any connections; this confirms that most of the scientific publications retrieved do not include WoS categories that include the ecosystems and their services, which confirms the low number of documents about Green GDP shown in Table 1 and 2. Li and Fang (2014) signaled the lack of data on marine ecosystems for better use for economic-environmental procedures for Green GDP and SNA, which reinforces the isolation of Oceanography in Figure 2.

Until the search and data retrieval date, only one article was published in 2022 by a Moroccan author. Sabbahi (2022) valued the ecosystem service of pollinating insects in fruit, oilseed, pulses, spices, and vegetable plantations, in different ranges of dependence on pollinating insects, using a bioeconomic model. The results show the positive impact of insects on ensuring food security and contributing to biodiversity preservation. Furthermore, the contribution of pollinators added more than US$1.2 million to Moroccan agriculture, which represents 8.5% of the local agribusiness GDP. It also appears that the data obtained can be used to develop indicators that allow adding the gain promoted by pollinating insects to the local Green GDP.

Table 4 and Figure 4 present the distribution of publications retrieved by countries, including documents with different countries of the co-authors.

Table 4: List of publishing countries of the 106 documents retrieved, in descending order

Descending Order	**Number of documents**	**Countries**
1	30	USA
2	25	China
3	13	Germany
4	10	United Kingdom
5	8	Australia

Descending Order	Number of documents	Countries
6	6	Spain
7	5	The Netherlands
8	5	South Africa
9	4	Finland
10	4	Sweden
11	3	Canada
12	3	Denmark
13	3	France
14	3	Japan
15	3	Poland
16	3	Taiwan
17	2	Austria
18	2	Brazil
19	2	India
20	2	Italy
21	2	Norway
22	2	Portugal
23	2	Russia
24	2	Singapore
25	1	Belgium
26	1	Bhutan
27	1	Czech Republic
28	1	Georgia
29	1	Malta
30	1	Mexico

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Descending Order	Number of documents	Countries
31	1	Monaco
32	1	Morocco
33	1	Mozambique
34	1	Slovakia
35	1	Tanzania
36	1	Togo
37	1	Zambia

Source: Own elaboration.

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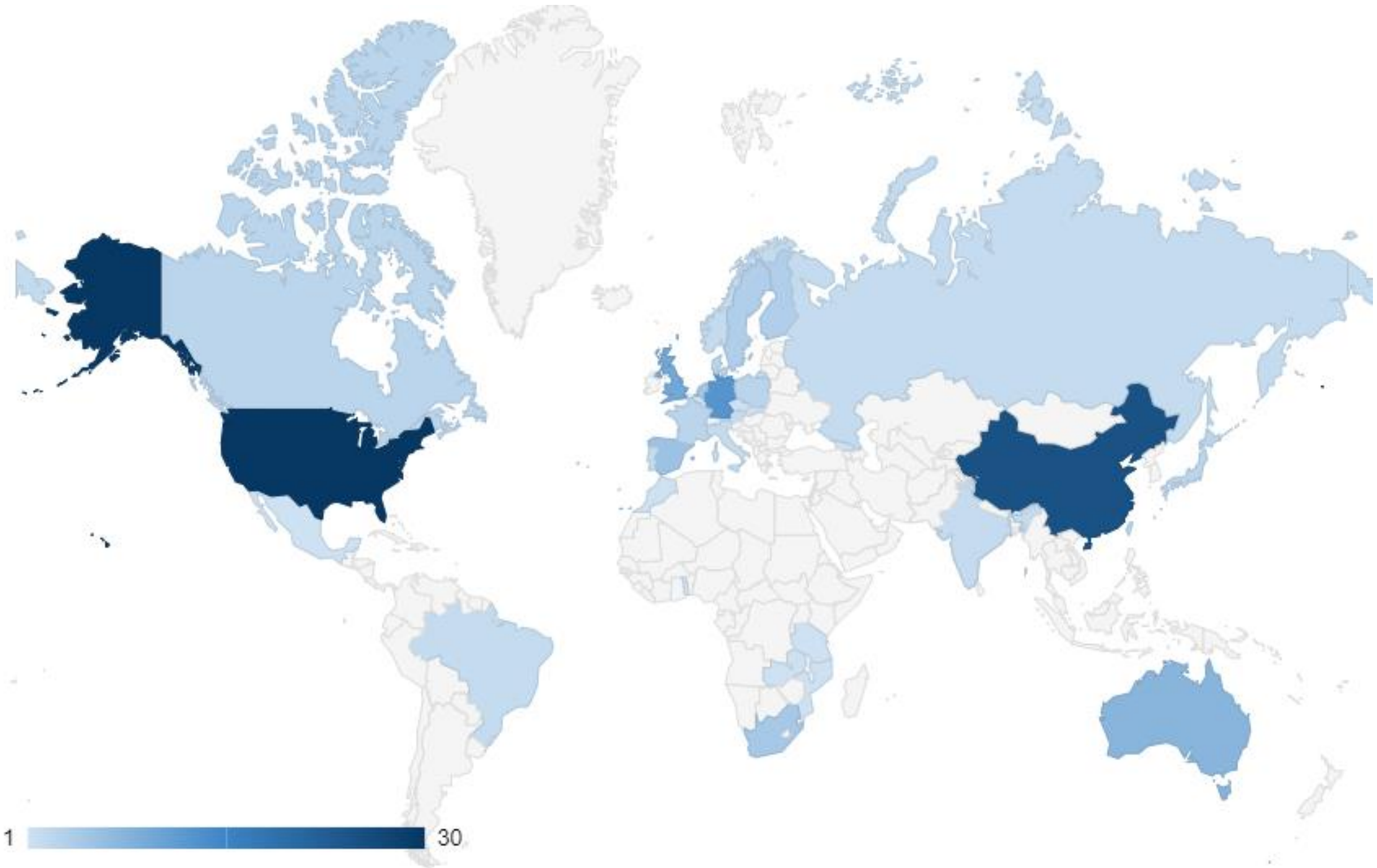

Figure 4: Countries that published the 106 retrieved documents. Source: Own elaboration.

The United States of America (USA), China, Germany, and the United Kingdom dominate, with the presence of countries such as Bhutan, Malta, Monaco, and Togo. It is noticeable that studies on the economic valuation of the environment and SNA in all continents are completed or in progress. There is an expressive number of documents recovered from Africa; only Brazil and Mexico represent Latin America. The 2023 Global Assessment of Environmental-Economic Accounting highlights Brazil, Mexico, Colombia, and Costa Rica as the Latin America countries who have regular compilation and national dissemination of SEEA (UN, 2025). However, Gois and Nogueira (2025) highlighted that Mexico, Brazil, Colombia, and Ecuador are the most advanced Latin American countries in Environmental Accounting for Green GDP calculation. Probably, these countries are not significant on the corpus due to possible data publication in grey literature. Types of this literature, such as government documents, dissertations, theses, and institutional reports, are not indexed in the WoS database. This fact constitutes a possible bias in this study, as it does not retrieve non-scientific documents in other languages besides English.

In Latin America and Caribe, Santoyo et al. (2025) demonstrated that Costa Rica, Guyana, and the Dominican Republic have better integration of economic and environment policies (sustainable development), with Green GDP higher than conventional GDP, while larger economies, such as Mexico and Argentina, have difficulties to connect economy and ecology. Brazil has a smaller difference between GDP and Green GDP, which means that sustainable development is more advanced (Santoyo et al., 2025). USA and China appear as countries with the higher number of publications retrieved, but their compilation and dissemination status of SEEA is lower than countries like Germany, United Kingdom, India, Brazil, Nigeria, and Indonesia, probably due to the exclusion of government documents, dissertations, theses, and institutional reports (UN, 2025).

Figure 5 presents a cluster map indicating the degree of interaction of co-author countries of the retrieved documents. The polarization of the USA, China, and Germany and, to a lesser extent, of Australia, the United Kingdom, France, and Finland are shown. There are fifteen *clusters*, of which seven are shown in Figure 5 and detailed in Table 5. The *clusters* represent polarizations between co-author countries based on groupings of their publications from the same continent, common borders or not (Van Eck; Waltman. 2014).

Table 5: Clusters shown in Figure 4

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Cluster	**Countries**
1	Austria, Finland, Czech Republic, Sweden, Taiwan, Zambia
2	Denmark, Spain, Italy, Monaco, Norway, United Kingdom
3	Australia, Belgium, Bhutan, Canada, Netherlands
4	France, Mozambique, Poland, Portugal
5	USA, Japan, Mexico, Tanzania
6	China, Scotland, Singapore
7	Germany and Georgia

Source: Own elaboration.

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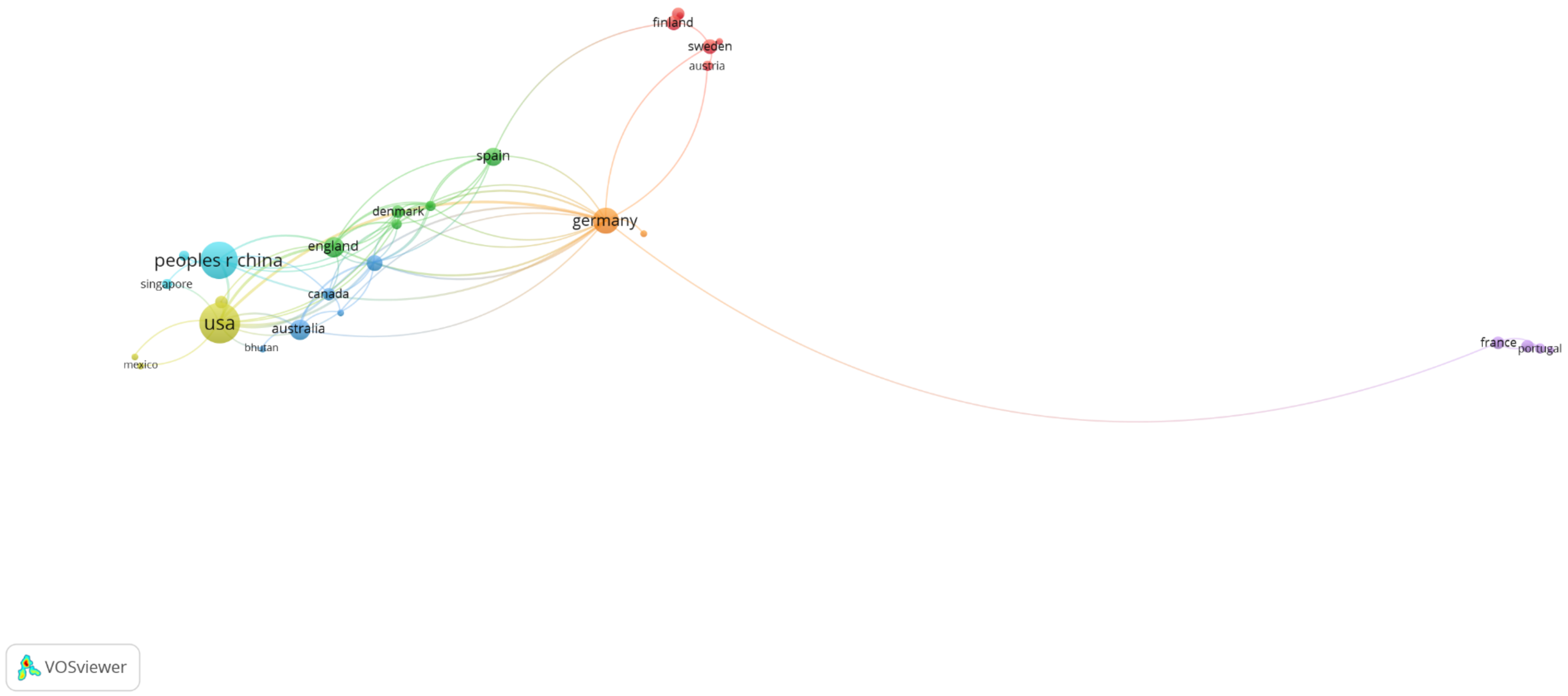

Figure 4: Map of clusters of co-author countries. Source: Own elaboration.

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The other eight individual clusters (South Africa, Brazil, Slovakia, India, Malta, Morocco, Russia, and Togo) are not present because they contain only one country; they did not publish documents co-authored with other countries and probably are co-authored by institutions in the same country.

Among the documents recovered, there are 194 institutions responsible for the publications, with a concentration on universities and Research, Development, and Innovation (RD&I) institutes such as the Chinese Academy of Sciences (4 documents) in China; The Australian National University (3 documents), in Australia; Fudan University (3 documents), in China; and the University of California, Berkeley (3 papers) and University of Vermont (3 papers), both in the USA. Such information confirms the data presented in Figure 2. As Anjos (2020) pointed out, universities and RD&I institutions focus on developing knowledge for dissemination, linked or not to market or society demands.

There are banking institutions such as *Banque France* (1 document), Central Bank of Malta (1 document) and *Danmarks Nationalbank* (1 document), international organizations such as the World Bank (2 documents) and International Monetary Fund (1 document) and institution without for-profits such as Resources for the Future (2 documents). Studies published by institutions with no scientific or technological affiliation represent future commercial interests that will generate competitive advantage (Anjos 2020).

Figure 6 presents the cluster map of the co-author institutions, in which there is a polarization of Fudan University, The Australian National University, the University of California, Berkeley, the Norwegian University of Life Sciences, and Beijing Normal University. There is also a cluster with equivalent domains such as *Potsdam Institut für Klimafolgenforschung* (2 documents), Duke University, Duke Kunshan University, University of Washington, and University of Calgary (1 document each), interconnected with other clusters from Fudan University, University of California/Berkeley, and Norwegian University of Life Sciences, which are all partners in a single publication, of Yin et al. (2021).

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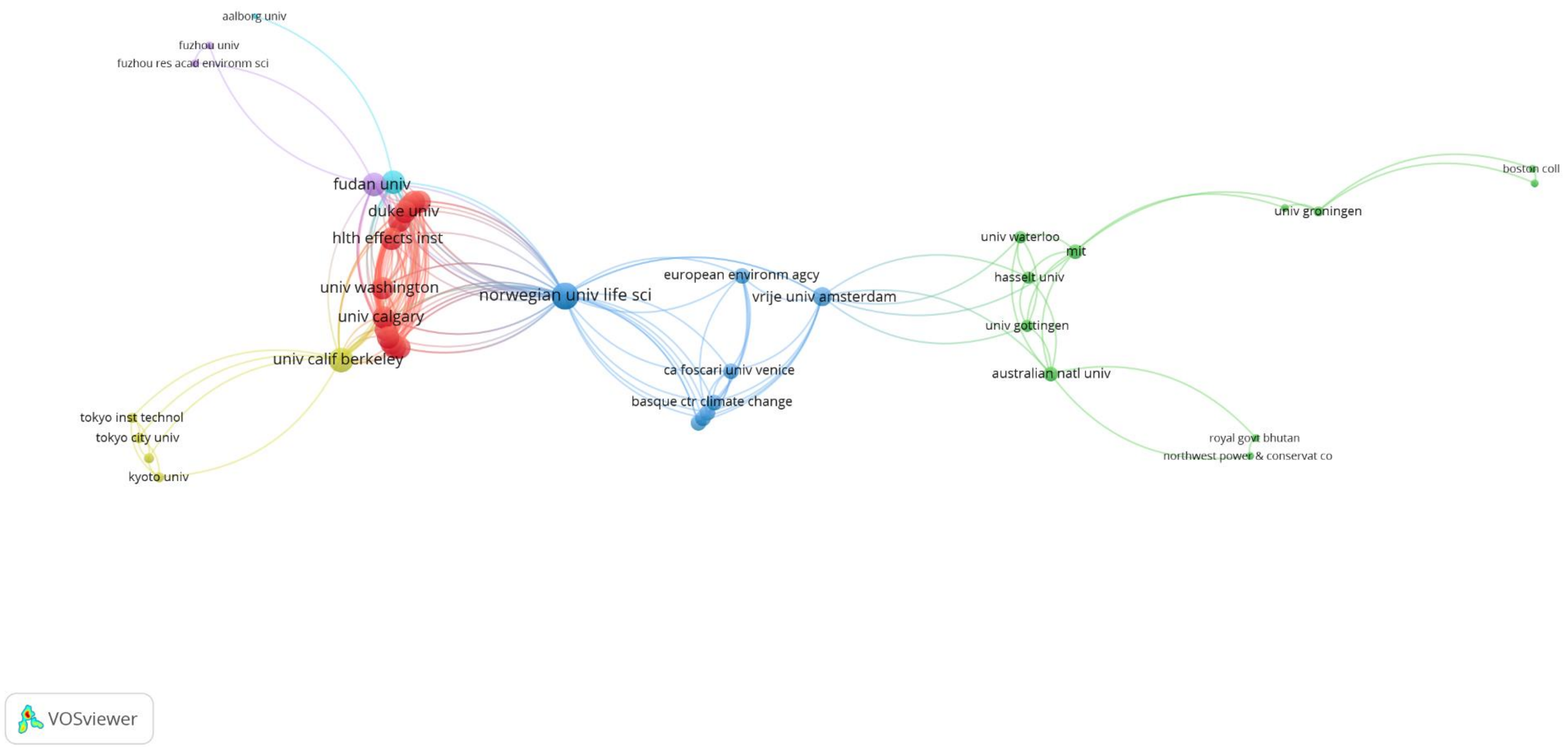

Figure 6: Map of clusters of co-author institutions. Source: Own elaboration.

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The 106 documents retrieved in the search were published by 324 authors, with two publications for each of the fifteen authors listed in Table 6 and only one publication for the other 309 authors. Researchers from The Australian National University and the Norwegian University of Life Sciences, among the authors listed in Table 6, confirm the polarization of these two institutions exerted in the map of clusters of co-author institutions in Figure 6.

Table 6: Fifteen authors with the highest number of publications among the 106 documents retrieved

Authors	**Institutions**	**Countries**
Aizenman, Joshua	University of Southern California	USA
Boyd, James	Resources for the Future	USA
Chen, Jibo	Nanjing University of Information Science & Technology	China
Costanza, Robert	Australian National University	Australia
de Lange, Willem	Council for Scientific & Industrial Research (CSIR)	South Africa
Dong Xiao-lin	Chang'an University	China
Jinjarak, Yothin	University of London	UK
Muller, Nicholas Z	Carnegie Mellon University	USA
Nahman, Anton	Council for Scientific & Industrial Research (CSIR)	South Africa
Navrud, Stale	Norwegian University of Life Sciences	Norway
Song Cheng	Chang'an University	China
Wang, Guizhi	Nanjing University of Information Science & Technology	China
Wu Ying-chao	Chang'an University	China
Yang Jian-jun	Chang'an University	China
Yin, Hao	Tsinghua University	China

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Source: Own elaboration.

The publications retrieved in the search were published in 74 journals and annals of scientific events. Table 7 presents the journals with more than one publication and their impact factors in 2020.

Table 7: Journals with more than one publication among the 106 documents retrieved

Records	**Journal**	**ISSN**	**Impact factor in 2024**
10	Ecological Economics	0921-8009	6.3
5	Environmental & Resource Economics	0924-6460	3.4
4	Review of Income and Wealth	0034-6586	1.8
3	International Journal of Environmental Research and Public Health	1660-4601	4.614
3	Proceedings of the National Academy of Sciences of the United States of America	0027-8424	9.1
2	Accounting Review	0001-4826	4.4
2	Ecological Indicators	1470-160X	7.4
2	Ecosystem Services	2212-0416	6.6
2	Environmental Science and Pollution Research	0944-1344	-
2	Journal of International Money and Finance	0261-5606	3.3
2	Sustainability	2071-1050	3.3
2	Waste Management	0956-053X	7.1

Source: Own elaboration.

The listed journals cover areas such as Economics, Environmental Sciences, Ecology and Finance, and Business, which are more prominent and compatible with the findings in Figure 2. There are also journals on Public, Environmental and Occupational Health topics, presented in Figure 2 in a dispersed and punctual manner in a few years. Figueiredo (2016) points out the interdisciplinarity and multidisciplinarity of Environmental Sciences from the influence of external contexts of environmental and scientific management, which reflects the evolution of Sustainable Development over the years, and which culminated in important documents such as the Brundtland Report, the CBD, the Paris Agreement, and the Nagoya Protocol.

This article is a theoretical essay that presents the state-of-the-art relationship between Environmental Economic Valuation and the System of National Accounts (SNA), unifying accounting, and economic elements to develop future indicators for Green Gross Domestic Product (Green GDP) calculation.

Holub, Tappeiner and Tappeiner (1999) and Boyd (2007) highlighted the incompatibility of economics and environmental sciences on spatial and time scales in the period of the publication of their papers. At the time, there were no valuation methods for adapted environmental assets. Other negative points were the necessity for correct pricing of all assets in monetary terms and the fictitious character of monetization of environmental assets that leads to misinterpretation. Furthermore, the few macroeconomic aggregates suitable for the environmental context resulted in a reduction of the analytical potential of the accounting system for the inclusion of environmental indicators (Holub; Tappeiner; Tappeiner, 1999). This scenario made the SEEA inappropriate for use on Green GDP at that period, according to economists' inability to include ecosystem services on accounts (Boyd, 2007).

Compared to Holub, Tappeiner and Tappeiner (1999) and Boyd (2007), Li and Fang (2014) and Yuan, Lo and Yang (2017) published their research results ten years later in other social, economic, and environmental world scenarios. Both papers pointed to another description of Green GDP that denotes its viability for application and the alignment with SEEA, with two challenges.

The first challenge refers to the contribution of ecosystem services to economic activities before, during, and after the verification to calculate the Green GDP using only one framework. An example is the migration of some animals through continents that provide different services in more than one ecosystem (Yuan; Lo; Yang, 2017; King et al., 2021). The second challenge is a different perception and the economic and legal aspects between each country to obtain the Green GDP, which leads to few scientific studies about this theme with the correlation of each SNA and the mechanisms to incorporate in the national welfare (Yuan; Lo; Yang, 2017).

King et al. (2021) suggested using economic valuation methods to incorporate the environmental assets into SEEA calculation and further use for Green GDP. Comte et al. (2022) reinforce the valuation methods as mechanisms to apply a monetary value to ecosystem services that could make it easier to construct and manage public policies to protect ecosystems and their sustainable industrial use.

There still are scientific gaps in the association of valuation methods used to give ecosystem services a monetary value to reflect the real national wealth (Comte et al. 2022). However, the temporal gap between Holub, Tappeiner and Tappeiner (1999), Boyd (2007), Li and Fang (2014), and Yuan, Lo and Yang (2017) present different interpretations of the theme discussed in the paper in different decades and shows the evolution of research to obtain a trustworthy GDP better and for stronger connection to each country's social, economic, and environmental situations.

5. Final considerations

The CBD is considered one of the most important international regulatory frameworks on the environment and the guideline for developing regulatory legislation on biodiversity in some countries. The integration of ecosystems in the planned actions of the public and private sectors also meets the goals established in the Sustainable Development Goals (SDGs) by contemplating natural capital in the environmental, economic, and social fields.

Natural capital needs to be quantified and evidenced in the System of Environmental-Economic Accounts, as opposed to the traditional System of National Accounts. After analysis and discussions, it became evident that the information brought by the Gross Domestic Product reflects only the information of the economic system, without considering the environmental system in which we are inserted. Thus, it is necessary to develop environmental satellite accounts to be included in the Green Gross Domestic Product.

For the quantification and disclosure of the national ecological heritage, that nation's natural resources must be valued to be included in the calculation of the Green GDP. Furthermore, the economic valuation of the environment will contribute to the measurement of the depletion (depreciation) of environmental resources, which must be considered in the calculation of the Green GDP through the reduction of the national ecological heritage and support fiscal sustainability practices and climate disclosure reports by developing indicators, including updating standards like International Sustainability Standards Board (ISSB).

Through the bibliometric analysis of the state-of-the-art relationship between the Economic Valuation of the Environment and the System of National Accounts, it was possible to systematize the studies carried out between 1945 and 2022 on economic valuation and gross domestic product, including the environmental component, which recovered 106 articles and four articles, respectively.

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It found the existence of publications on the subject on all continents, especially Europe, Asia, and North America, and many African documents. Among the institutions, there is a predominance of universities and R&D organizations, and banks, which are interested in the subject aiming at competitiveness in its market. It was also noticed that interactions between countries and publishing institutions were found, which shows the existence of partnerships for the generation and sharing of knowledge.

The first publications of the temporal scope, in 1993 and 1997, coincided with the formal beginning of research in the monetization of environmental services. Another important finding is the publication of documents on Environmental Sciences, Environmental Studies, and Ecology as of 1997 and on Agricultural Policy and Economics as of 2014, which shows the evolution of valuation and association with GDP with a focus on the environment. and later in the economic exploitation of biodiversity targeting issues such as renewable energy and food security. This scientific evolution also occurred concomitant with international initiatives to control climate change and greenhouse gas emissions, 2030 Agenda for Sustainable Development, Rio+20, Paris Agreement, and Kyoto Protocol, associated to Artificial Intelligence tools to integrate SEEA data with national information for higher quality data organization and future and faster disclosure and information access. As limitations were perceived in this study, gaps were identified regarding the lack of consensus on the limits that a model should apply, with the purpose of quantification and disclosure of natural capital, requiring the development of a conceptual framework for the consolidation of this understanding. In the same sense, the lack of validated methodologies for the inclusion of natural capital in the calculation of national wealth, which can be systematized in a future study by incorporating grey literature to expand the corpus and to reduce bias from each country (lack of access to data, institutional capacity, and funding).

Considering the limitations above, developing a proposal for calculating any country's Green Gross Domestic Product is still at an early stage. However, the signatory countries' ratification of the Nagoya Protocol can stimulate the application of economic valuation methods to strengthen the national sovereignty of ecosystems and biodiversity and guarantee the adequate inclusion of environmental assets in the calculation of national wealth. Furthermore, an adequate and validated conceptual framework can be an analytical tool to resolve externalities for developing public policies to support decision-making for the conservation and preservation of national biodiversity.

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The impacts of the European Union Deforestation-free Regulation (EUDR) on the Brazilian agri-food system: global governance, regulatory sovereignty, and climate justice

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Abstract
This research critically analyzes the impacts of the European Union Deforestation-Free Regulation (EUDR) on the Brazilian agri-food system. From this perspective, the EUDR, embedded into the European Green Deal, emerges as a potential mechanism for global governance of both the climate and the global agri-food system. The study discusses its potential impacts on the strategic supply chains of soybeans, beef, cocoa, and coffee, covering the regulatory, commercial, and political dimensions of the legislation. The central argument of this work is that, although anchored in legitimate environmental commitments, the EUDR reflects a use of extraterritorial regulatory power by the European Union that may reinforce North-South asymmetries and limit Brazil's regulatory autonomy, intensifying disputes along global value chains. This work articulates debates on climate justice, regulatory sovereignty, and environmental barriers by examining how the EUDR reconfigures the intersections between global food security governance and international climate regimes in the Global South. By adopting the EUDR as a case study, the research seeks to understand how changes in environmental governance emerge in response to global challenges and how they can reconfigure the role of exporting countries in the international sustainability regime. The study contributes to the debate on climate justice, international cooperation, and the challenges of building collaborative arrangements that are sensitive to environmental conservation and the diversity of contexts in global food trade.

Keywords: EUDR; Global Governance; International Trade; Climate Justice.

Resumo
Esta pesquisa analisa criticamente os impactos da Regulamentação Antidesmatamento da União Europeia (EUDR) sobre o sistema agroalimentar brasileiro. Nessa perspectiva, a EUDR, inserida no European Green Deal, emerge como um potencial mecanismo de governança global tanto do clima quanto do sistema agroalimentar global. O estudo discute seus impactos potenciais sobre as cadeias estratégicas de soja, carne bovina, cacau e café, abrangendo as dimensões regulatórias, comerciais e políticas da legislação. O argumento central deste trabalho é que, embora ancorada em legítimos compromissos ambientais, a EUDR reflete um uso do poder regulatório extraterritorial pela União Europeia que pode reforçar as assimetrias Norte-Sul e limitar a autonomia regulatória do Brasil, intensificando disputas ao longo das cadeias globais de valor. Este trabalho articula debates sobre justiça climática, soberania regulatória e barreiras ambientais ao examinar como a EUDR reconfigura as intersecções entre a governança global da segurança alimentar e os regimes climáticos internacionais no Sul Global. Ao adotar a EUDR como estudo de caso, a pesquisa busca compreender como as mudanças na governança ambiental emergem em resposta aos desafios globais e como podem reconfigurar o papel dos países exportadores no regime internacional de sustentabilidade. O estudo contribui para o debate sobre justiça climática, cooperação internacional e os desafios de construir arranjos colaborativos que sejam sensíveis à conservação ambiental e à diversidade de contextos no comércio global de alimentos.

Palavras-chave: EUDR; Governança Global; Comércio Internacional; Justiça Climática.

1. Introduction

Global governance has undergone significant transformations due to economic, climate, and health crises, in addition to the advancement of transnational environmental regulations. The interdependence between food systems and global environmental challenges has spurred new regulatory instruments that are reshaping relations among states, the private sector, and civil society. International food trade, already highly regulated, faces a growing set of technical, sanitary, and environmental standards, many of which are linked to sustainability and climate change (NAIDIN; VEIGA; RIOS, 2022).

Pendrill et al. (2019) explain that studies have shown that deforestation, the second largest source of greenhouse gas emissions, is largely driven by the expansion of agriculture and forestry, with a strong influence from foreign demand. Pendrill et al. (2019) argue that deforestation emissions account for a significant portion of 15% of the total carbon footprint of food consumption in European Union countries, which demonstrates the urgency of implementing political measures that act directly on international supply chains. In this context, the European Union Deforestation –Free Regulation (EUDR) emerges as a central example of how environmental governance manifests on a global scale. As part of the European Green Deal, the EUDR (Regulation (EU) 2023/1115) prohibits the import into the bloc of products such as beef, cocoa, coffee, and soybeans that are linked to deforestation that occurred after December 31, 2020.

This measure, which seeks to reduce emissions and curb biodiversity loss, reflects the EU's attempt to internalize its climate commitments and promote more sustainable consumption patterns. By doing so, the EU advances a regulatory shift that incorporates environmental criteria directly into its trade policy, representing a transition from voluntary certification mechanisms to public, mandatory, and binding ones (FERNANDES, 2024).

The regulation acknowledges the importance of forests and the EU's historical responsibility for importing products linked to deforestation. Therefore, it imposes strict rules to restrict the entry and export of products related to environmental degradation, seeking to influence international practices and promote more sustainable consumption patterns (REGULATION (EU) 2023/1115). The EUDR covers products such as beef, cocoa, coffee, soybeans, wood, rubber, and palm oil, and defines what constitutes deforestation and forest degradation.

Sanctions and corrective measures are provided to curb non-compliance (REGULATION (EU) 2023/1115, Articles 24 and 25). A risk classification system for exporting countries, such as Brazil, is established, encouraging improvements in environmental enforcement for high-risk countries (REGULATION (EU) 2023/1115, Article 29). International cooperation is also emphasized as an essential instrument to combat deforestation, strengthen the rights of local communities, and ensure transparency in supply chains (Articles 29 and 30).

However, the EUDR, as a form of governance, is not exempt from controversy. By imposing traceability and due diligence standards without a consolidated multilateral negotiation process, it strains the principles of regulatory sovereignty and commercial predictability for exporting countries, such as Brazil. This lack of a structured dialogue with the World Trade Organization (WTO) leads to questions from nations in the Global South, who see the measure as a form of "regulatory imperialism" (FERNANDES, 2024).

The EUDR fits into this context as an instrument of environmental governance with extraterritorial effects, symbolizing a transition from private and voluntary forest certification mechanisms to unilateral public mechanisms of a mandatory and binding nature (FERNANDES, 2024). The European law represents a regulatory shift by the European Union, which now incorporates environmental criteria directly into its trade policy, claiming coherence with the commitments made in the Paris Agreement (2015) and the European Green Deal, which establishes the goal of climate neutrality by 2050 at the latest.

The law translates the European effort to align trade and sustainability but also reveals the limits and contradictions of contemporary climate governance, marked by normative asymmetries and disputes between environmental universalism and the diversity of national contexts. Thus, understanding the EUDR from the perspective of global climate governance implies recognizing its dual role: on the one hand, as a "law with evident extraterritorial effects that challenges principles of sovereignty in forest regulation," as Fernandes (2024) argues; on the other hand, as an attempt to internalize international climate commitments, as we can observe in the regulation itself:

> Combating deforestation and forest degradation constitutes an important part of the package of measures needed to reduce greenhouse gas emissions and to comply with the Union's commitments under the European Green Deal as well as with the Paris Agreement adopted under the United Nations Framework Convention on Climate Change (3) (the 'Paris Agreement'), and the Eighth Environment Action Programme adopted by Decision (EU) 2022/591 of the European Parliament and of the Council (4), and with the legally binding commitment under Regulation (EU) 2021/1119 of the European Parliament and of the Council (5) to reach climate neutrality at the latest by 2050 and reduce greenhouse gas emissions by at least 55 % compared to 1990 levels by 2030. (REGULAMENTO (UE) 2023/1115, 2023, p. 11)

At a time when the global governance of food security is moving out of merely sectoral forums to occupy the arena of public, business, and international policy, the EUDR emerges as an exemplary case of extraterritorial regulation with practical effects on producers, exporters, and regulators in developing countries.

This article is justified by the need to understand the regulatory, commercial, and political impacts of the EUDR on the Brazilian agri-food system and on the country's climate action. Although the debate on transnational environmental regulation has advanced, there is a scarcity of studies that articulate the EUDR with the global governance of food security and with regulatory sovereignty (DUTRA, 2022).

The work addresses this gap, seeking to fill the lack of critical analyses of the EUDR as an instrument of international regulatory power and its consequences for exporting countries in the Global South. This perspective is reinforced by authors like Margulis (2013), who already pointed to the transition from an international food security regime to a "regime complex," where conflicting norms and rules generate unresolved tensions. The study articulates the interaction between food security governance, climate regimes, and international trade to examine how the EUDR reconfigures the relationship between regulatory sovereignty and environmental justice in the Global South.

The central hypothesis holds that, although the EUDR has a legitimate environmental foundation, it expresses a form of international regulatory power that can accentuate North-South asymmetries, limiting Brazil's regulatory autonomy and intensifying disputes along global value chains. By exploring the interaction between global governance of food security and climate, regulatory sovereignty, and international trade, the work articulates debates on environmental barriers, climate justice, and the institutional responses of the Brazilian State. Furthermore, analysing the EUDR as a case study, the research seeks to understand how changes in environmental governance emerge in response to global challenges and how they can reconfigure the role of exporting countries in the international sustainability regime.

The article is organized in five sections. The first one presents the research's methodology. Subsequently, section three outlines the theoretical framework on global governance, regulatory sovereignty, and international trade, with a focus on the North-South dynamic. The fourth section analyzes the potential impacts of the EUDR on international trade relations and sustainability, as well as its adherence to the Paris Agreement. Given the limitation of concrete data available, quantitative and qualitative indicators are presented to evaluate its effects on the agri-food chains (soybeans, beef, cocoa, and coffee), also considering the challenges to regulatory sovereignty and inequalities among global actors. The conclusion addresses suggestions for public policies and environmental diplomacy, in addition to outlining pathways for future research.

2. Methodology

This research adopts a qualitative approach to critically and multidisciplinarily analyze the impacts of the European Union Deforestation-Free Regulation (EUDR) on the Brazilian agri-food system. The article is configured as a case study, which delves into the effects of the EUDR on Brazil's regulatory sovereignty and competitiveness.

This methodological choice is justified by the complexity of the topic, which covers legal, political, economic, and commercial aspects, demanding a contextualized and in-depth analysis of the phenomena. The investigation, structured through a protocol of qualitative document analysis (Bowen, 2009), utilized a corpus of primary and secondary sources. This includes EU legislation (e.g., REGULATION (EU) 2023/1115), official communications from the Brazilian Ministry of Foreign Affairs (e.g., BRASIL, 2025), and specialized academic literature focused on EUDR and agri-food impacts, with priority given to recent publications from 2022 to 2025.

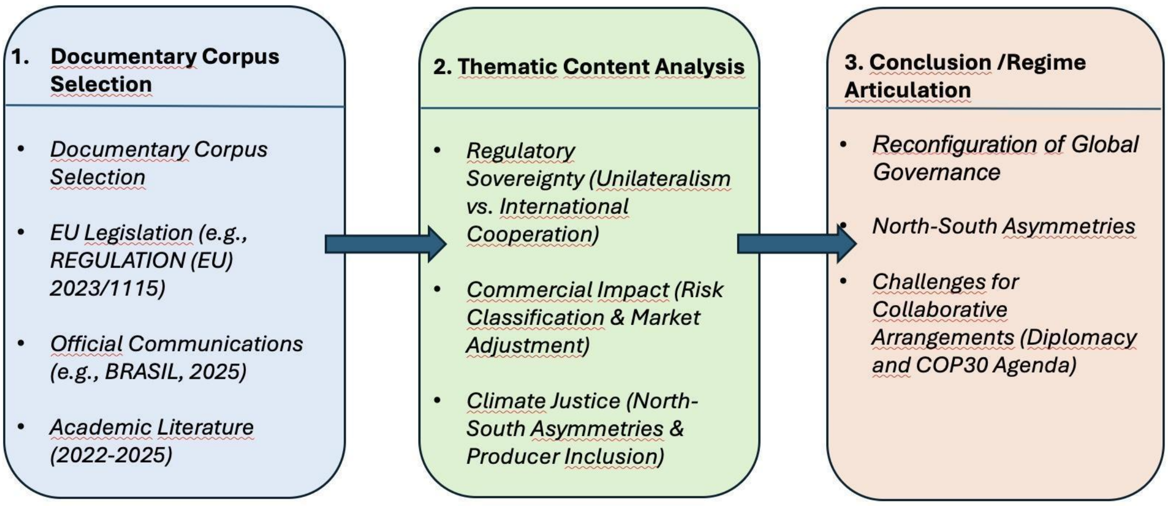
The data analysis employed a thematic content approach, focusing on three dimensions: regulatory sovereignty (unilateralism vs. international cooperation), commercial impact (risk classification and market adjustment), and climate justice (North-South asymmetries and producer inclusion).

Issues of financing and financial inclusion, fundamental for the Sustainable Development Goals (FAO, 2024), still face structural obstacles that affect the adaptation of Brazilian exporters to the EUDR's requirements. By analyzing these multiple dimensions, the research contributes to the debate on global governance, trade justice, and the transformations in Brazil-European Union relations.

Additionally, this research adopts a critical and multidisciplinary analytical perspective. The analysis transcends the mere description of impacts to examine the power dynamics underlying the EUDR regulation. For this purpose, the study is based on concepts such as climate justice and North-South asymmetries, exploring how the EUDR, despite its environmental objectives, can reconfigure global value chains to the detriment of exporting countries like Brazil.

Figure 1 illustrates the three analytical stages of the research: i) selection of the documentary corpus; ii) thematic content analysis, and iii) discussion of the Global Governance–Sovereignty–Climate Justice nexus.

Figure 1 – Analytical Stages of the Qualitative Document Analysis of the EUDR



2. Global Governance and the EUDR

Initially centered on multilateral agreements between nation-states, global governance has evolved to incorporate a series of new actors and processes. In this sense, environmental politics has emerged as a fertile ground for the study of transnational governance, a key concept for understanding regulations like the EUDR. As Hale (2020) argues, it transcends the actions of governments and intergovernmental bodies, driven by subnational and non-state actors, such as activist networks, companies, and NGOs, who establish links and act politically across national borders. The author defines this governance as the processes by which non-state actors adopt rules to achieve public goals.

The global governance of food security became a central issue after the food crises of 2007-2008, which revealed institutional limitations and motivated reforms, such as the restructuring of the Committee on World Food Security (CFS), which sought more participatory decision-making processes (CANDEL; BIESBROEK, 2018; McKEON, 2015).

Organizations such as the United Nations Food and Agriculture Organization (FAO), the Committee on World Food Security (CFS), and the World Food Programme (WFP) mediate national interests and global demands for food security, promoting a more plural and dynamic governance (McKEON, 2015). The growing complexity of the topic requires multi-sectoral coordination (CANDEL; BIESBROEK, 2018).

The contemporary debate addresses normative fragmentation and conflicts between regulatory frameworks. Margulis (2013) highlights that divergent norms in the regimes of agriculture, trade, and human rights generate political conflicts, hindering cohesive food policies, especially in developing countries. The presence of private interests and corporate capture can compromise the effectiveness and justice of governance, reinforcing the debate on alternatives such as food justice and agroecology (McKEON, 2015; DONNADELLI; FRAUNDORFER, 2016). Points of intersection between food security and climate change policies are also observed.

In a similar context, Keohane and Victor (2011) argue that the area of climate change is governed by a "regime complex," not a single comprehensive system. This means that, instead of a centralized hierarchy, global governance is a set of institutions and agreements that coexist, often in parallel or in competition. This reality is a direct result of the ineffectiveness of traditional multilateral regimes. For example, the Kyoto Protocol, despite its nearly universal membership, had a "limited, shallow, and ultimately symbolic" effect, as it imposed no obligations on developing countries and was not ratified by key nations like the United States (Keohane and Victor, 2011).

Therefore, it can be said that the European Union Deforestation-Free Regulation (EUDR), even being a public and state measure, fits into the logic of transnational governance. By imposing due diligence and traceability standards on European importers, the EUDR exerts direct influence over the conduct of non-state actors (such as producers, companies, and cooperatives) in Brazil and other exporting countries.

The EUDR is, therefore, an exemplary case study of how environmental governance tools manifest today, operating in parallel or even overlapping with traditional multilateral regimes. Global environmental governance, although with historical roots, has expanded into a complex and multifaceted system with the participation of diverse actors. Hale (2020) describes this evolution:

> The 1972 Stockholm Earth Conference (the environmental Bretton Woods) marked the emergence of what has become a large and complex set of environmental regimes. Today, more than 1,300 multilateral environmental agreements govern all aspects of the natural world (Mitchell 2018). Alongside them, a host of transnational actors, networks, and governance institutions have emerged to form a critical part of global environmental governance. (Hale, 2020, p. 204)

The EUDR is an ambitious transnational environmental regulation, integrated into the European Green Deal and the EU’s climate policy, designed to mitigate deforestation and its emissions (EUROPEAN COMMISSION, 2024; MOTAR FISHER et al., 2024). Its extraterritorial nature imposes obligations on operators and exporters in third countries that access the European market (GARCIA, 2025; SCOTT, 2014).In addition to technical requirements, the EUDR raises a fundamental debate about regulatory sovereignty and trade justice. From a critical perspective, this kind of regulation can be seen as a manifestation of power that deepens historical inequalities (SANTOS, 2007b).

Latin American governments, including Brazil, argue that the extraterritorial scope of the regulation constitutes a unilateral trade barrier that imposes a "one-size-fits-all" standard, ignoring local realities and disproportionately burdening small producers. This unilateral approach, which may not be effective in reducing deforestation, is perceived as a threat to Brazil's autonomy in its own environmental and commercial policies (Moura, 2025). The risk of green protectionism is evident, as the categorization of "zero risk" for some countries benefits EU producers, creating a competitive disparity (Moura, 2025).

The EUDR is complemented by the European Corporate Sustainability Due Diligence Directive, reinforcing the "Brussels Effect," where the EU projects its standards globally, impacting supply chains in Brazil (TREVIZAN; MENDES, 2025; BRADFORD, 2020; GARCIA, 2025). The regulation requires due diligence and traceability to prove legal origin and no link with deforestation (REGULATION (EU) 2023/1115; MOTAR FISHER et al., 2024).

In Brazil, exporters of soybeans, beef, and leather are already testing traceability systems to comply with the EUDR, with geolocated data collection and compliance analysis (PROFOREST, 2025). Although there have been advances, challenges persist in adapting the systems, especially for small producers. The requirement for detailed geolocation and risk classification integrates a new regulatory paradigm for international commodity trade (MOTAR FISHER et al., 2024; MARGULIS, 2013). Garcia (2025) observes that extraterritoriality forces operators to adapt processes outside the EU, under penalty of exclusion.

The "Brussels Effect" can generate positive externalities, inducing traceability and auditing in Brazilian agribusiness, but also aggravate vulnerabilities (TREVIZAN;

MENDES, 2025). The EUDR reinforces the EU's "normative power," imposing extraterritorial environmental standards as a foreign policy strategy (MOTAR FISHER et al., 2024; MARGULIS, 2013; GARCIA, 2025; EUROPEAN UNION, 2016).

Its implementation generates debates about regulatory justice and asymmetric impacts. Despite advances in transparency, the EUDR can exacerbate inequalities and exclude small producers due to high compliance costs (MOTAR FISHER et al., 2024). Inconsistencies in monitoring methods (PROFOREST, 2025) require dialogue. Strands of the literature point to a disconnect between European and extra-community norms, generating trade distortions (GARCIA, 2025; BRADFORD, 2020).

The global institutional fragmentation makes coordination and coherence in responding to crises difficult (MARGULIS, 2013). The EUDR, inserted in this regime complex, demands normative alignment and strengthening of the administrative capacity of the Global South to avoid negative effects, such as the transfer of commodities to less stringent markets (MOTAR FISHER et al., 2024).

4. Impacts and Challenges of the EUDR for the Brazilian Agri-Food System and for Climate Actions

4.1. Sectoral Impacts and Compliance Challenges

Economic and commercial effects of the EUDR vary among strategic sectors of Brazilian agribusiness. A comparative analysis of the sectors, carried out by Cesar de Oliveira et al. (2024), through a "Compliance Likelihood Index" (CLI), reveals significant differences and specific challenges for each commodity.

Coffee has the highest compliance index (0.89). It is associated with the lowest deforestation risk (only 0.1%), and the EU market accounts for 49.8 % of Brazil's coffee export. Therefore, the sector has high incentives to comply with the EU requirements. In addition, remote sensing systems and digital tracking platforms under implementation already cover approximately 94% of producers that export coffee to the EU (COLUSSI et al., 2024)

Soy also shows high compliance potential as a large share of Brazilian production is exported (68%), and 15% of this total is directed to the EU. The sector is mostly comprised of large producers, which have greater capacity to bear the costs of implementing the traceability requirements set by the EUDR. This combination of variables resulted in the second-highest probability of compliance in the index (0.64) in the study. Paradoxically, the exclusion of the Cerrado, which accounts for over 60% of Brazil's soybean output, undermines the environmental coherence of the EUDR, revealing inconsistencies between its stated goals and territorial application (COLUSSI et al., 2024).

On the other hand, the beef sector has the lowest compliance index (0.3), suggesting that the transition to deforestation-free supply chains is the most challenging. According to Cesar de Oliveira et al. (2024), this is due to very low market incentives (the EU/UK represents only 8.26% of Brazil's exports in 2021) and the fact that cattle is responsible for a large percentage of absolute deforestation in Brazil (61.2% between 2005 and 2018). Cocoa also has a low probability of compliance (the second lowest index), with similarly low market incentives, as the EU/UK are not the main importers of the commodity (4.48% in 2021).

Table 1 – Levels of Compliance and Sectoral Challenges for the EUDR

Commodity/ Sector	**Compliance Likelihood Index (CLI)**	**Key Challenges**	**Opportunities/Observations**
Coffee	0.89 (Highest)	Low challenges. High traceability coverage of exporters to the EU by existing digital tracking platforms (94%).	Lowest deforestation risk (0.1%); Strong potential for *compliant* status.
Soybeans	0.64 (Second Highest)	Exclusion of the Cerrado biome (60% of output); High costs for small producers.	Large producers capable of absorbing compliance costs.
Beef	0.3 (Lowest)	Low market incentives (EU/UK = 8.26% of exports); High historical deforestation link (61.2% of deforestation).	Requires major structural transition and robust traceability systems.
Cocoa	Low (Second Lowest)	Low market incentives (EU/UK = 4.48% of exports); Prevalence of small producers (hinders traceability).	Requires technical and financial support for smallholder inclusion.

Source: Adapted from Cesar de Oliveira et al. (2024) and Colussi et al. (2024).

The research findings indicate that while sectors such as coffee already demonstrate low risks and high coverage of sustainability standards, others, such as beef, will face strong structural challenges. The study also reinforces that the prevalence of small producers, in sectors like cocoa and coffee, represents an obstacle to compliance, considering the need for technical and financial resources to implement traceability. The adoption of criteria that disregard the existent diversity of producers in Brazil can result in unnecessary collective punishment, as small and medium producers can be affected by generalized restrictions and barriers even if they are not linked to deforestation (COLUSSI et al., 2024).

4.2. Regulatory Sovereignty and Trade Justice Implications

According to Trevizan (2024), the implementation of the EUDR will bring challenges and opportunities for Brazil, requiring productive sectors to adapt to European requirements through the strengthening of forest certifications, the fulfillment of due diligence procedures, and the use of monitoring technologies, such as georeferencing and satellite tracking systems. The active participation of the Brazilian State is pointed out as crucial to guarantee the effectiveness of these instruments, facilitating coordination among government, producers, and international partners. Furthermore, the need for the development of a more structured international forest regime reinforces the relevance of Brazil-EU diplomatic engagement for building collaborative policies that preserve the country's competitiveness in global trade.

The reaction, engagement, and actions of non-state actors, although growing and influential in environmental governance, are significantly shaped by the national context in which they are inserted and by local policies. Therefore, the scope, effectiveness, and practical impact of transnational governance are largely determined by the "shadow of the state", which influences the most entrepreneurial forms of authority and regulation (Hale, 2020).

To date, the response of the Brazilian government has been both reactive and proactive. The pressure from the European regulation pushes the country to adapt its productive sectors, with the adoption of advanced tracking and geolocation technologies.

However, Brazilian diplomacy argues that the success of the regulation will depend on its capacity to harmonize environmental commitments with fair trade practices, ensuring that sustainability efforts do not inadvertently create new economic disparities

(Moura, 2025). Cooperating with the EU, pointed out as essential for Brazil, is a way to align practices and preserve competitiveness, instead of simply accepting an imposition. Accordingly, the State's action becomes crucial to mediate this new dynamic (Trevizan, 2024).

Furthermore, the implications of the EUDR for Brazilian agribusiness can be better understood by analyzing its country classification system. The regulation establishes a risk classification system that categorizes countries and regions based on their level of deforestation risk: low, standard, or high. In this context, the Brazilian government received with concern the country's classification in the "standard risk" category (BRASIL, 2025).

The Ministry of Foreign Affairs (MRE) released a note that reiterates its critical stance regarding the legislation, arguing that the EUDR is a "unilateral and discriminatory" measure that disregards national efforts for forest preservation. The Ministry outlines its "strangeness" that most countries with large areas of tropical forest were classified with a higher risk than countries that practice temperate climate agriculture (BRASIL, 2025).

In response to pressures from various countries and organizations, the application of the EUDR was postponed by 12 months, with the new effective date set for December 30, 2025, for large and medium-sized companies, and June 30, 2026, for small and micro-enterprises (EY Tax News, 2025).

The original timeline represented a "significant challenge for many companies," which led the European Commission to propose the postponement to allow more time for preparation (EY Tax News, 2025). However, the implementation of the EUDR has been marked by continuous uncertainty. The European Commission itself expressed concerns about the readiness of the information technology system that underpins the law, warning of the risk of "repeated and long-lasting disruptions" that could paralyze the application of the regulation (Preferred by Nature, 2025).

According to Jack Hurd (2025), "Deforestation policy can encourage agricultural adaptation," as government policy has the potential to "help farmers and the agricultural sector adapt to greener practices, free of deforestation, much like a 'just transition'." The author reinforces that the postponement can be an opportunity to "assess early progress, refine the tools and build the capacity needed" for successful implementation, which could mitigate the risks of market segmentation and the exclusion of small producers.

5. Conclusion

The impacts of the EUDR on Brazil are multiple, diverse, and interdependent. The regulation not only redefines market access criteria but also reconfigures power relations in supply chains, pressures the Brazilian State's regulatory capacity, and the ability of producers to adapt to the requirements. By projecting unilateral norms of international reach, the EUDR needs to be inserted into the debate on sovereignty, regulatory justice, and the limits of global environmental governance.

This analysis of the EUDR shows that, although it has clear environmental objectives, the regulation reinforces the normative power of the European Union and poses challenges to Brazil's sovereignty. Traceability and due diligence requirements increase costs and can exclude small producers, evidencing inequalities in agri-food global value chains. Sectors like coffee and soy could adapt more easily, while beef and wood face complex barriers, reflecting the productive diversity of Brazil. Thus, the EUDR redefines power relations, demanding greater articulation among the State, producers, and international partners.

This research also highlights that Brazil needs to transform this agenda into a strategic opportunity. The United Nations Climate Change Conference (COP30), to be held in Belém, Pará, emerges as an ideal stage for the country to lead the discussion on models of cooperation, incentives for green transition pathways, and the protagonism of small producers, among other issues.

Brazilian diplomacy should advance institutional models of South–North dialogue grounded in technical cooperation, capacity-building funds for smallholders, and joint verification mechanisms co-managed with EU agencies. This strategic positioning implies advocating not only for fair trade but also for the institutionalization of mechanisms that specifically address North-South asymmetries, such as bilateral green certification agreements and targeted financing instruments to reduce traceability costs, which are disproportionately borne by small and medium-sized producers.

The environmental conferences and climate weeks, furthermore, which take place annually, can become platforms for improving EU's active listening of partner countries' viewpoints. Through this enhanced dialogue, the EU could increase the alignment of EUDR's requirements with the needs of upstream actors in the chain.

Effectively addressing the complexities of the EUDR and advancing the COP30 agenda requires transcending traditional state action through multilateral partnerships: private sector innovation, governmental support, international agency resources, and academic knowledge production must converge to foster and implement sustainable, non-exploitative production models. This synergy is essential for a robust global investment in climate mitigation and adaptation, while prioritizing the urgent green transition and productive adaptation needs of the Global South.

This study, although limited to the Brazil-EU trade relationship, contributes to broader debates on regulatory justice, coloniality, and global governance, highlighting the North-South tensions in the international environmental agenda. The analysis emphasizes the importance of strengthening Brazil's regulatory capacity and environmental diplomacy, balancing sustainability and competitiveness. Future research could further explore the social, economic, and environmental effects of the EUDR, as well as inclusion mechanisms for Global South producers.

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The Potential of Brazilian Agriculture for Reducing Greenhouse Gases: An Analysis of Coffee Growing and Lessons for COP30

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Summary

This article analyzes the potential of Brazilian coffee production to contribute to national greenhouse gas (GHG) mitigation targets under the recently established Brazilian Emissions Trading System (SBCE). The methodology uses a scenario analysis, based on census data, to assess how transaction costs determine a minimum viable area for market participation, impacting the sector's aggregate potential. The results reveal a critical duality: although there is a vast theoretical mitigation potential, estimated at 13 million tons of CO_2eq, its realization is severely limited by economic barriers that could prevent up to 67% of this total from being realized. The high costs of certifying and monitoring carbon credits exclude most coffee growers, especially family farmers, which constitute the structural foundation of the sector. We conclude that the effectiveness of the carbon market as a climate policy in Brazil depends on institutional innovations—such as collective certification through cooperatives and the development of low-cost monitoring technologies—to reduce transaction costs. Additionally, it is recommended that voluntary instruments, such as carbon-neutral coffee labeling, be promoted to encourage the adoption of good agricultural practices in an inclusive manner and achieve Brazil's GHG reduction targets. Such measures are crucial to ensuring broad and equitable participation of rural producers, aligning the market instrument with the reality of national agriculture.

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Keywords: GHG Mitigation; Carbon Market; Low Carbon Agriculture; Transaction Costs; Coffee Growing.

Resumo

Este artigo analisa o potencial da cafeicultura brasileira para contribuir com as metas nacionais de mitigação de gases de efeito estufa (GEE) no âmbito do recém-estabelecido Sistema Brasileiro de Comércio de Emissões (SBCE). A metodologia utiliza uma análise de cenários, baseada em dados censitários, para avaliar como os custos de transação determinam uma área mínima viável para a participação no mercado, impactando o potencial agregado do setor. Os resultados revelam uma dualidade crítica: embora exista um vasto potencial teórico de mitigação, estimado em 13 milhões de toneladas de CO_2eq, sua efetivação é severamente limitada por barreiras econômicas que podem impedir a realização de até 67% desse total. Os altos custos de certificação e monitoramento dos créditos de carbono excluem a maioria dos cafeicultores, especialmente os agricultores familiares, que constituem a base estrutural do setor. Conclui-se que a eficácia do mercado de carbono como política climática no Brasil depende de inovações institucionais, como a certificação coletiva via cooperativas e o desenvolvimento de tecnologias de monitoramento de baixo custo, para reduzir os custos de transação. Adicionalmente, recomenda-se que instrumentos voluntários, como a rotulagem de café carbono neutro, sejam promovidos para incentivar a adoção de boas práticas agrícolas de forma inclusiva e atingir as metas de redução de GEE do Brasil. Tais medidas são cruciais para assegurar a participação ampla e equitativa dos produtores rurais, alinhando o instrumento de mercado à realidade da agricultura nacional.

Palavras-chave: Mitigação de GEE; Mercado de Carbono; Agricultura de Baixo Carbono; Custos de Transação; Cafeicultura.

1. Introduction

Addressing climate change has established itself as one of the most pressing challenges of our time, mobilizing the international community to seek solutions to mitigate the rise in the planet's average temperature. In this context, Brazil has made ambitious commitments, setting targets to reduce its greenhouse gas (GHG) emissions by 48% by 2025 and 53% by 2030, compared to 2005 levels, and to achieve net emissions neutrality by 2050. To operationalize these targets, Law 15.042/2024 established the Brazilian Greenhouse Gas Emissions Trading System (SBCE), a regulated carbon market that serves as the country's main climate policy instrument (BRASIL, 2024).

The SBCE follows the global trend of expanding carbon pricing, with 80 instruments covering approximately 28% of global emissions by early 2025, according to the World Bank (2025). This expansion is notable in large middle-income economies, such as Brazil. International experience with these markets, which generated more than

USD 100 billion in 2024, offers lessons for the implementation and improvement of the Brazilian system.

The agricultural sector emerges as a central player in this strategy, displaying a dual nature. On the one hand, it represents a significant source of emissions, accounting for 27.2% of Brazil's total GHG emissions in 2014 (Freitas et al., 2016). On the other, it is recognized as a provider of mitigation solutions. The SBCE legislation itself explicitly includes "more efficient agricultural and livestock systems" and the "increase of carbon stocks in agricultural soils and pastures" as eligible sources for generating carbon credits, positioning the sector not only as a target of regulation but also as a provider of environmental solutions.

To investigate the dynamics and challenges of this integration, this study adopts Brazilian coffee farming as an in-depth case study. This choice is justified by the sector's relevance, as Brazil is the largest coffee producer and exporter and the second-largest consumer of this beverage in the world. According to Conab – National Supply Company (2025), Brazil's 2024 coffee harvest was 54.2 million 60-kg bags, from an area of 1.88 million hectares, with an average productivity of 28.8 bags per hectare. In monetary terms, the Gross Value of Coffee Production in 2024 was estimated at R$78.2 billion (Brazil, 2025). Regarding coffee growers, it is worth noting that the country has more than 264,000 coffee-producing establishments in 1,448 municipalities, with 78% of these coffee farms considered family-owned (IBGE, 2019).

The central research problem lies in the hypothesis that, although the theoretical mitigation potential of coffee farming is significant, its implementation is threatened by economic barriers intrinsic to the functioning of carbon markets. The high transaction costs associated with the certification, monitoring, reporting, and verification (MRV) of credits create a minimum scale of economic viability that can, in practice, exclude most producers from the market. Therefore, the objective of this article is to quantify the impact of this scale barrier on the global effectiveness of the carbon market for the agricultural sector and discuss the implications for designing a climate policy that is both environmentally effective and socially inclusive.

2. Fundamentals of Agriculture's Contribution to GHG Emissions and Mitigation

The agricultural sector's participation in climate mitigation strategies is a global and national imperative. In June 2023, Decree 11.550/2023 was enacted, establishing guidelines for the development of Sectoral Climate Change Mitigation Plans (BRASIL, 2023). These Sectoral Plans cover several sectors listed in the National Climate Change Policy (PNMC), including the agricultural sector. This sector plays a prominent role in any strategy to mitigate the causes of climate change. As Freitas et al. (2016) rightly point out, the release of greenhouse gases (GHG) from agriculture reached 423.1 million tons of CO_2eq in 2014, representing 27.2% of the country's total emissions.

In Brazil, agricultural efforts are formalized through policies such as the Sectoral Plan for Consolidating a Low-Carbon Economy in Agriculture (Plano ABC+), which aims to promote the adoption of sustainable technologies and production practices. Launched for the 2020-2030 decade, it succeeds and expands the previous plan (2010-2020), consolidating an approach that integrates GHG mitigation, climate adaptation, and productivity gains. The plan is the embodiment of climate policy for the sector that holds one of the greatest potential contributions to national goals.

Agriculture can contribute to GHG reduction in two main ways: by reducing direct emissions (e.g., through animal manure management or the optimized use of nitrogen fertilizers) and by removing carbon dioxide (CO_2) from the atmosphere, sequestering it in biomass and, primarily, in the soil. Table 1 presents quantitative area targets for the adoption of technologies that reduce GHG emissions, as covered by the ABC+ Plan.

Table 1. Quantitative Targets of the ABC+ Plan (2020-2030) by Technology

Technology (SPSABC)	**Adoption Target (Area/Volume/Unit)**
Practices for the Recovery of Degraded Pastures (PRPD)	30 million hectares
Direct Grain Planting System (SPDG)	12.5 million hectares
Crop-Livestock-Forest Integration Systems (iLPF)	10 million hectares
Bioinputs (including FBN)	13 million hectares
Planted Forests (FP)	4 million hectares
Irrigated Systems (IS)	3 million hectares
Agroforestry Systems (SAFs)	100 thousand hectares

Animal Production Waste Management (MRPA)	208.4 million m^3 of treated waste
Intensive Termination (IT)	5 million animals slaughtered

Source: Brazil (2021).

Technologies such as no-till farming, integrated crop-livestock-forestry (iLPF) and other intercropping, the restoration of degraded pastures, and agroforestry systems, mentioned in the ABC+ Plan, are recognized for their potential to increase soil carbon stocks. This is an ecosystem service that can be quantified and promoted through environmental policies.

Thus, the formulation of public and private policies focused on sustainability has become a priority. In this context, economic and voluntary environmental policy instruments emerge as complementary alternatives to traditional command-and-control mechanisms by promoting market incentives and incentives for the adoption of sustainable practices. The next two sections present the fundamentals of the carbon market through the tradable permit system and the fundamentals of carbon-neutral labeling as a voluntary environmental policy instrument.

2.1. The Tradable License System as an Economic Instrument of Environmental Policy

The tradable permit system is an environmental policy instrument in which a regulatory agency issues permits representing degradation/pollution quotas corresponding to a specific maximum degradation/pollution threshold for a given geographic area. After the initial distribution and/or sale among polluting/degrading agents in that region, it is possible and recommended to negotiate these permits among these agents. This method of controlling aggregate levels of environmental degradation allows for the establishment of a feasible physical limit for pollution/degradation and a total number of permits or quotas equivalent to the assimilative, carrying, and/or sustainable capacity of the environment.

According to Sterner and Coria (2012), this environmental policy instrument establishes property rights related to the right to pollute or degrade the environment and helps remove the externalities implicit in the absence of property rights or the environment's "public good" character. Thus, creating a market, with a price mechanism, to trade the right to generate externalities reduces their adverse effects.

Theoretically, this system promotes cost-effectiveness, as the reduction effort is allocated where the cost is lowest, in line with the equimarginal principle (Baranzini et al., 2017). The success of the instrument, however, depends on well-defined property rights, rigorous monitoring, and a competitive market (Schmalensee; Stavins, 2017; Sterner; Coria, 2012).

Although the tradable license system is recognized for its theoretical cost-effectiveness, in achieving reduction targets at the lowest aggregate cost (Perman et al., 2003), its practical application is challenged by transaction costs, which can alter the cost-effectiveness ranking of the instruments.

Furthermore, as pioneered by Coase (1937), the magnitude of transaction costs can make or break the functioning of a market. This assertion could even compromise the effectiveness of an environmental policy based on tradable licenses.

Thus, in the case under study – the insertion of coffee farming into the carbon market – transaction costs, especially those related to carbon credit certification, are relatively significant (Santos; Nogueira, 2025). A comparative study of transaction costs in carbon offset projects by Cacho et al. (2013) indicated the unfeasibility of smaller-scale projects in terms of productive area. Thus, these authors highlight the need to reduce transaction costs to make smaller-scale projects viable and, to this end, suggest three strategies: a. carrying out collective projects to share costs; b. utilizing existing infrastructure/management capacity; and c. reducing information costs, especially through implementation and monitoring methodologies (Cacho et al., 2013).

The issue of feasibility scale raises another relevant evaluation criterion: equity. This criterion seeks to identify how the costs and benefits of the environmental management policy instrument are distributed. Assessing this aspect is important because maximizing the benefit/cost ratio can lead to social injustice, causing the less privileged segments of society to bear the costs and receive few benefits. In this context, it is also necessary to choose the perspective from which equity will be sought, which can be weighted by the criteria of equality, ability to pay, favoring the less privileged, competitive conditions, among others. Finally, equity in a policy can also be sought from a spatial/geographical perspective by reducing regional disparities.

2.2. Labeling as a Voluntary Instrument of Environmental Policy

Voluntary environmental policy instruments are mechanisms to encourage the adoption of sustainable practices that do not require direct state coercion. In contrast to command-and-control instruments, which impose legal obligations, voluntary instruments rely on the spontaneous participation of companies and producers, stimulated by market pressures, reputation, economic incentives, and the pursuit of environmental differentiation (SEGERSON, 2013; CASTRO, 2006).

According to Segerson (2013), the effectiveness of these approaches depends on three fundamental conditions: (i) sufficiently strong participation incentives so that the benefits outweigh the costs of the obligations assumed; (ii) adequate monitoring to ensure voluntary compliance; and (iii) mechanisms that reduce free-riding behavior among participants in collective programs. In the context of carbon-neutral coffee labeling, these conditions are essential, as the success of certification depends both on the credibility of the audit and on consumers' perception of the added environmental value.

In terms of economic efficiency, voluntary instruments tend to have lower administrative costs and greater flexibility in implementation, as they allow agents to adjust their mitigation strategies according to their production realities (Segerson; Li, 1999). However, the OECD (2003) emphasizes that the effectiveness of these approaches is generally limited, as they rarely incorporate mechanisms that equalize marginal reduction costs among producers. This means that, in the case of coffee farming, small farms may face proportionally higher fixed audit and compliance costs, which reduces the attractiveness of individual certification.

The motivation for adopting voluntary instruments is associated with both market and institutional factors. According to Castro (2006), companies and producers can adopt proactive stances aimed at reducing costs, accessing new markets, obtaining price premiums or financing, and improving their corporate image. In the case of carbon-neutral labeling, adoption can be explained by the growing consumer demand for products with a lower carbon footprint and the possibility of adding economic and reputational value to certified coffee.

However, Segerson (2013) warns that significant environmental improvements are less likely in contexts of weak political will for mandatory policies, since voluntary participation is limited to those who perceive positive net benefits. Thus, there is a trade-off between rigor and adherence: more demanding requirements tend to reduce the participation rate, even if they increase the environmental credibility of the seal.

Additionally, Segerson (2013) notes that certification and labeling programs function as signaling instruments, reducing information asymmetry between producers and consumers. Thus, carbon-neutral labeling reflects an effort to convert environmental benefits—public goods—into tradable private goods (Prakash, 2000), internalizing positive externalities related to emissions mitigation. This dynamic reinforces the role of environmental certification as a hybrid instrument between environmental policy and market strategy.

Environmental labeling functions as a market mechanism to mitigate information asymmetry, a classic problem in agricultural products whose sustainability attributes are "credence goods", as their quality cannot be verified by the consumer. In the absence of a credible signal, quality uncertainty can harm high-standard producers, as predicted by Akerlof (1970). Third-party certification acts as a costly and effective signal (Stiglitz, 1987), allowing producers to reliably communicate their practices, correct this market failure, and justify a price premium (Caswell; Mojduszka, 1996). In the coffee sector, these sustainability standards help structure the market and create value (Giovannucci; Ponte, 2005).

Finally, it is worth noting that voluntary, performance-based approaches—such as carbon-neutral certification—tend to be more effective than those based on specific practices, as they allow flexibility in choosing emission reduction methods and encourage technological innovation (Segerson, 2013). This characteristic is particularly relevant in coffee farming, where soil, climate, and technological conditions vary widely between regions and producers.

In short, carbon-neutral coffee labeling can be interpreted as a concrete application of voluntary environmental policy instruments. Its effectiveness depends on the credibility of the audit, the reduction of compliance costs for small producers, and the existence of market incentives that guarantee economic and reputational returns proportional to environmental effort.

2.3. Transaction Costs and the Viability Scale Barrier

Despite the theoretical elegance of tradable allowance markets, their practical application is conditioned by the existence of transaction costs, a concept pioneered by Coase (1937). In the context of carbon markets, these costs manifest as the expenses required to define, validate, monitor, and trade carbon credit. They include the high costs of developing methodologies, third-party validation, continuous monitoring of adopted practices, and periodic verification of mitigation results.

These costs have a particular economic characteristic: a significant portion of them is fixed, meaning they do not vary proportionally with the scale of the project. The administrative expense to certify credits for a 10-hectare property can be very similar to that for a 500-hectare property. This dynamic creates an inevitable consequence: the existence of a minimum scale for economic viability. Small-scale projects that generate a small volume of carbon credits may become financially unviable, as the potential revenue from the sale of credits is insufficient to cover the high fixed transaction costs.

This phenomenon transforms a theoretically neutral market instrument into a mechanism that, in practice, selects participants based on their scale. The study by Santos and Nogueira (2025) estimates that, for Brazilian coffee production, this minimum viable area is between 50 and 320 hectares, a threshold that excludes most producers. The literature suggests strategies to mitigate this barrier, such as aggregating small producers into collective projects, using existing management infrastructure (such as cooperatives), and reducing information costs through simplified implementation and monitoring methodologies, as suggested by Cacho. et al. (2013).

Reducing certification costs through collective projects is a common practice in the voluntary sustainability labeling process, which is part of voluntary environmental policy instruments. This certification has established itself as one of the main instruments for encouraging the adoption of environmentally responsible agricultural practices in Brazilian coffee production (Moreira et al., 2011). In addition to differentiating the product in specialized markets, certification can serve as a mechanism to motivate the adoption of good environmental practices, including measures aimed at reducing environmental impact, rational management of natural resources, and valuing rural labor (Duarte; Ferreira, 2019; Pereira, 2014).

For small producers, individual certification faces significant economic barriers, particularly due to fixed audit and compliance costs (Duarte; Ferreira, 2019). However, in the Brazilian context, collective certification through cooperatives emerges as the main strategy to overcome this barrier. In this model, the fixed audit and compliance costs, which make individual certification unfeasible (Duarte; Ferreira, 2019), are distributed among members, generating economies of scale that enable the participation of small producers (Latynskiy; Berger, 2017). Initiatives such as Certifica Minas Café demonstrate that this approach is a strategic path toward sustainable coffee production, by making the process accessible and strengthening local governance (Minas Gerais, 2020; Perosa; Sparsis , 2016; Araújo et al., 2016).

Thus, for a coffee grower with approximately 10 hectares, sustainable certification is viable and strategic when implemented collectively. Group certification reduces fixed costs, improves environmental management capacity, and promotes competitive insertion in differentiated markets, consolidating its position as an instrument for sustainable rural development and mitigation of agricultural emissions.

3. Analytical Approach to Mitigation Potential

The methodology adopted in this study is a scenario-based quantitative forecasting approach designed to assess the impact of different carbon market configurations on the aggregate potential for greenhouse gas (GHG) mitigation and revenue generation in Brazilian coffee production. The approach goes beyond a simple potential estimate, structuring itself as an analytical framework to investigate how the critical variable of transaction costs—embodied in different levels of minimum economic viability—determines the environmental effectiveness and social equity of the Brazilian Emissions Trading System (SBCE). The methodological design was conceived to test the central hypothesis of the study: that the effectiveness of a market instrument is not intrinsic, but rather a direct function of the institutional design that supports it, especially regarding its ability to include or exclude small producers who form the basis of the national agricultural sector.

3.1. Modeling Fundamentals and Data Sources

The empirical analysis is based on the integration of two primary data sources, whose combination allows for the isolation and quantification of the effect of the scale barrier. The deliberate choice to separate the characterization of the sector's agrarian structure from environmental and economic impact parameters constitutes the foundation of the methodological strategy, allowing for an accurate assessment of the gap between the total theoretical potential and the potential that can actually be mobilized under different market conditions.

The structural basis for the analysis comes from the 2017 Agricultural Census, conducted by the Brazilian Institute of Geography and Statistics (IBGE). This data source offers a detailed and granular portrait of the national coffee industry, providing the universe of rural establishments and their precise distribution by area strata. The use of this data is crucial because it allows us to quantify, for each scenario, the share of the total area and the number of producers that would be eligible or excluded from the carbon market, revealing the magnitude of the impact of the entry barrier.

The technical and economic coefficients that parameterize the model were extracted from the prospective study by Santos and Nogueira (2025). This research provides the essential estimates for modeling, namely:

GHG Mitigation Potential: The average emission reduction coefficient per hectare, expressed in tons of carbon dioxide equivalent (tCO_2eq), achievable with the adoption of a portfolio of low-carbon agricultural practices in coffee production. According to Cecafé and Imaflora (2022), the carbon balance (emissions minus sequestration) showed that good agricultural practices effectively increased carbon stocks by 7.58 tCO2eq ha-1 of green coffee compared to conventional practices. Thus, to calculate the GHG reduction potential, the minimum viable area for each scenario was multiplied by 7.58.

Revenue Generation Potential: The estimated revenue per hectare (in R$/ha) from the sale of generated carbon credits. This value incorporates assumptions about the market price of carbon and the conversion rate of mitigation potential into tradable credits. This study considered the amount of R$ 277 per carbon credit, which corresponds to the most optimistic projection (Quote 3) by Santos and Nogueira (2025). Thus, to calculate the revenue generation potential, the viable area of each scenario was multiplied by the average emission reduction coefficient per hectare (7.58) and also by 277.

A central assumption of the model is the homogeneity of these coefficients across different production scales and even across different regions. It is assumed that the mitigation potential and revenue per hectare are constant, regardless of property size and soil and climate conditions. While recognizing that, in reality, variations in productivity and efficiency may exist, this simplification is a necessary methodological decision to enable the analysis. It allows for the analytical isolation of the effect of the scale barrier imposed by transaction costs, which is the central focus of this research, preventing the results from being confounded by other variables.

It is important to emphasize that the analysis is based on the technical and economic coefficients of Santos and Nogueira (2025), whose methodology already incorporates a robust sensitivity analysis to address carbon market uncertainties. The authors do not limit themselves to a single value, but construct nine scenarios based on the combination of three projections of fixed certification costs (low, medium, and high) and three carbon credit price projections. This approach reveals a spectrum of results in which the minimum area required to enable market participation varies considerably, ranging from 50 hectares in the most optimistic scenario (low costs and high prices) to 320 hectares in the most pessimistic (high costs and low prices).

Despite this variation, the fundamental conclusion remains consistent across all scenarios: the commercialization of carbon credits is economically unviable for the vast majority of coffee growers, since even the most favorable scenario (50 ha) still excludes 88% of the country's producers (Santos; Nogueira, 2025). This finding lends greater solidity to the central hypothesis of this work. Thus, the methodology allows us to clearly measure how much of the mitigation potential is lost solely due to market design.

3.2. Construction of Economic Feasibility Scenarios

The scenarios analyzed should not be interpreted as predictions, but rather as simulations of different public policy and market environments. Each minimum viable area threshold (10, 50, 100, and 200 hectares) serves as a proxy for the level of success of institutions in mitigating transaction costs, as per the theoretical discussion presented in Section 2. The transition between scenarios, from the most optimistic to the most restrictive, directly reflects the consequences of different regulatory choices, illustrating the trade-off between the microeconomic efficiency of individual projects and the macroenvironmental effectiveness and social inclusion of the policy as a whole.

Scenario 1: Optimistic (10-hectare limit) – Broad Inclusion via Institutional Innovation This new scenario represents the theoretical maximum mitigation potential that could be achieved under a highly effective and inclusive climate policy framework. It models a reality in which transaction costs have been drastically reduced, making participation in the carbon market economically viable even for small-scale family farms. The plausibility of this scenario is anchored in two institutional innovations discussed in the article's theoretical framework: Aggregation via Collective Action: Based on the strategies proposed by Cacho et al. (2013), this scenario presupposes the widespread adoption of "programmatic" or "aggregated" projects, in which cooperatives and producer associations act as intermediaries. By consolidating thousands of small properties into a single project, the high fixed costs of developing methodology, certification, and MRV (Monitoring, Reporting, and Verification) are distributed among all participants, drastically reducing the cost per producer and per hectare.

Market Incentives via Voluntary Instruments: In line with the discussion on environmental labeling, this scenario also assumes the consolidation of voluntary markets for carbon-neutral products. Obtaining a price premium through labels such as "carbon-neutral coffee" generates an additional source of revenue for small producers. This market incentive, as theorized by Segerson (2013), not only helps cover residual compliance costs but also strengthens the attractiveness of participation, transforming GHG mitigation from a burden into a value-adding opportunity.

<u>Scenario 2:</u> Moderate (50-hectare limit) – Partial Inclusion This scenario reflects a market environment where partial progress has been made in reducing transaction costs, but barriers remain significant for most smallholder farmers. It corresponds to the lower viability limit estimated by Santos and Nogueira (2025) and simulates a reality in which some cooperative structures are able to participate or where MRV technologies have become more accessible, but not yet sufficient to engage the base of the production pyramid.

<u>Scenario 3:</u> Restrictive (100-hectare limit) – Structural Exclusion This scenario models the implementation of a conventional carbon market, or "business-as-usual," in which transaction costs remain high and there are no institutional mechanisms to support the aggregation of small projects. The market operates under a logic of pure microeconomic efficiency, favoring medium- to large-scale properties that have the capital and technical capacity to absorb these costs. It represents a failure of policy to

adapt to the structural reality of Brazilian agriculture, characterized by the predominance of family farming.

Scenario 4: Highly Restrictive (200-hectare limit) – Elite Market This scenario simulates a market with prohibitive entry barriers, where only the largest and most capitalized agricultural companies can participate. It illustrates the most extreme outcome of a poorly designed policy, in which the market instrument serves a minimal fraction of the sector, resulting in marginal environmental effectiveness and maximizing social exclusion and income concentration.

By framing the scenarios in this way, the analysis demonstrates that the level of mitigation achieved by the SBCE is not a predetermined outcome, but a direct consequence of the policy choices made during its design phase. The substantial difference in outcomes between the 10-ha and 200-ha scenarios quantifies the opportunity cost—both environmental and social—of opting for an exclusionary path over an inclusive one. The "Optimistic" scenario therefore establishes a crucial analytical benchmark, defining maximum potential. The gap between this benchmark and the other scenarios can be conceptualized as the "Mitigation and Equity Gap": the sum of the unrealized climate benefit and the rural development opportunity lost due to persistently high transaction costs.

3.3. Scope of Analysis and Levels of Geographic Aggregation

To capture both the aggregate and distributional consequences of the different feasibility scenarios, the study employs a multilevel analysis. This approach allows for a deeper and more nuanced understanding of the policy's impacts, revealing dynamics that would remain hidden in a single-level analysis.

National Level: The primary objective of national-scale analysis is to quantify the macro-impact of policy design. It measures the overall environmental effectiveness of the carbon market in each scenario, calculating the aggregate GHG mitigation and revenue potential. More importantly, this level measures the full magnitude of the "Mitigation and Equity Gap," answering the central question: "How much of the total national potential is effectively realized or lost due to the scale barrier?"

Municipal Level: The analysis is then expanded to the municipal scale, a deliberate methodological choice to investigate the spatial heterogeneity of impacts. A national average alone would mask critical local dynamics, since the agrarian structure—the ratio of family to large-scale farming—varies drastically across Brazil's different coffee-growing regions. This subnational analysis was designed to expose how the exclusionary effects of transaction costs can exacerbate existing regional inequalities. It demonstrates how a seemingly neutral national policy (by establishing a single eligibility criterion by area) can, in practice, generate a geography of "carbon oases"—municipalities with a predominance of large farms that benefit from the market—and "carbon deserts"—municipalities dominated by family farming that are completely marginalized. This approach directly connects the economic instrument to issues of distributive justice and regional development, reinforcing the need to consider the equity criterion in the design of environmental policies, as discussed in Section 2.1. To ensure the relevance of the analysis, the selection of municipalities for the case study focused on the 28 municipalities that make up the 99.5th quantile of the total area cultivated with coffee in Brazil, ensuring that the investigation focuses on the most significant production centers in the country.

4. Mitigation Potential of Coffee Growing: Results and Discussion

The scenario analysis quantifies the vast mitigation potential of coffee farming and, at the same time, reveals how different environmental policy instruments determine its implementation. The results demonstrate that, while the regulated carbon market (SBCE) faces structural barriers that limit participation, voluntary instruments such as environmental labeling emerge as a strategic way to include family farming and maximize the sector's climate and social impact.

4.1. National Aggregate Potential

The national-scale analysis, presented in Table 1, contrasts two distinct policy models. The 50-, 100-, and 200-hectare scenarios, projected by Santos and Nogueira (2025), simulate the likely outcomes of the SBCE, where transaction costs for the sale of carbon credits create scale barriers. In contrast, the inclusive 10-hectare scenario was specifically inserted to estimate the maximum potential that could be achieved through a policy encouraging the labeling of "carbon-neutral coffee," for example. This voluntary instrument, rather than relying on the sale of credits, creates value through a price premium in the consumer market, making the adoption of sustainable practices viable even for small producers, especially when organized in cooperatives.

Table 1. National Mitigation Potential and Revenue from Carbon Credits from Coffee Farming under Different Feasibility Scenarios

Minimum viable scale (ha)	Area (ha)	Tons of GHG (tCO_2eq)	Revenue (R$)
10	1,717,654	13,019,817	-
50	1,093,251	8,286,843	2,295,455,395
100	823,909	6,245,230	1,729,928,771
200	567,951	4,305,069	1,192,503,997

Source: Prepared by the authors based on data from Santos and Nogueira (2025) and projection of inclusive area for inclusive scenario.

The data reveal a significant difference. The labeling scenario (10 ha) demonstrates that Brazilian coffee production has the technical potential to mitigate approximately 13 million tons of CO_2 equivalent (tCO_2eq). However, if climate policy is restricted to the carbon market (SBCE), even in its most optimistic configuration (50 ha), the realizable potential drops to 8.3 million tCO_2eq. In a more restrictive scenario (200 ha), which reflects the reality of high transaction costs, the potential plummets to 4.3 million tCO_2eq.

This means that a policy focused exclusively on the regulated market would fail to realize between 36% and 67% of the sector's total mitigation potential. The difference of nearly 8.7 million tCO_2eq between the labeling scenario and the more restrictive SBCE scenario represents the "opportunity cost" of not implementing a complementary policy to encourage voluntary instruments. It is clear that, for Brazil to achieve its climate goals, promoting labeling is not just an option, but a strategic necessity to engage the base of the production pyramid.

In this context, the results suggest that planning for this Brazilian Emissions Reduction Market under the *cap-and-trade system* should consider institutional means of reducing certification costs and allowing for the aggregation of the diffuse potential of small producers to maximize the policy's effectiveness. Based on the options presented by Cacho et al. (2013), it is recommended that these certification processes be conducted by coffee grower cooperatives that, through aggregation, increase the scale of production by combining the productive areas of their members, allowing for the sharing of these costs. It is worth mentioning that this practice of collective certification, through cooperatives, for example, has already been adopted for sustainable labeling certifications, considered voluntary environmental policy instruments.

Furthermore, implementation and monitoring methodologies can be developed through agricultural technology research, such as lower-cost carbon balance methodologies. This technological advancement can reduce Measurement, Reporting, and Verification (MRV) costs in the case of carbon credit trading, as well as sustainable labeling audit costs inherent to these certification processes, without compromising their international credibility.

4.2. Asymmetric Impacts at the Municipal Level

The municipal-level analysis deepens this conclusion, showing how a labeling policy could function as a powerful instrument for regional development, precisely in areas that would otherwise be marginalized by the carbon market. Tables 2, 3, and 4 expose the heterogeneity of impacts, where the local agrarian structure determines who wins and who loses.

Table 2. Potential area for adopting good practices that reduce GHG emissions per municipality in area ranges from 10, 50, 100 and 200 hectares.

Municipality	Property area from 10 hectares (in hectares)	Property area from 50 hectares (in hectares)	Property area from 100 hectares (in hectares)	Property area from 200 hectares (in hectares)
Patrocínio (MG)	25,326	17,883	10,866	2,235
Boa Esperança (MG)	18,804	15,444	12,363	7,275
Três Pontas (MG)	18,952	14,679	11,793	6,503
Campos Gerais (MG)	22,382	14,196	9,756	5,799
Piumhi (MG)	13,901	12,327	10,707	8,565

São Sebastião do Paraíso (MG)	15,399	12.117	9,377	5,949
Machado (MG)	12,775	10,472	7,279	3,955
Monte Carmelo (MG)	12,999	10,256	7,026	7,026
Garça (SP)	10,059	8,628	7,580	5,389
Ibiraci (MG)	12,664	8,319	5,078	2,078
Araguari (MG)	11,673	7,856	4,324	1,609
Linhares (ES)	14,737	7,839	4,282	1,797
Jaguaré (ES)	12,247	7,032	4,840	2,478
Campestre (MG)	12,954	6,665	4,772	3,598
Rio Bananal (ES)	15,905	5,874	2,606	589
São Mateus (ES)	11,408	5.205	3.019	1,644
Manhuaçu (MG)	12,969	4,928	1,660	1,660
Nova Venécia (ES)	10,334	4,341	1975	803
Carmo do Rio Claro (MG)	8,485	4,247	1983	-
Vila Valério (ES)	9,155	4.113	2,813	1904
Santa Margarida (MG)	7,933	3,780	2,789	1,334
Lajinha (MG)	6,972	3.261	1917	567
Afonso Cláudio (ES)	9,393	3.215	1,091	382
Pancas (ES)	8,823	3,069	1,578	594
Iúna (ES)	7,583	3,039	1,664	903
Simonésia (MG)	7,539	2.187	798	-
Castelo (ES)	7,411	1903	183	-
Nova Resende (MG)	9,027	1,892	775	-

Source: Prepared by the authors based on data from Santos and Nogueira (2025) and projection of inclusive area for inclusive scenario.
Note: The selection represents the 28 municipalities in the 99.5 quantile, which together account for 0.5% of the total area cultivated with coffee in Brazil.

This effect is evident at the municipal level, as illustrated in Table 3. The municipalities of Patrocínio (MG) and Carmo do Rio Claro (MG), for example, clearly illustrate the impacts that could occur if the regulated carbon market allows the participation of coffee farms with an area of 50 hectares or more, or, more restrictively, at least 200 hectares. In Patrocínio, the inclusion of farms with an area of 50 hectares or more would result in agricultural revenue of R$37.5 million and a reduction of 135,600 tons of CO_2 equivalent.

However, if eligibility is limited to properties with 200 hectares or more, these values plummet to R$4.7 million in revenue and only 16,900 tons of GHG reduction in the municipality of Patrocínio, indicating a significant loss of economic and environmental potential. In contrast, in the more inclusive scenario, which encourages GHG reductions on properties with 10 hectares or more, Patrocínio would have the potential to reduce 191,971 tCO_2eq.

Table 3. Quantity of GHG reduction by municipalities in area ranges from 10, 50, 100 and 200 hectares.

Municipality	GHG reduction on properties from 10 hectares (in ton of CO_2eq)	GHG reduction on properties from 50 hectares (in ton of CO_2eq)	GHG reduction on properties from 100 hectares (in ton of CO_2eq)	GHG reduction on properties from 200 hectares (in ton of CO_2eq)
Patrocínio (MG)	191,971	135,553	82,364	16,941
Boa Esperança (MG)	142,534	117,066	93,712	55,145
Três Pontas (MG)	143,656	111,267	89,391	49,293
Campos Gerais (MG)	169,656	107,606	73,950	43,956
Piumhi (MG)	105,370	93,439	81,159	64,923
São Sebastião do Paraíso (MG)	116,724	91,847	71,078	45,093
Machado (MG)	96,835	79,378	55,175	29,979
Monte Carmelo (MG)	98,532	77,740	53,257	53,257
Garça (SP)	76,247	65,400	57,456	40,849
Ibiraci (MG)	95,993	63,058	38,491	15,751

Araguari (MG)	88,481	59,548	32,776	12.196
Linhares (ES)	111,706	59,420	32,458	13,621
Jaguaré (ES)	92,832	53.303	36,687	18,783
Campestre (MG)	98.191	50,521	36,172	27,273
Rio Bananal (ES)	120,560	44,525	19,753	4,465
São Mateus (ES)	86,473	39,454	22,884	12,462
Manhuaçu (MG)	98,305	37,354	12,583	12,583
Nova Venécia (ES)	78,332	32,905	14,971	6,087
Carmo do Rio Claro (MG)	64,316	32,192	15,031	-
Vila Valério (ES)	69,395	31,177	21,323	14,432
Santa Margarida (MG)	60.132	28,652	21,141	10.112
Lajinha (MG)	52,848	24,718	14,531	4,298
Afonso Cláudio (ES)	71,199	24,370	8,270	2,896
Pancas (ES)	66,878	23,263	11,961	4,503
Iúna (ES)	57,479	23,036	12,613	6,845
Simonésia (MG)	57,146	16,577	6,049	-
Castelo (ES)	56,175	14,425	1,387	-
Nova Resende (MG)	68,425	14,341	5,875	-

Source: Prepared by the authors based on data from Santos and Nogueira (2025) and projection of inclusive area for inclusive scenario.
Note: The selection represents the 28 municipalities in the 99.5 quantile , which together account for 0.5% of the total area cultivated with coffee in Brazil.

Table 4. Potential revenue from the sale of carbon credits by municipalities in area ranges from 50, 100 and 200 hectares.

Municipality	Income on properties from 50 hectares (in R$)	Income on properties from 100 hectares (in R$)	Income on properties from 200 hectares (in R$)

Patrocínio (MG)	37,548,220	22,814,906	4,692,740
Boa Esperança (MG)	32,427,150	25,958,096	15,275,026
Três Pontas (MG)	30,820,910	24,761,290	13,654,089
Campos Gerais (MG)	29,806,774	20,484,282	12,175,928
Piumhi (MG)	25,882,508	22,481,060	17,983,588
São Sebastião do Paraíso (MG)	25,441,580	19,688,512	12,490,877
Machado (MG)	21,987,640	15,283,425	8,304,156
Monte Carmelo (MG)	21,534,112	14,752,211	14,752,211
Garça (SP)	18,115,866	15,915,423	11,315,068
Ibiraci (MG)	17,467,072	10,662,073	4,363,094
Araguari (MG)	16,494,929	9,078,930	3,378,353
Linhares (ES)	16,459,235	8,990,744	3,773,089
Jaguaré (ES)	14,764,809	10,162,354	5,202,958
Campestre (MG)	13,994,234	10,019,578	7,554,577
Rio Bananal (ES)	12,333,403	5,471,714	1,236,700
São Mateus (ES)	10,928,730	6,338,874	3,451,841
Manhuaçu (MG)	10,347,124	3,485,436	3,485,436
Nova Venécia (ES)	9,114,624	4,146,829	1,686,027
Carmo do Rio Claro (MG)	8,917,256	4,163,626	-
Vila Valério (ES)	8,635,902	5,906,344	3,997,753
Santa Margarida (MG)	7,936,715	5,855,952	2,800,947
Lajinha (MG)	6,846,992	4,025,048	1,190,507
Afonso Cláudio (ES)	6,750,407	2,290,729	802.070
Pancas (ES)	6,443,857	3,313,264	1,247,198
Iúna (ES)	6,380,867	3,493,834	1,895,993
Simonésia (MG)	4,591,957	1,675,529	-

Castelo (ES)	3,995,653	384,238	-
Nova Resende (MG)	3,972,557	1,627,237	-

Source: Prepared by the authors based on data from Santos and Nogueira (2025).
Note: The selection represents the 28 municipalities in the 99.5 quantile , which together account for 0.5% of the total area cultivated with coffee in Brazil.

Municipalities like Carmo do Rio Claro (MG), Nova Resende (MG), and Castelo (ES), where family farming is the backbone of the local economy, would have their mitigation potential completely eliminated under a restrictive SBCE scenario. However, these municipalities have significant potential under the 10-hectare scenario. In Carmo do Rio Claro, for example, a labeling policy could mobilize the mitigation of over 64,000 tCO_2eq, transforming what would otherwise be a "carbon desert" into a hub for sustainable coffee production and value-added value.

Labeling, therefore, not only has the potential to increase the total volume of mitigation but also to distribute it more equitably, generating economic and environmental benefits in regions that would otherwise be ignored by a market-based policy with high transaction costs. This reinforces the argument that promoting reduced certification costs is a tool for correcting market failures and promoting climate justice at the regional level.

4.3. Policy Implications and Recommendation: Integrating Regulated Market and Voluntary Incentives

The results converge to a clear conclusion: the design of climate policy for Brazilian agriculture should not be a choice between the regulated market (SBCE) and voluntary instruments (labeling), but rather a strategy of intelligent integration between both. The recommended integration between the regulated market (SBCE) and voluntary instruments (labeling) resonates with global efforts. The FAO (2023) advocates for True Cost Accounting (TCA) to uncover hidden costs in agriculture, which disproportionately affect smallholder producers.

The World Bank (2025) documents the expansion of ETSs like the SBCE, covering 28% of global emissions, but also points to the evolution and challenges of carbon credit markets. This study's results indicate that the SBCE, on its own, is an insufficient instrument for the reality of national coffee farming, as its transaction costs make it structurally exclusionary for 78% of producers. Relying solely on it for climate policy could result in low environmental effectiveness and a deepening of socioeconomic inequalities. Thus, a dual strategy, combining an accessible SBCE with credible voluntary labeling, aligns Brazil with global trends and the need to include the diverse actors and true costs of national agriculture in an effective and just climate policy.

The analysis of the 10-hectare scenario, however, is suggestive of the path forward. It demonstrates that the greatest mitigation potential lies precisely in the family farming segment on smaller properties, which can be mobilized by reducing certification costs.

Regarding labeling as a voluntary instrument, it is important to mention the dilemma of "premium erosion" and " mainstreaming ." The work of Giovannucci and Ponte (2005) warns that, as the supply of certified coffee increases and the practice becomes more common, the price differential compared to conventional coffee tends to decrease—a process known as *mainstreaming*. This phenomenon is also observed by Silva and Nonnenberg (2023), who highlight the reduction in premiums with the popularization of certification, although they do not use the term. This implies that the premiums observed today are not guaranteed in perpetuity, requiring certified producers to continually innovate and differentiate themselves to maintain their competitive advantage.

Therefore, it is recommended that an active public policy be implemented that promotes both "carbon-neutral coffee" labeling and other sustainability seals, as well as reducing MRV costs for generating carbon credits. Such a policy should include:

1. Support for Collective Certification: Promote and subsidize the structuring of cooperatives and associations so that they can manage group certification processes, dilute fixed costs and providing technical assistance to small producers.
2. Simplification and Credibility: Invest in research to develop low-cost Measurement, Reporting and Verification (MRV) protocols that maintain international credibility without placing a disproportionate burden on producers.
3. Valuation Campaigns: Develop marketing and awareness campaigns, both in the domestic and international markets, so that consumers recognize the added value of low-emission coffee, guaranteeing the price premium that makes the system viable.

By combining the economic instrument of the SBCE for large properties with the voluntary instrument created by labeling for small and medium-sized producers, Brazil can build a robust, effective climate policy aligned with its agricultural reality, transforming an environmental challenge into an opportunity for sustainable rural development.

5. Final Considerations

The analysis conducted in this study demonstrates that, although Brazilian coffee production has a GHG mitigation potential exceeding 13 million tons of CO_2eq, more than half of this potential is at risk of not being realized if the high transaction costs inherent in certification processes exclude small- and medium-scale producers. Implementing environmental policies to reduce GHG emissions without inclusive mechanisms can be environmentally ineffective, failing to mobilize the majority of the abatement potential, and socially exclusionary, concentrating the benefits on a limited number of large properties.

Furthermore, it should be recognized that the scenarios presented quantify the maximum mitigation potential, assuming that all eligible producers in each area would participate in the program. In practice, the adoption of low-carbon practices and participation in environmental markets are complex processes, influenced by a range of factors that transcend simple economic viability, such as access to technical assistance, credit availability, risk perception, and social capital.

Therefore, the actual adoption rate is likely below 100%, meaning that the constraint imposed by the feasibility threshold may actually be even greater than estimated. This limitation does not weaken, but rather strengthens the study's main conclusion: the urgency of active and well-designed public policies is even more critical to overcome not only economic barriers, but also information and capacity barriers that limit farmers' effective participation.

Given this diagnosis, the implementation of an active public policy that promotes both "carbon-neutral coffee" labeling and other sustainability seals, as well as the reduction of MRV costs for generating carbon credits, is crucial to aligning economic efficiency with environmental effectiveness and social equity. Based on the analysis and specialized literature, clear and actionable public policy recommendations emerge: a) It is recommended that SBCE regulation encourage and facilitate the creation of "aggregate" or "programmatic projects." b) The government should direct research and development resources, through research institutions such as Embrapa and universities, toward the creation of technologies that drastically reduce Monitoring, Reporting, and Verification (MRV) costs. c) Develop marketing and awareness campaigns, both domestically and internationally, so that consumers recognize the added value of low-emission coffee.

The transition to low-carbon agriculture is an opportunity for Brazil to reconcile its environmental, economic, and social objectives. However, for this opportunity to materialize, policy instruments must be designed for the realities of the Brazilian countryside , considering regional differences and tailored to each agricultural crop in our country. An inclusive and effective environmental policy will not emerge spontaneously. It needs to be built with an intelligent institutional architecture that recognizes and overcomes the barriers that currently impede the participation of the majority.

For future research, we suggest expanding the assessment of the adoption of good agricultural practices to reduce GHG emissions to other Brazilian agricultural crops, such as livestock and grain production. Additionally, further study is needed on the potential for adopting these practices through voluntary environmental policy instruments, with a focus on the marketing of products with a "carbon neutral" label.

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Just Transition and Low-Carbon Agriculture: Lessons from Brazilian Pig Farming for the COP30 Climate Agenda

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Abstract
This study assesses how economic instruments arranged as a coherent policy mix can accelerate the decarbonization of Brazil's swine sector within a just transition framework. A systematic review (2015–2025) from Web of Science identified 26 studies covering sectoral greenhouse gases (CH_4/N_2O), mitigation options (anaerobic digesters, manure management, precision nutrition), and instrument design (carbon taxation and emissions trading - ETS; payments for environmental services - PES; green rural credit; standards/certification; and extension services). The evidence indicates that stand-alone policies tend to deliver limited and uneven outcomes. By contrast, integrated mixes that combine price signals with revenue recycling, targeted PES, concessional finance, and technical assistance are associated with faster technology adoption, lower abatement costs, and broader smallholder inclusion. Based on these findings, a governance-ready architecture is delineated that couples: (i) federal pricing and regulatory frameworks with earmarked revenues for credit and technical assistance; (ii) state-level financial instruments and PES supported by proportionate monitoring, reporting, and verification (MRV); and (iii) territorial cooperative arrangements enabling producer aggregation, certification, and market access. Positioned in the run-up to COP30 (Belém), the analysis specifies key trade-offs and feasibility conditions, including MRV indicators, distributive safeguards, and pooling mechanisms. The synthesis suggests that a combination of carbon tax, ETS, PES, green credit, and extension offers a balanced pathway that aligns efficiency, equity, and environmental integrity in the swine value chain.

Keywords: Swine sector; COP30; Carbon pricing; Emissions trading (ETS); Payments for environmental services (PES).

Resumo
Este estudo avalia como instrumentos econômicos, dispostos como um mix coerente de políticas, podem acelerar a descarbonização do setor suinícola brasileiro no marco de uma transição justa. Realizou-se uma revisão sistemática (2015–2025) na *Web of Science*, que

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identificou 26 estudos abrangendo: gases de efeito estufa setoriais (CH_4/N_2O), opções de mitigação (biodigestores anaeróbios, manejo de dejetos, nutrição de precisão) e desenho de instrumentos (tributação de carbono e comércio de emissões – ETS**,** pagamentos por serviços ambientais – PSA, crédito rural verde**,** normas/certificação e assistência técnica e extensão). As evidências indicam que políticas isoladas tendem a produzir resultados limitados e desiguais. Em contraste, arranjos integrados que combinam sinais de preço com reciclagem de receitas, PSA focalizados**,** financiamento concessionário e assistência técnica estão associados a adoção tecnológica mais rápida**,** menores custos de abatimento e maior inclusão de pequenos produtores. Com base nesses achados, delineia-se uma arquitetura pronta para governança que articula: (i) marcos federais de precificação e regulação, com receitas vinculadas a crédito **e** assistência técnica; (ii) instrumentos financeiros e PSA em nível estadual, apoiados por MRV proporcional (monitoramento, reporte e verificação); e (iii) arranjos cooperativos territoriais que possibilitam agregação de produtores**,** certificação e acesso a mercados. Situada no contexto preparatório da COP30 (Belém), a análise explicita trade-offs e condições de viabilidade, incluindo indicadores de MRV, salvaguardas distributivas e mecanismos de pooling. A síntese sugere que a combinação de imposto sobre carbono, ETS, PSA, crédito verde e extensão rural oferece uma trajetória equilibrada, que alinha eficiência**,** equidade e integridade ambiental na cadeia de valor suinícola.

Palavras-chave: Setor suíno; COP30; Precificação de carbono; Comércio de emissões (CSE); Pagamentos por serviços ambientais (PSA).

1 Introduction

The intensification of climate impacts in recent decades has placed Brazil facing a structural dilemma: how to sustain agricultural expansion while simultaneously reducing greenhouse gas (GHG) emissions resulting from this production model. Extreme climate events, such as prolonged droughts, floods, and record-breaking heat events, directly affect food security, the energy matrix, and the ecological balance of sensitive biomes such as the Amazon (Mariani et al., 2016; Giatti et al., 2016). Amid this scenario, the COP30 summit in Belém in 2025 puts the Amazon back at the center of the global climate debate, demanding concrete responses to mitigate emissions and build low-carbon rural economies.

Among Brazil's productive sectors, pig farming is doubly important: it is a central component of food security and the trade balance, but it is also a significant source of methane (CH_4) and nitrous oxide (N_2O) emissions, resulting from inadequate waste management and intensive use of inputs (Oliveira et al., 2022; Ferreira et al., 2023). Although the sector is not among the largest emitters in Brazilian agriculture, its emissions intensity per unit of product is high, making it a strategic field for the development of mitigation policies, technological innovation, and environmental justice.

The urgency of this debate is reinforced by Brazil's commitment to the Paris Agreement and the revision of its Nationally Determined Contribution (NDC), which sets emissions reduction targets of 48% by 2025 and 53% by 2030 (BRAZIL, 2023; UNFCCC, 2023). Meeting these targets depends, to a large extent, on the ability to incorporate agriculture, especially intensive systems, into a just transition model capable of combining economic efficiency, social inclusion, and environmental integrity.

In this context, economic instruments of environmental regulation emerge as decisive tools for the transition. Carbon pricing, emissions trading systems (ETS), and payments for environmental services (PES) constitute mechanisms that seek to internalize the social cost of emissions and encourage sustainable production practices (Nordhaus, 2018; Blanchard; Gollier; Tirole, 2023). However, their application in the Brazilian agricultural sector is still incipient, marked by structural inequalities, low institutional capacity, and limited access to climate finance.

At the same time, international experience offers relevant evidence. Sweden, a pioneer in adopting a carbon tax since 1991, has demonstrated that the combination of market instruments and redistributive policies can reduce emissions without compromising economic growth (Jonsson; Ydstedt; Asen, 2020). In Canada and the European Union, hybrid policies that combine ETS and green subsidies have proven effective in inducing technological innovation and protecting small producers (Parry et al., 2022; Blanchard et al., 2023). These experiences suggest paths for the Brazilian case, where the implementation of pricing mechanisms needs to be compatible with the principle of equity and the socioeconomic specificities of rural areas.

The central hypothesis of this article is that the decarbonization of the Brazilian pig industry will not be achieved solely through isolated technological innovations, but from an integrated policy arrangement that combines economic instruments (carbon pricing, including ETS), payments for environmental services (PES)**,** incentive policies, and robust regulatory frameworks, supported by public investments directed toward clean technologies. Viewed through a just transition lens, this arrangement must redistribute costs and benefits and ensure effective access to finance and markets for smallholders, positioning the sector as a benchmark in agri-environmental policy. The combination of carbon pricing, payments for environmental services, and public investments geared towards clean technologies can make the sector an example of a just transition agri-environmental policy.

Thus, this study seeks to analyze how economic instruments can contribute to the decarbonization of pig farming and, more broadly, to the development of a low-carbon agriculture sector. It begins with a systematic literature review, focusing on national and international publications addressing the relationship between pig farming, GHG emissions, and environmental regulation. The analysis is structured around three axes: (i) theoretical foundations of environmental economics and market instruments; (ii) empirical evidence on mitigation and technological innovation in pig farming; and (iii) assessment of the possibilities and limitations of implementing these mechanisms in the Brazilian context.

Thus, the research aims to contribute conceptual and empirical support to the COP30 debate, highlighting the role of family farming, environmental governance, and climate finance in the transition to more sustainable, inclusive, and resilient production systems.

2 Theoretical framework and international context

Since the 1990s, policymaking aimed at mitigating climate change has been supported by the conceptual framework of environmental economics. The neoclassical perspective, represented by authors such as Pigou (1920) and Baumol and Oates (1988), argues that market failures resulting from negative externalities, such as greenhouse gas (GHG) emissions, should be corrected by internalizing environmental costs. This logic underpins the use of economic instruments, such as taxes, subsidies, and emissions trading systems, capable of aligning private interests with collective well-being (Motta; Mendes, 2001; Nusdeo, 2006).

At the beginning of the 21st century, this approach was consolidated by the theory of the social cost of carbon, developed by William Nordhaus (2018), which proposes a pricing model based on the marginal cost of emissions on global economic well-being. The so-called DICE (Dynamic Integrated Climate-Economy) demonstrated that the absence of prices that reflect environmental impact leads to the overproduction of carbon-intensive goods and, consequently, climate degradation. Nordhaus ' logic underpins the current carbon pricing policies adopted by more than 70 countries, according to the *World Bank (2023)*.

Nicholas Stern (2007) argues, the climate problem is not limited to a market failure, but constitutes the "greatest market failure in history." The author advocates coordinated government action to create long-term economic incentives, combining regulation, technological innovation, and cost redistribution. This view broadens the focus of classical environmental economics, incorporating ethical and social dimensions of mitigation, which will be revisited later in the concept of just transition.

Additionally, the Dasgupta Report (2021) introduces the notion of natural capital as an essential component of economic accounting and environmental governance. For the author, production systems should not treat nature as an infinite input, but as an asset that underpins the economy. This approach, adopted by organizations such as the Organization for Economic Cooperation and Development (OECD) and the World Bank, guides public policies that integrate biodiversity, climate mitigation, and productive inclusion, especially in diverse countries like Brazil.

In the field of Latin American ecological economics, Lustosa, Cánepa, and Young (2003) and Motta and Mendes (2001) emphasize that internalizing environmental externalities through economic instruments is a prerequisite for reconciling growth and sustainability. Furthermore, the authors argue that the effectiveness of these instruments depends on institutional capacity and distributive justice in the allocation of resources. Thus, environmental policies cannot be socially neutral: they must recognize the structural inequalities that permeate the Brazilian countryside.

The just transition is based on the recognition that decarbonization, if not accompanied by social protection and economic inclusion policies, tends to reproduce inequalities. This perspective is particularly relevant to Brazilian agriculture, where family systems and small farms are predominant, vulnerable to market fluctuations and regulatory restrictions.

The effectiveness of the policy arrangement depends on multilevel governance that links economic instruments to public policies (Hooghe; Marks, 2003). At the federal level, carbon pricing, including emissions trading systems (ETS) and regulatory standards should signal prices and earmark revenues for green rural credit and technical assistance (Howlett; Rayner, 2007). At the state level, sectoral agencies and public banks operationalize financing, guarantees, and payments for environmental services (PES). At the municipal level, cooperatives and inter-municipal consortia pool smallholders to reduce transaction costs, standardize practices (biodigesters, manure management, precision nutrition), and certify emissions reductions for market access (Ostrom, 2009). Taken together, this arrangement aligns prices, finance, and regulation, converting price signals into technology adoption, productive inclusion, and measurable emissions reductions.

International governance perspective, COP30, being hosted in Belém, assumes a symbolic and strategic role. Located in the Amazon, a region that accounts for approximately 45% of Brazil's emissions related to land-use change (MMA, 2023), the conference emphasizes the need for solutions that integrate agricultural production, forest conservation, and climate finance. The convergence of the green economy, agriculture, and climate requires instruments capable of articulating productive efficiency, social inclusion, and environmental preservation, a central axis of the debate leading up to COP30.

Finally, recent literature proposes the formation of policy mixes, which are combinations of economic instruments and public policies, as the most effective strategies to address the complexity of the climate challenge (Cocker, 2025; Blanchard; Gollier; Tirole, 2023). Such arrangements combine carbon pricing, tax incentives, and innovation subsidies, articulating market mechanisms with state regulation. As Kotz et al. (2024) note, the climate transition depends on a new macroeconomic pact that mobilizes public investment, green credit, and sustainable industrial policies.

Thus, the contemporary debate on economic instruments goes beyond the scope of environmental efficiency: it is part of a new development paradigm, in which mitigation, equity and governance become inseparable dimensions of the climate economy.

3 Methodology

This research adopts a qualitative, exploratory approach, based on a review of national and international literature. The main objective was to identify gaps in the research field on the interface between climate change and pig farming, especially regarding decarbonization and economic instruments of environmental regulation.

According to Linde and Willich (2003), a systematic review is a methodology capable of gathering scientific evidence based on the existing literature, allowing the identification of both convergences and controversies in the studies analyzed, in addition to providing theoretical support for future research. Galvão and Ricarte (2019) emphasize that this type of approach requires methodological rigor in defining the databases consulted, search strategies, and inclusion and exclusion criteria for publications.

The article collection and selection stage was conducted in the *Web of Science database*, using descriptors related to the study's central themes: "climate change and swine production," "climate effects on piglet production," "impacts of climate change on Brazil," and "gas emissions and swine production." To refine the results, the Boolean operators AND and OR were used, as well as quotation marks to locate exact expressions in the bibliographic searches. The timeframe criteria included publications published between 2015 and 2025, in English and Portuguese, as shown in Table 1.

Table 01: Research descriptors.

((“Pig production” OR “Swine production”) AND (“Climate Change”) AND (“Pig production”) OR (“Greenhouse gas emissions” OR “Climate effects on food production”) OR (“Piglet production) AND “(Brazil)”.

From the studies located through the search strategy applied to the *Web of Science database*, 26 articles were selected to compose the corpus of this systematic literature review. The results obtained from this methodological procedure are summarized in the following section. Presented below, Table 2 catalogs the identified studies, their respective instrument types, and the expected observations.

Table 2: Policy mix for Brazilian swine sector

Study (year)	Instrument	Mitigation lever	Notes
Angonese et al. (2007)	Carbon credits/PES	Anaerobic digester (CH_4)	Payback with incentives
Esperancini et al. (2007)	Energy incentive	Biogas replacing LPG/electricity	Dependent on tariffs and logistics

Martins & Oliveira (2011)	Implicit tariff/feed-in	Biogas-based power generation	Scale and maintenance are critical
Avaci et al. (2013)	Microgeneration/net metering	Biogas	Grid conditions matter
Cherubini et al. (2015)	(standards/labeling)	LCA of pork products	Market signal
Andretta et al. (2018)	(standards)	Precision nutrition	Diet reformulation
Monteiro et al. (2017a)	—	Feeding programs	Sensitive to ingredient composition
Monteiro et al. (2017b)	—	Ingredient variation	Cost/footprint trade-offs
Ribeiro et al. (2018)	Tax/regulatory	Production structure	Input-intensive sectors
Cerri et al. (2010)	Portfolio	Land use/livestock	Integrates LULUCF
FAO (2019)	Standards/good practices	Husbandry/feeding	Technical guidance
Pietramale et al. (2021)	—	Management practices	Heterogeneity
Christofoletti & Pereda (2021)	Carbon tax	Distribution/regressivity	Requires compensations
Alvim & Sanguinet (2021)	Carbon tax	Meat/dairy	Recommends hybrid approaches
Parry et al. (2022)	Tax vs. ETS	Instrument design	Design guidance
Oliveira et al. (2022)	—	Challenges and opportunities	Brazil focus
Barioni et al. (2022)	Portfolio	Climate-smart livestock	Policy integration
Ferreira et al. (2023)	Instrument review	Multiple levers	Brazilian swine sector
Santos & Castro (2021)	PES for waste	Management/recycling	Local design
World Bank (2023)	Pricing (global map)	—	Price trends

Schmalensee & Stavins (2017)	ETS	Cap-and-trade	MRV/markets
Jonsson et al. (2020)	Carbon tax + compensation	General economy	30-year stability
Dasgupta (2021)	Green accounting	Natural capital	Basis for PES
Stern (2007)	Policy/innovation	—	Long-term policy pact
Blanchard, Gollier & Tirole (2023)	Policy mix	—	Combination of instruments
Cocker (2025)	Policy mix	—	Transferable to agriculture

Source: Author's elaboration

4 Results and discussion

This section aims to present an analytical synthesis of the main findings of the selected articles. Initially, the authors are identified and the contributions of each study in relation to the different environmental policy instruments are systematized. Next, a theoretical discussion is developed in line with the hypothesis outlined in the introduction to this essay.

4.1 Carbon pricing and hybrid instruments

Over the past two decades, carbon pricing has established itself as one of the most discussed instruments in international climate governance. Based on environmental economics theory, it seeks to internalize the social costs of greenhouse gas (GHG) emissions, correcting market failures associated with environmental degradation (Nordhaus, 2018; Motta; Mendes, 2001).

According to the World Bank (2023), more than 70 jurisdictions have already implemented carbon taxes or emissions trading systems (ETS), covering about 25% of global emissions. These experiences reveal that the effectiveness of the instrument depends not only on the carbon price but also on its institutional design and complementary policies.

In the literature analyzed, it is observed that carbon taxes offer simplicity and price predictability, being suitable for sectors with less capacity for immediate innovation, for example, small pig farms (Parry; Black; Zhunussova, 2022). Emissions trading systems (ETS) offer greater regulatory flexibility, allowing economic agents to negotiate quotas and reduce emissions more efficiently (Schmalensee; Stavins, 2017).

The Swedish experience, studied by Jonsson, Ydstedt, and Asen (2020), shows that the adoption of a carbon tax can coexist with economic stability and growth, as long as it is combined with social compensation mechanisms and reinvestment in innovation. On the other hand, Christofoletti and Pereda (2021) warn that, in Brazil, a uniform tax can generate regressive effects, penalizing small producers and widening regional inequalities.

In this sense, Blanchard, Gollier, and Tirole (2023) and Cocker (2025) advocate the use of policy mixes, where combinations of economic instruments and public policies are more robust alternatives. This hybrid approach integrates carbon pricing, green subsidies, payments for environmental services (PES), and public investments directed at innovation, allowing a balance between economic efficiency, social justice, and political viability.

In the Brazilian case, Alvim and Sanguinet (2021) highlight that hybrid policies can reduce negative sectoral impacts and facilitate the climate transition in agribusiness, especially when associated with green rural credit mechanisms and technical-financial support programs.

4.2 Innovations and mitigation in pig farming

The reviewed studies indicate that pig farming plays a relevant role in the mitigation agenda, both due to its direct emissions and the potential for efficiency gains. The main sources of GHG in the sector are methane (CH_4), from the anaerobic decomposition of manure, and nitrous oxide (N_2O), related to fertilization and waste management (FAO, 2019; Ferreira et al., 2023).

Mitigation strategies focus on three fronts: manure management, precision nutrition, and the use of sustainable technologies. In management, the use of biodigesters stands out as a high-potential alternative. Research by Franco Martins and Oliveira (2011) and Avaci et al. (2013), and Anis et al. (2020) demonstrates that anaerobic digestion significantly reduces methane emissions and generates economic benefits through the production of biogas and biofertilizers. Even on a small scale, the financial return is viable when associated with incentive policies and carbon credits (Esperancini et al., 2007; Angonese et al., 2007).

In the nutritional field, Andretta et al. (2018) and Monteiro et al. (2017a, 2017b) show that optimized diets with lower crude protein content reduce nitrogen excretion, decreasing N_2O emissions. Furthermore, the replacement of conventional ingredients with agro-industrial co-products, as proposed by Vastolo; Calabró; Cutrignelli (2022) and Kebreab et al. (2016), demonstrates simultaneous sustainability gains and cost reduction.

These technological advances, however, cannot be sustained in isolation. Cerri et al. (2010) and Ribeiro et al. (2018) emphasize that the success of mitigation practices depends on structural public policies that ensure financing, technical assistance, and recognition of positive environmental practices. In this sense, payment for environmental services (PES) appears as a strategic instrument, as it recognizes and rewards positive externalities, such as methane capture or the restoration of degraded areas (Oliveira; Souza, 2016; Santos; Castro, 2021).

In general, studies indicate that the integration of technological innovation and economic instruments **is** key to decarbonizing pig farming. The adoption of biodigesters, for example, becomes much more viable when combined with tax incentives, green credit lines, and the trading of carbon credits, as proposed by Sofitri (2025).

4.3 Policy mixes and just transition

The transition to low-carbon agriculture requires a coordinated set of public policies, economic instruments, and governance mechanisms that combine environmental efficiency, social equity, and economic viability. This logic guides the concept of policy mixes, which proposes the integration of different instruments, whether fiscal, regulatory, or financial, into arrangements capable of promoting synergies between climate mitigation, technological innovation, and sustainable rural development (Blanchard; Gollier; Tirole, 2023; Cocker, 2025).

In the Brazilian case, this perspective is especially relevant due to the structural heterogeneity of agriculture, marked by the coexistence of large agro-export enterprises and small family farms with limited investment capacity. The isolated implementation of carbon taxes or emissions markets tends to deepen inequalities and weaken producers with less room for adaptation (Christofoletti; Pereda, 2021). Therefore, it is essential to combine economic mitigation instruments with compensatory policies and just transition mechanisms that recognize regional and productive asymmetries.

As argued by Dasgupta (2021) and Kotz et al. (2024), long-term economic sustainability depends on incorporating natural capital as a central element of government accounting and planning. Carbon pricing and payments for environmental services (PES) should be conceived not only as fiscal instruments but as components of a green development strategy, in which the government acts as a driver of innovation and a regulator of climate inequalities.

In this sense, the just transition, a concept formulated by the International Labor Organization (ILO, 2019) and jointly integrated into the UNFCCC negotiations of the United Nations, contributes to a more strategic approach. It recognizes that mitigation policies can generate unequal impacts across regions, sectors, and social groups, and proposes the creation of safety nets and productive reconversion, ensuring that the costs of decarbonization do not fall disproportionately on workers and small producers. In the context of pig farming, this means combining economic incentives for the adoption of clean technologies (such as biodigesters and composting) with green credit lines, technical assistance, and simplified access to carbon markets.

Furthermore, it is necessary to strengthen institutional arrangements for multi-scalar climate governance, integrating federal, state, and municipal actions and expanding the participation of universities, civil society organizations, and agricultural cooperatives. COP30, taking place in Belém, in the heart of the Amazon, represents a unique opportunity for Brazil to demonstrate leadership in building low-carbon agricultural models with social inclusion.

From this perspective, lessons from the literature and international experiences indicate that the decarbonization of pig farming can serve as a laboratory for climate innovation, combining pricing instruments, PSA, and technological incentives under a single governance framework. This combination is the basis of a new agro-environmental paradigm, in which animal production ceases to be seen as an obstacle and becomes an integral part of the solution for Brazil's climate neutrality.

In short, the success of the low-carbon agricultural transition will depend on the ability of the State and society to structure coherent policy mixes that align fiscal, environmental, and social policies. Only through this integration will it be possible to reconcile economic competitiveness, food security, and climate justice, which are central objectives of the global debate that will culminate at COP30.

Table 3 synthesizes the relationship between policy instruments and their economic, social, and environmental impacts, as well as the governance enablers required for implementation. The systematization draws on the review corpus (2015–2025) and principles of policy mixes, making it possible to visualize coherences, trade-offs, and feasibility conditions for a just transition in the swine sector.

Table 3: Policy Instruments, Expected Impacts, and Governance Enablers

Instrument	Economic impacts	Environmental impacts	Governance enablers
Carbon tax (tiered)	Predictable signal; revenue for credit/TA	CH_4/N_2O via induced adoption	Federal law; revenue earmarking; simple MRV
ETS (sectoral window)	Least-cost abatement via trading	Certified reductions; linkage potential	Registry; aggregator for small farms
PES (methane capture, soil)	New income stream; de-risking	biodigester/composting uptake	State/municipal PSA laws; verification
Green rural credit	Low-cost finance; capex coverage	Tech diffusion; co-benefits on waste	Public banks; TA; guarantees
Standards/certification	Market access; price premiums	MRV discipline; spillovers	Multi-stakeholder schemes

Source: Author elaboration

5 Considerations

The decarbonization of Brazilian pig farming poses a structural challenge that transcends the technological field and imposes the need to reconfigure environmental governance, public policies, and the role of the State in fostering sustainability. Although the sector has a significant set of technical solutions, such as biodigesters, composting, precision nutrition, and energy recovery, their large-scale adoption is still limited by financial barriers, regulatory discontinuity, and institutional fragility.

The results obtained in this research indicate that the integration of economic instruments and redistributive policies constitutes the most promising path for the transition towards low-carbon agriculture. The combination of carbon pricing and emissions trading systems (ETS) and Payments for environmental services (PES) has the potential to create a virtuous cycle of mitigation, innovation, and productive inclusion. Such instruments, when combined with stable regulatory frameworks and just transition mechanisms, can align economic efficiency, environmental protection, and social justice, dimensions that, in isolation, tend to weaken.

In this scenario, the Brazilian State assumes a central role in coordinating and institutionalizing climate policy. It is responsible for structuring a regulatory framework that (i) establishes gradual and sectoral emissions reduction targets, adjusted to the mitigation capacity of each agricultural sector; (ii) expands access to green credit and climate funds for small and medium-sized producers; (iii) creates reliable emissions monitoring and certification mechanisms compatible with the requirements of the international carbon market; (iv) recognizes and rewards sustainable agro-environmental practices through PES specifically for rural areas; (v) and strengthens public technical assistance and rural extension systems, which are essential for the dissemination of innovations and the strengthening of family farming.

The effectiveness of these instruments, however, depends on the consolidation of multi-scalar and participatory governance**,** capable of integrating the federal, state, and municipal levels, as well as incorporating universities, research institutes, social movements, and cooperative organizations. This institutional architecture is essential to ensure the continuity and legitimacy of climate policies and prevent the green transition from reproducing historical inequalities in the countryside.

Table 4 offers a concise comparison of the principal economic instruments for decarbonizing the swine sector: carbon tax**,** ETS, and PES, linking their sectoral applications to the advantages and limitations identified in the literature. The synthesis supports the design of policy mixes, clarifying where each instrument is likely to be most effective and specifying the governance and measurement (MRV) conditions needed for credible implementation.

Table 4: Economic Instruments for Decarbonizing the Swine Sector: Applications, Advantages, and Limitations

Economic instrument	Application to swine production	Potential advantages	Potential disadvantages
Carbon tax	Levy on estimated CH_4 and N_2O emissions per ton of pork produced.	Price predictability and revenue generation.	Potentially regressive; requires reliable emissions estimates; risk of disproportionate burden on smallholders.
ETS (Emissions Trading System)	Emission caps for farms with the possibility of trading allowances.	Flexibility and incentives for innovation.	High implementation complexity; requires more stringent monitoring.
PES (Payments for Environmental Services)	Remuneration for adopting biodigesters, reforestation, and other sustainable practices.	Accessible to smallholders; recognizes positive externalities; supports productive inclusion.	Depends on public budgets and governance capacity; measurement criteria may still be fragile.

Source: Author elaboration based on Cerri et al. (2010), Ribeiro et al. (2018), Alvim & Sanguinet (2021), and Sofitri (2025).

From this perspective, the just transition acquires strategic relevance because it reinforces that climate mitigation cannot come at the expense of social exclusion or income concentration, but must incorporate instruments for compensation, professional training, and productive diversification. In the context of pig farming, this means making low-carbon practices economically viable and ensuring conditions for small producers to participate in the green economy without compromising their livelihoods.

The COP30, being hosted in Belém, has a unique political and symbolic character. Located in the heart of the Amazon, the conference projects onto Brazil the expectation of leadership in tackling climate change and building sustainable production models. In this context, pig farming can serve as a laboratory for mitigation policies, demonstrating that it is possible to reconcile productivity, energy efficiency, and environmental responsibility.

It is therefore concluded that the decarbonization of pig farming and, by extension, of national agriculture, depends on the articulation between effective economic instruments and inclusive public policies. and lasting institutional mechanisms. This integration will enable the transformation of emissions mitigation into a driver of sustainable development and technological innovation, proactively inserting Brazil into global low-carbon chains.

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COP30 Challenges: Where are employment and income in the Brazilian bioeconomy (2011–2021)

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Abstract
This article addresses the lack of comparable metrics to guide analysis of the bioeconomy in Brazil, a topic that has been treated as a driver of development and climate change but lacks comparable metrics to guide policies and investments. This article aims to measure and characterize the 100% BIO core using microdata from the RAIS (2011–2021) based on two indicators: the core's share of formal employment and its share of the wage bill. This is a quantitative-descriptive study, with sectoral (CNAE) and territorial breakdowns and an assessment of the temporal evolution of these indicators. The results show stability in the share of formal employment at a constant level and a similar share of the wage bill, with a slight increase at the end of the series. Behind this average stability, spatial reconfiguration is observed, with relative gains in the Central-West and South regions, associated with agro-industrial densification, and a loss of traction of traditional primary complexes in states in the Southeast and Northeast. At the sectoral level, the transformation links linked to biomass stand out, such as food and beverage processing, slaughter and dairy, and the pulp and paper chain. In new agricultural fronts, formal employment remained resilient in the 2020–2021 biennium, but gaps persist between employment and income participation where local processing is incipient. In light of these findings, the two indicators used allow prioritizing territories and monitoring initiatives by revealing where the 100% BIO core generates not only formal jobs but also a greater share of income. The study's contribution is to offer standardized and replicable measurement with administrative data, enabling sectoral and territorial comparisons and continuous monitoring of the Brazilian bioeconomy.

Keywords: Bioeconomy; Biological Base; Spatial Distribution; Formality, COP30.

Resumo
Este artigo enfrenta a ausência de métricas comparáveis para orientar a análise da Bioeconomia no Brasil, assunto esse que tem sido tratada como vetor de desenvolvimento e clima, mas carece de métricas comparáveis para orientar políticas e investimentos. Este artigo visa mensurar e caracterizar o núcleo 100% BIO utilizando microdados da RAIS (2011–2021), a partir de dois

indicadores: participação do núcleo no emprego formal e participação do núcleo na massa salarial. Trata-se de estudo quantitativo-descritivo, com recortes setoriais (CNAE) e territoriais e avaliação da evolução temporal desses indicadores. Os resultados mostram estabilidade da participação no emprego formal em patamar constante e participação da massa salarial próxima, com leve elevação ao final da série. Por trás dessa estabilidade média, observa-se reconfiguração espacial com ganho relativo de regiões do Centro-Oeste e do Sul, associado ao adensamento agroindustrial, e perda de tração de complexos primários tradicionais em estados do Sudeste e Nordeste. No plano setorial, destacam-se os elos de transformação vinculados à biomassa, como processamento de alimentos e bebidas, abate e laticínios, e a cadeia de celulose e papel. Em novas frentes agrícolas, há resiliência do emprego formal no biênio 2020–2021, mas persistem hiatos entre participação no emprego e na renda onde o processamento local é incipiente. À luz desses achados, os dois indicadores empregados permitem priorizar territórios e acompanhar iniciativas ao revelar onde o núcleo 100% BIO gera não apenas postos formais, mas também maior parcela da renda. A contribuição do estudo é oferecer mensuração padronizada e replicável com dados administrativos, viabilizando comparações setoriais e territoriais e o monitoramento contínuo da bioeconomia brasileira.

Palavras-chave: Bioeconomia; Base Biológica; Distribuição espacial; Formalidade, COP30.

1. Introduction

The bioeconomy has consolidated its place on the scientific and public agendas by linking the use of renewable biological resources with innovation, productivity and sustainability (Carbonell et al., 2021; Ollinaho , Kröger , 2023; Gama, Brasileiro, 2024) In Brazil, this field connects to unique comparative advantages, notably the greatest biodiversity on the planet (housing between 10% and 15% of all known species) (Carbonell et al., 2021; Barbosa et al., 2021; Brasil, 2023a; Queiroz-Stein et al., 2024), consolidated agro-industrial chains and a conceptual debate that directly affects the measurement of employment and income and the territorial reading of opportunities (Willerding et al., 2020). The literature distinguishes axes that combine biotechnology, bioresources, and bioecology, which requires a clear definition of the bioeconomic core for measurement purposes (Lima, Pinto, 2022; Souza et al., 2023; Gama, Brasileiro, 2024)[1]. The breadth of definitions has direct implications for sectoral targeting and indicator development; therefore, distinguishing between entirely bio-based activities and activities with partial biomass inputs is essential for accurate analyses. In the context of COP30, this article presents the 2011–2021 series on bioeconomy employment

[1] This conceptual breadth is considered the main problem in the bioeconomy metadiscourse and requires a clear definition of the bioeconomic core for measurement and evaluation purposes. The lack of unified criteria results in challenges in classifying activities (Lima, Pinto, 2022; Ollinaho, Kröger, 2023; Gama, Brasileiro, 2024).

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and income from a territorial perspective; the challenge for the conference is to align targets and instruments with verifiable indicators of job creation and wages.

In this study, the emphasis is on fully bio-based activities, that is, cases in which all added value is attributed to the bioeconomy (Lima, Pinto, 2022; Serigati, Possamai, Diz, 2023). This approach follows a typology adopted in recent literature, which contrasts this core with segments that have only partial participation of biological inputs, not explored here[2]. The operationalization uses CNAE 2.0, with explicit selection of the classes that comprise the 100% bio-based set. This distinction is necessary to calculate the fully bio-based activities and to understand the full impact of the bioeconomy value chain in Brazil, which, according to Lima and Pinto (2022), can represent approximately 20% of Brazilian GDP. Despite the advances in literature and the accumulation of international and national experiences, there remains a lack of a transparent and replicable operationalization of the 100% BIO core to measure formal employment and income in Brazil, with comparability between states and a spatial interpretation that connects sectoral specialization and labor market performance. This absence tends to limit the dialogue between policy formulation, business strategies, and evidence on the territorial distribution of employment and wages in the primary and downstream sectors (Lima, Pinto, 2022; Moscon et al., 2024; Ansanelli et al., 2025)

Given this scenario, this study aims to measure and characterize the relevance of the bioeconomy in the Brazilian formal labor market, focusing on state-level comparisons and a spatial interpretation of productive specialization. This study uses microdata from the Annual Social Information Report (RAIS) between 2011 and 2021[3].The database covers almost all formal employment, allowing for the estimation of state-level indicators of participation in bio-based employment and income and the mapping of municipal specialization by dominant bio-based group, highlighting asymmetries between employment and income with implications for qualification and value-added policies.

Thus, this study aims to answer the following questions: (i) What is the importance of employment and wages in the 100% BIO core sector, and how are they distributed across Brazil between 2011 and 2021? (ii) Which groups of activities in the 100% BIO core sector stand out

[2]Activities with partial participation of biomass inputs (*bio-based* bias less than 100%): Where only part of the production is composed of biological inputs (Lima; Pinto, 2022)

[3]However, it is necessary to recognize the limitations of RAIS for the period, including the break in the historical series in 2022 due to the migration of 77% of establishments to eSocial, which generates "artificial" variations in the links and requires caution in direct comparisons with previous years.

by state and municipality, and how did this composition evolve at the beginning and end of the series? The analysis is based on two indicators: formal employment and wages in the 100% BIO core sector. Estimated by state and mapped at the municipal level, these indicators enable complementarity by providing inputs for the COP30 goals and guide the prioritization of territories and groups of activities with greater job and income generation.

Following this introduction, the text presents a literature review, emphasizing the breadth and controversies of the bioeconomy concept and its implications for measuring employment and territorial distribution. The methodology is then detailed, including sources, construction of the CNAE dictionary, and definition of indicators. The following section presents results and discussion, highlighting the mapping of linkage intensity and the panels of the dominant BIO group by municipality, in addition to the state series. Finally, the conclusion revisits implications for training policies, technological induction, and reduction of regional asymmetries.

2. Literature review

The conceptual foundations of ecological economics were established by Georgescu-Roegen (1966), especially in works published between 1966 and 1977 (Cechin, Veiga, 2010; Mejias, 2019; Barbosa et al., 2021; Gama, Brasileiro, 2024). He highlighted the intrinsic connection between economics and biological systems and highlighted the unsustainability of economic growth in the face of limited natural resources and waste generation, in light of the second law of thermodynamics (Mejias, 2019; Barbosa et al., 2021). His ideas, by emphasizing the entropic nature of the economic process, gained repercussion in Europe and challenged the dominant neoclassical economics (Gama, Brasileiro, 2024).

However, the bioeconomy, as a more formal concept, emerged in the 1990s as an economic alternative that leveraged biotechnological advances in industrial contexts. It began to be recognized globally as a way to address environmental and social challenges through the sustainable management of natural resources, evolving into a sustainable economic model based on renewable resources (Willerding et al., 2020). In the early 2000s, the prefix " bio " was officially combined with "economy" in an American *Biomass document Research and Development Board* (2001), which approached the bioeconomy as a "revolution" and a "technological return to a sustainable past" (Pavone, 2012; Gama, Brasileiro, 2024). In Europe, the first document to present a new bioeconomy configuration was a 2002 European

Commission strategic report, focusing on the technological development of new bio-based products and the replacement of fossil resources (Gama, Brasileiro, 2024). The European Commission has since supported the bioeconomy with a focus on biorefining and bio innovations. The concept of "green jobs" was also revitalized internationally in 2008, following the green economy paradigm, with a new occupational profile focused on environmental management and sustainable innovation (Moscon et al., 2024).

Carbonell documents et al. (2021), Germany implemented its first national bioeconomy strategy in 2011. Since then, around 50 countries, including 15 from the European Union and Nordic countries, have incorporated the bioeconomy into their strategic policies [4]. In 2015, the First Global Bioeconomy Summit, held in Berlin, consolidated an operational definition: bioeconomy refers to the production, use, and conservation of biological resources, integrated with scientific knowledge, technologies, and innovation, with the purpose of offering information, products, processes, and services in multiple sectors of the economy, with an orientation towards sustainability (Scheiterle et al., 2018; Barbosa et al., 2021). In the same year, the UN 2030 Agenda, with its 17 Sustainable Development Goals, was presented and came into force in 2016, establishing a global framework for sustainable development (Brasil, 2023a; Gama, Brasileiro, 2024). This agenda even dialogues with proposals from the Georgescu-Roegen Minimum Bioeconomic Program aimed at sustainable development (Gama, Brasileiro, 2024). Works such as Gama and Brasileiro (2024), Rodrigues et al. (2024), and Oliveira et al. (2024) highlight Bugge et al. (2016), in which they organize the bioeconomy into three complementary visions, as shown in Table 1:

Table 1: Conceptual architecture of the bioeconomy (summary)

Biotechnological vision	It is based on the premise that innovation in biological sciences can boost economic growth and job creation through the use of biomass in more environmentally efficient processes and products. The OECD describes this agenda as a change in economic and social structure aimed at capturing new growth and well-being benefits by exploiting latent value in biological products and processes (Gama, Brasileiro, 2024). From this perspective, biotechnology functions as an instrument for implementing the bioeconomy, with impacts on human health and agricultural and livestock productivity.
Bioresources vision	It moves from "how to innovate" to "what to produce," focusing on bio-based goods and bioenergy. It involves processing and converting biomass, creating specific value chains, and replacing non-renewable inputs with renewable biological resources. This path combines growth and sustainability objectives and

[4]The decade from 2010 to 2020 saw a gradual increase in publications on the topic, with significant growth from 2015 onwards, and a greater number of publications in 2019 (Gama, Brasileiro, 2024).

	includes the use of forest bioactive substances for new production segments. Brazil fits in here by seeking to capture value from its biological resources (Barbosa et al., 2021).
Bioecological vision	It shifts the emphasis to ecosystem integrity and the optimization of nutrient and energy use, establishing a circular model that reduces the need for external inputs. This perspective harks back to the Georgescu-Roegen tradition, associated with ecological economics and the implications of entropy for economic activity, with a focus on sustainability and social well-being that goes beyond linear metrics like GDP (Mejias, 2019; Barbosa et al. 2021; Gama, Brasileiro, 2024).

Source: prepared by the author, 2025.

The conceptual breadth of the three perspectives directly affects measurement. Different choices of segmentation alter the universe of activities and, therefore, employment and income indicators. For purposes of comparable sectoral and territorial analysis, recent literature recommends specifying a bioeconomic core with transparent inclusion/exclusion criteria. For this article, the fully biologically based segment (100% bio core) is adopted, in contrast to segments with partial participation of biological inputs (Serigati, Possamai, Diz, 2023). This delimitation increases traceability and reduces ambiguities, an essential condition for constructing historical series and territorial indicators that adhere to public policy goals.

2.1 Scope and controversies of the bioeconomy in Brazil, with effects on employment and territorial distribution

The bioeconomy, understood as the production and use of renewable biological resources, waste and co-products to generate high value-added goods, such as food, feed, bioproducts and bioenergy, constitutes a strategic axis for sustainable development in Brazil (Carbonell et al., 2021; Lima, Pinto, 2022). Due to its extensive natural capital endowment and high biomass availability, the country is often positioned as a world power in bioeconomy (Carbonell et al., 2021). With the greatest tropical biodiversity on the planet, which brings together around 20% of known species, including 116,000 animals and 55,000 plants, Brazil has unique conditions to exercise leadership on this topic (Barbosa et al., 2021; Carbonell et al., 2021). According to Barbosa et al. (2021), the domestic scope includes agriculture, livestock, forestry, fishing, food, pulp, paper, and segments of the chemical, biotechnology, and energy industries. In 2019, the bioeconomy accounted for about 20% of GDP (Barbosa et al., 2021; Carbonell et al., 2021). The expansion of this agenda, however, faces conceptual disputes and complex effects on the labor market and territorial income distribution (Brazil, 2023).

The concept is polysemic and the subject of dispute, especially in Brazil, where it is necessary to distinguish sustainability-oriented arrangements from practices that reinforce extractive logics (Ollinaho, Kröger, 2023; Gama, Brasileiro, 2024; Queiroz-Stein et al., 2024). According to Gama and Brasileiro (2024), the debate arises in the tension between economic growth and effective sustainability. Critics point out that aligning policies and markets without social and environmental safeguards can increase pressure on common goods and territories. In this context, it is proposed to differentiate the "plantation economy," based on monocultures and intensive exploitation, from the "zociobiodiverse economy," anchored in sustainability, traditional knowledge, and social inclusion (Ollinaho, Kröger, 2023).

Controversy persists over the adoption of the term in Brazil; for example, classifying Amazonian Forest economies as a bioeconomy on the same level as soybean monocultures leads to misunderstandings. Large agribusiness groups have influenced the national agenda, labeling Indigenous and agroforestry practices as bioeconomy and linking them to heavily extractive sectors (Gama, Brasileiro, 2024). In response, social movements advocate an "ethics of unacceptability" for activities that deforest, pollute, and threaten livelihoods, while valuing the knowledge of Indigenous peoples and local communities (Gama, Brasileiro, 2024; Barbosa et al., 2021). According to Carbonell, et al. (2021), regulation is a necessary condition for sustainable trajectories, with the advancement of molecular biology techniques and opportunities linked to biodiversity repositioning biosafety and access to genetic heritage as decisive issues. Law 13.123/2015 established a self-declaration system to reduce barriers to research and stimulate related economic activities. It is, therefore, necessary to ensure the integrity of processes, compliance, and benefit sharing with traditional communities and indigenous peoples, in line with international trends (Carbonell, et al., 2021).

At the institutional level, the National Confederation of Industry introduced the topic in 2013 with "*Bioeconomy: Agenda for Brazil's Development*," which boosted economic, social, and environmental discussions (Mejias, 2019; Barbosa et al., 2021; Queiroz-Stein et al., 2024). As an offshoot of the National Strategy for Science, Technology, and Innovation 2016–2022, the government launched action plans in biotechnology and bioeconomy, while the Biodiversity Law improved rules for access to genetic heritage and stimulated sustainable production chains (Barbosa et al., 2021; Carbonell et al., 2021). The federal government, through the Ecological Transformation Plan (launched in 2023), established the bioeconomy as one of the structural pillars for the country's productive and sustainable development (Brazil, 2023). This plan is integrated into the programs of the 2024-2027 Multi-Year Plan (PPA) and aims to mobilize and redirect public and private investments. To this end, the government seeks to develop the Brazilian Sustainable Taxonomy and, in May 2023, established the framework for issuing thematic sovereign bonds to finance the ecological transition. The magnitude of the financing effort aligns with the estimated annual investment requirement of 3.5% to 4% of GDP between 2020 and 2050 for Brazil to achieve climate neutrality.

Table 2: Overview of bioeconomic approaches in Brazil

Bioenergy	The country has consolidated its leadership since Proálcool in 1975 and the National Program for the Production and Use of Biodiesel in 2005 (Muçouçah, 2009; Carbonell et al., 2021). In 2022, renewable sources represented 47.4% of the Brazilian energy matrix, compared to 16% on a global average, which highlights the relevance of ethanol, biodiesel and bioelectricity (Carbonell et al., 2021; Brasil, 2023a). Law 13,576/2017, RenovaBio, guides expansion with sustainability criteria. Internationally, bioenergy has a significant impact on job creation, accounting for approximately half of the jobs reported in the sector (Verdes, 2008).
Agribusiness	Agriculture, livestock, forestry, and fishing account for a significant portion of the industry. In 2018, the sector accounted for approximately 21% of GDP, 20% of employment, and 42.4% of exports. Grain production grew 293% between 1990 and 2018, from 58 to 228 million tons, while planted area increased 63%, from 38 to 62 million hectares. The productivity gains helped prevent deforestation of 87 million hectares during the period (Carbonell, et al., 2021).
Chemical biologically based	The portfolio is expanding, with a focus on renewable plastics and installed industrial capacity. Brazil is among the ten largest chemical industries in the world and maintains the fourth most important industrial sector in its production base, which favors the scalability of bio-based solutions (Carbonell, et al., 2021).
Recycling (circular dimension)	In 2006, 10.3 billion aluminum cans were recovered, resulting in an estimated annual savings of 1,976 GWh, enough to power a city with over one million inhabitants. Globally, the recycling chain supports approximately 12 million jobs, with Brazil, China, and the United States participating (Verdes, 2008).

Source: prepared by the author, 2025.

Regarding economic scope, the bioeconomy involves primary activities and industrial segments of food, pulp, paper, chemicals, biotechnology, and energy. General equilibrium exercises estimate a share of close to 20% in value generation in Brazil, GDP-BIO (Lima, Pinto, 2022; Carbonell et al., 2021). This capacity stems from extensive agricultural crops and biodiversity, which is home to between 10% and 15% of known species and provides a basis for innovation in bioproducts and bioprocesses. To exploit opportunities, it is important to promote technological densification and increase competitiveness on a sustainable basis (Willerding et al., 2020). According to Carbonell et al. (2021), innovation coevolves across five interconnected dimensions: raw materials, technologies, products, business models, and regulation. In Brazil, however, this process must be aligned with new market demands, using *big data*, artificial intelligence, and genetics.

However, the productive rearrangements associated with the bioeconomy affect the generation and quality of employment unequally (Moscon et al., 2024). Green jobs, understood as decent positions that contribute to reducing emissions and/or environmental improvement, become a reference in the transition (Muçouçah, 2009; Ansanelli et al., 2025). In 2022, green activities showed greater formality, 86%, and higher average income compared to environmentally sensitive activities, 59% formality (Moscon et al., 2024). In 2008, formal green jobs were estimated at 2,653,059, equivalent to 6.73% of the formal total (Muçouçah, 2009; Ansanelli et al., 2025). Between 2012 and 2022, the proportion of formal links in green activities, around 17% of the total, remained stable (Moscon et al., 2024). Furthermore, bioeconomic expansion raises questions about inequality and labor. Agricultural modernization and automation, associated with Industry 4.0, tend to reduce the likelihood of job retention in highly automated agricultural occupations, while higher education increases this probability (Fernandes et al., 2024). In the Amazon, many bioproducts maintain low technological density, such as *fresh fruits* and unpurified oils, with a strong influence on origin marketing in value addition (Willerding et al., 2020).

Despite job creation, agriculture has low average pay, R$621.61 in 2006, indicating sectoral heterogeneity and polarization (Brasil, 2007). Vulnerability to automation is high; for example, as discussed by Fernandes et al. (2024), in 2019, approximately 88% of formal workers in the sector were in occupations with a high probability of automation; in these occupations, the expected probability of maintaining employment is 6.66% lower. Education has the greatest positive impact, with individuals with a bachelor's degree having an 11.21% higher probability of remaining employed compared to those with primary education. Nevertheless, the territorial distribution of activities is heterogeneous and often accentuates regional inequalities (Souza et al., 2023; Brasil, 2023a). Therefore, reducing these disparities is the objective of the Brazilian Sustainable Taxonomy (TSB) (Gama, Brasileiro, 2024). The differences appear in income indicators, as raised by (Brazil, 2023) average income in the Federal District is 213% higher than that of Maranhão.

At the regional level, the following production and innovation hubs stand out: (i) the Amazon region being the main area for the bioeconomy with a “socio-environmental” focus, with bioindustry and biotechnology networks centered in Manaus and other state capitals

(Willerding et al., 2020; Oliveira et al., 2024). However, there is an economic, social and cultural imbalance between hub cities and the interior. As Willerding observes et al. (2020), scientific production remains more concentrated in basic research, with less translation into technological development and intellectual property; (ii) Southeast region, Campinas meets the conditions for a world-class innovation ecosystem in bioeconomy, supported by high expenditures in R&D. The State of São Paulo, according to Carbonell et al. (2021) expenditure intensity higher than that of European countries such as Italy, Spain, and Portugal; (iii) MATOPIBA as a front for *commodity* -oriented agricultural expansion, with a concentration of formal jobs in western Bahia and southern Maranhão. However, the formal market showed resilience between 2020 and 2021, but the structure remains heterogeneous, with inequalities in wealth distribution (Loayza, Reis, Jesus, 2024). Given the territorial disparity, according to Perroux's (1977) pole theory, in which more representative agglomerations concentrate economic, political, and population activity, there is a need for coordination between regional, national, and international structures to intensify commercial, scientific, and technological exchanges (Perroux, 1977; Willerding et al., 2020; Souza et al., 2023).

At the global level, the bioeconomy has been treated as a strategy for sustainable food and agriculture. According to FAO (2024), its advancement requires international collaboration and cooperation, oriented toward addressing global challenges and disseminating environmentally sound technologies. In this context, as discussed by the World Bank (2024), the idea of a Just Transition for workers and communities becomes imperative, with a view to ensuring that the ecological transformation is socially inclusive. In this scenario, the measurement of work takes on a prominent role, as evidenced by studies on Green Jobs, whose methodologies classify sectors according to emissions and their capacity to generate new green occupations and technologies (Winkler et al., 2024; Ansanelli et al., 2025). For this reason, incorporating the social dimension and sustainability criteria becomes a prerequisite for designing and evaluating policies (World Bank, 2024). In Brazil, a National Bioeconomy Strategy has already been established (FAO, 2024; Brazil, 2024a). The document is grounded in the values of justice, ethics and inclusion, and it makes explicit objectives such as reducing inequalities, promoting regional development, expanding education and professional training, stimulating entrepreneurship and generating new jobs while preserving sustainability (Brazil, 2024a, 2024b). The emphasis on social and environmental indicators is explained by the fact that multiple national bioeconomy strategies adopt common sustainability targets, and Brazil

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seeks to strengthen its bioeconomy in alignment with the Sustainable Development Goals, SDGs (FAO, 2024).

In general, the bioeconomy in Brazil offers ample room for action, but its implementation requires addressing structural challenges (Brasil, 2023a). Overcoming conceptual controversies requires differentiating between extractive arrangements and proposals centered on sociobiodiversity, with fair benefit sharing and effective community participation (Carbonell et al., 2021). The success of the sector depends on the convergence of the State, companies, academia and civil society (Willerding et al., 2020; Barbosa et al., 2021), in line with the *Quintuple Helix model* (Carayannis et al., 2012; Willerding et al., 2020)[5]. According to Brasil (2023a), the construction of a Brazilian Sustainable Taxonomy, with explicit priority on reducing regional inequalities and generating decent work, is a decisive step towards guiding a coherent and socially just transition. To this end, the literature converges in pointing out that consistent public policies are needed to qualify the workforce for new technological demands (Moscon et al., 2024; Fernandes et al., 2024) and ensure that ecological transformation results in inclusive and sustainable development in social terms (Verdes, 2008; Brasil, 2023a).

3. Methods and procedures

The Annual Social Information Report (RAIS) is a source of statistical data that acts as an annual census to monitor and characterize the formal labor market in Brazil, covering approximately 97% of this segment (Brasil, 2007; Muçouçah, 2009) and due to its structure, informal and self-employed workers are excluded. However, the microdata were obtained from the Database platform and subjected to cleaning, standardization, and aggregation routines in the RStudio software. For the analyses, the reference date was used through an active employment indicator on December 31, characterizing the stock of formal employment relationships between 2011 and 2021. For this purpose, the database consists of the reference year, municipal identifiers (code of the municipality of the workplace and, alternatively, the municipality of the establishment), CNAE 2.0 classification in the class (4 digits) when the data

[5] The *Quintuple Helix* model is an "innovation" *framework* that expands previous models by explicitly including Environment and Society as drivers of knowledge production (Carayanis et al., 2012). It is based on the interaction of academia, business, government, society and the environment, and is used to guide social and economic development.

in the subclass granularity (7 digits) was aggregated to the corresponding 4 digits, and average monthly remuneration of the relationship[6].

In this study, focused on the bioeconomic nucleus, the CNAE 2.0 divisions were delimited based on activities considered 100% bio-based, following the tabulation of Lima and Pinto (2022) and Serigati, Possamai and Diz (2023) applying the method used by Souza et al. (2023). To this end, the typology of goods representative of the bioeconomy of Lima and Pinto (2022) is adopted, which organizes the cut into two axes: fully bio-based activities, in which all added value is attributed to the bioeconomy; and activities whose production chains incorporate only a portion of biomass and biologically derived inputs, in which case only a fraction of the product is accounted for as bioeconomic. This study focuses on the first axis, without detailing the second component, as evidenced in Table 3, the delimitation of the bioeconomy was made with a dictionary that maps four-digit CNAE classes into thematic groups *A–K* aiming to consolidate sectoral results without losing traceability by class and calculated by link[7].

Table 3: Set of activities with 100% biological basis

Bio Group	Economic Activity	CNAE Class (4 digits)
A	Agriculture, including agricultural support and post-harvest	0111; 0112; 0113; 0114; 0115; 0116; 0119; 0121; 0122; 0131; 0132; 0133; 0134; 0135; 0139; 0141; 0142; 0161; 0163
B	Livestock, including support	0151; 0152; 0153; 0154; 0155; 0159; 0162; 0170
C	Forestry production, fishing and aquaculture	0210; 0220; 0230; 0311; 0312; 0321; 0322
D	Slaughter and meat products, including dairy and fishery products	1011; 1012; 1013; 1020; 1051; 1052; 1053
E	Sugar manufacturing and refining	1071; 1072
F	Other food products	1031; 1032; 1033; 1041; 1042; 1043; 1061; 1062; 1063; 1064; 1065; 1066; 1069; 1081; 1082; 1091; 1092; 1093; 1094; 1095; 1096; 1099
G	Beverage manufacturing	1111; 1112; 1113; 1121; 1122
H	Manufacture of tobacco products	1210; 1220
I	Manufacture of textile products	1311; 1312; 1313; 1314; 1321; 1322; 1330; 1340; 1351; 1352; 1353; 1354; 1359

[6] To locate formal ties, the municipality of the workplace was adopted as a rule. Using the municipality of the workplace as a territorial reference prioritizes ties to the territory where the occupation occurs; the municipality of the establishment is only used when the former is vacant. These procedures enabled the creation of standardized, time-comparable, and consistent panels for municipal maps, regional cross-sections, and descriptions of formal ties in the bioeconomy.

[7] The National Classification of Economic Activities (CNAE) is the official standard for statistics and identification of economic activities in Brazil. CNAE 2.0 was adopted by RAIS in 2006, although the initial publication included only the first 5 digits (class) (Brazil, 2007).

J	Manufacture of pulp, paper and paper products	1710; 1721; 1722; 1731; 1732; 1733; 1741; 1742; 1749
K	Biofuel production	1931; 1932

Source: prepared by the author based on Lima and Pinto (2022) and Serigati, Possamai and Diz (2023); 2025.

Given that this study analyzes the formal labor market in Brazil's bioeconomy segments and incorporates a spatial dimension by characterizing the distribution of formal employment across states in order to assess the importance of these segments in state economies, two indicators proposed by Souza et al. (2023) are adopted to capture the share in formal employment and the share in the wage bill. The first indicator, I_{po}, is the Share of Bioeconomy Formal Employment in the State Total, defined as the ratio between the number of formal employment relationships in core bioeconomy activities (100% BIO) and the total number of formal employment relationships in the state. The second indicator, I_{rend}, is the Share of the Bioeconomy Wage Bill in Total Formal Income, defined as the ratio between the wage bill generated by the bioeconomy and the total formal wage bill in the state. The corresponding expressions are given in Equations (1) and (2).

$$I_{po(e)} = \frac{\sum_{i=1}^{n} x_{i,e}}{\sum_{i=1}^{n} x_{i,e} + \sum_{i=n+1}^{m} x_{i,e}} \quad (1)$$

$$I_{rend(e)} = \frac{\sum_{i=1}^{n} r_{i,e}}{\sum_{i=1}^{n} r_{i,e} + \sum_{i=n+1}^{m} r_{i,e}} \quad (2)$$

Let {1, 2, …, m} be the set of all economic activities listed in CNAE 2.0. For each activity i in this set and for each state e, the number of formal links in activity i in state e is defined $x_{i,e}$as $r_{i,e}$ as the corresponding wage bill. In the adopted system, the activities$i = 1, \dots,$ n belong to the bioeconomy (100% BIO core) and the activities $i = n + 1, \dots, m$ form the complement in the CNAE 2.0 universe. The indicators $I_{po(e)}$and $I_{rend(e)}$quantify the relative participation of the bioeconomy in formal employment and in the state's own wage bill, maintaining consistency with Souza et al. (2020). $I_{po(e)} \in [0,1]$ and $I_{rend(e)} \in [0,1]$ values close to 0 indicate low participation of the bioeconomy in the state's occupational or income structure, values close to 1 indicate high concentration in these segments.

For average monthly remuneration, null or missing values were excluded from statistics that depend on salary, preserving employment counts when necessary. Monetary values were converted to 2021 reais based on the annual IPCA (Brazilian Consumer Price Index). To characterize the profile of formal bioeconomic employment relationships, two annual data sets (2011 and 2021) were generated, including state, municipality, CNAE group *A–K*, and demographic and work variables (age, sex, race/color, education, length of formal employment, and hours worked).

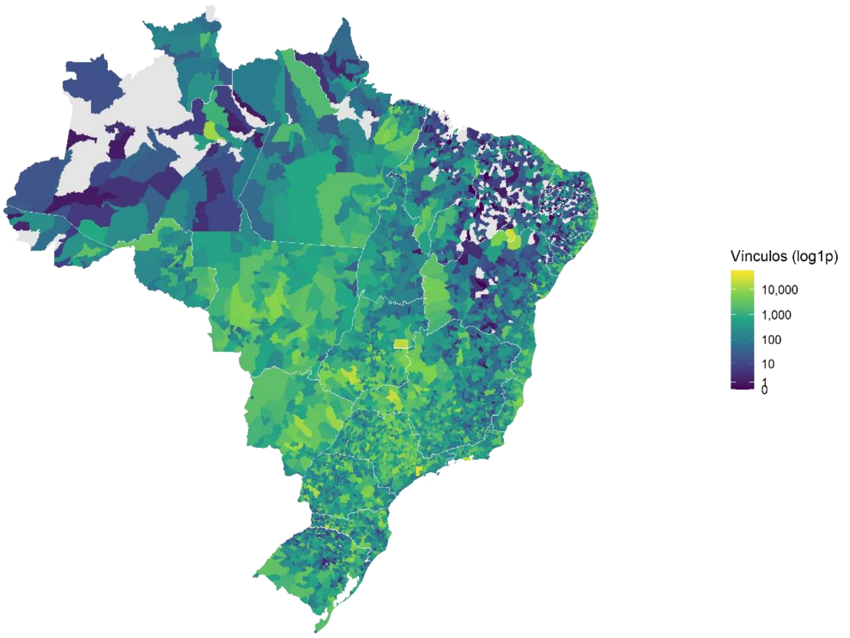
4. Results and discussion

Figure 1, of formal links of the 100% BIO basket in 2021, reveals a continuous arc of high density that starts in the South and advances through the interior of the Southeast, anchored by agro-industrial complexes and processing chains of biological origin (Serigati, Possamai, Diz, 2023; Souza et al., 2023). This concentration reflects the prominence of entirely biologically based activities, classified in the Primary and Bioindustry segments, in areas that have historically consolidated themselves as hubs of economic development (Lima, Pinto, 2022; Souza et al., 2023). Western Santa Catarina and Paraná, the interior of São Paulo, and the Triângulo Mineiro region form broad patches, resulting from the combination of agricultural production, slaughterhouses and dairy plants, sugar, food and beverage, textile, and pulp and paper manufacturing (Lima, Pinto, 2022; Souza et al., 2023). In Paraná, for example, the workforce is concentrated in this West-Southwest axis, characterized by the importance of the agroindustrial segment (Lima, Pinto, 2022; Loayza, Reis, Jesus, 2024). In the interior of São Paulo, the Campinas vector emerges as a prominent innovation ecosystem for the bioeconomy (Carbonell et al., 2021).

The Central-West region has clear poles in southern and eastern Mato Grosso, southwestern Goiás, and Mato Grosso do Sul, where the densification of grain, meat, and biofuels sectors is creating formal employment along logistics corridors. The emphasis on biofuels, such as ethanol, is central in this region, as large-scale production, by replacing gasoline, helps mitigate carbon emissions (Muçouçah, 2009). MATOPIBA forms an additional corridor in western Bahia and southern Maranhão and Piauí, expressing more recent agricultural frontiers, with the growing installation of processing units (Loayza, Reis, Jesus, 2024).

According to Loayza, Reis, and Jesus (2024), the resilience of the formal agribusiness labor market in MATOPIBA, which continued to grow in employment even during the pandemic period from 2020 to 2021, confirms the consolidation of this frontier as a pillar of the national economy. Finally, capital cities and metropolitan regions "light up" when they host BIO industrial plants or logistics functions that orbit these chains (Oliveira et al., 2024). These urban centers play a relevant role, not only in distribution and services, but also by bringing together actors and research institutions, such as universities and R&D centers, necessary for the development of innovation ecosystems in the bioeconomy, although, in certain contexts, the economic exploitation of highly complex bioproducts is still incipient (Willerding et al., 2020; Carbonell et al., 2021; Brazil, 2023).

Figure 1: Regional distribution of 100% BIO formal ties (2021)



Note: The legend's logarithmic scale is crucial: it allows comparisons between metropolises and small municipalities within the same frame, but reduces visual contrasts between mid-levels. Source: Prepared by the author, based on the December 31 inventory (RAIS) via Database | Grid: geobr / IBGE, 2025.

In the Northeast, the distribution takes on a mosaic shape, with bright areas in the Sugar Forest Zone of Pernambuco and Alagoas, and in the Sub-Middle São Francisco, fruit farming in Petrolina and Juazeiro, contrasting with inland areas of low formal density. This regional disparity is in line with the characterization of agribusiness in the North and Northeast states, which are geared towards primary production, often with a predominance of small properties and less technological development (Souza et al., 2023). The contrast with the inland areas reflects the historical presence of informal, unpaid labor and small-scale production for self-consumption (Souza et al., 2023; Loayza, Reis, and Jesus, 2024). According to Brasil (2023a), fruit growing hubs, in turn, constitute specific agro-industrial niches that can structure formal employment, in opposition to the climatic vulnerabilities and socioeconomic inequality that persist in much of the semi-arid region.

In the North, the light spots align with highway axes and expansion fronts in Pará, Rondônia, and Tocantins, reflecting the expansion of sectors such as agriculture and livestock farming in regions of the deforestation arc, often associated with monocultures (Oliveira et al., 2024). Extensive areas of the Amazon remain dark due to low population density, great distances, and a strong presence of occupations outside the formalization framework captured by RAIS. According to Willerding et al. (2020), this low formal density tends to highlight the low economic use of sociobiodiversity and the difficulty of generating formalized, higher-value jobs outside of large urban centers. The concentration of bioindustry in Manaus, Amazonas, and other state capitals reinforces the limitation of distant regions in adding value to rural production (Oliveira et al., 2024; Ansanelli et al., 2025).

In general, absolute volumes are concentrated in the South, Southeast, and Central-West, with significant relative gains in inland states. The Northeast and Amazon regions have a sparser distribution and are dependent on specific agro-industrial niches. This concentration is expected, according to Souza et al. (2023), because the South, Southeast, and Central-West regions are characterized by more modern agricultural activities, with greater use of formal employment contracts and higher average incomes[8].

The state-by-state series, as shown in Table 4, confirms the spatial pattern observed in Figure 1. The formal bioeconomy maintains a large base in the South and Southeast, with a growing contribution from the Central-West. In 2021, six units accounted for just over half of the country's BIO linkages. Among them are SP (872.4 thousand; 23.2% of the total), MG (504.7 thousand; 13.4%), PR (361.1 thousand; 9.6%), SC (262.9 thousand; 7.0%), RS (250.7 thousand; 6.7%), and GO (219.9 thousand; 5.9%). MT (190.7 thousand; 5.1%) and BA (163.2 thousand; 4.3%) complete the upper block, in line with bio-based agroindustrial and processing chains that structure formal employment.

Nationally, the trajectory from 2011 to 2021 presents three phases: (i) advance until 2014, with 3.67 million links and a 1.1% increase compared to 2011; (ii) decline until 2016,

[8] Finally, it is worth remembering that the legend in log10 compresses extreme differences and that the reference is the stock on December 31, data from RAIS, which tends to underestimate seasonal links in locations where the peak occurs in previous months, and to neglect the significant portion of informal links in agribusiness, especially in the North and Northeast (Muçouçah, 2009; Souza et al., 2023; Loayza, Reis, Jesus, 2024; Fernandes et al., 2024).

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with 3.52 million and a 4.1% reduction compared to the 2014 peak; (iii) recovery between 2017 and 2021, with 3.76 million and a 6.8% growth compared to 2016, that is, 3.6% above 2011. This behavior combines restructuring in traditional sugarcane-producing bases in the Southeast and Northeast with the consolidation of agro-industrial corridors in the South and Central-West. State variations reinforce the movement. The most intense expansions were observed in Mato Grosso, with a 30.8% increase; Goiás, 17.3%; MS, 18.1%; PR, 14.4%; and SC, 21.3%; in addition to Pará, 21.5%; and Tocantins, 42.6%, in the northern arc. There was stability with a slight gain in Minas Gerais, 6.1%, and Rio Grande do Sul, 6.2%. There were declines in São Paulo, a 7.9% drop, and Rio Grande do Sul, 16.7%, as well as a significant reduction in Alagoas, 40.6%.

Alagoas' 40.6% drop aligns with the sugar sector's contraction, as environmentally driven mechanization cuts low skilled jobs (Muçouçah, 2009). São Paulo and Rio de Janeiro also declined, though from high bases (Loayza, Reis, Jesus, 2024). In Mato Grosso and Goiás, growth tied to population gains and the densification of slaughterhouses, dairy, ethanol, and food and beverage plants drove a Central West rise in formal agribusiness employment, bucking the national decline, anchored in larger, more tech intensive farms (Loayza, Reis, Jesus, 2024; Souza et al., 2023). Santa Catarina and Paraná reinforce the southern agroindustrial belt and growth polarization in Paraná, while Pará, Rondônia, and Tocantins expand along farming and processing frontiers, consistent with above average green job growth in the North and Center West (Souza et al., 2023; Ansanelli et al., 2025)[9].

[9] It is worth noting that the data correspond to the stock on December 31, RAIS, which confers a downward bias and underestimates seasonal links in locations where peaks occur in previous months (Muçouçah, 2009; Brasil, 2007). High percentage variations in units with a small base, such as RR, 79.9%, partly reflect the reduced denominator at the beginning of the series.

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Table 1: Formal links in bioeconomy segments, by state, between 2011 and 2021

UF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
AC	6,029	5,857	6,055	6,518	7,028	7,396	7,338	6,846	5,997	5,879	6.159
AL	102,497	96,132	85,476	75,340	72,435	71,124	67,550	62,358	54,839	58,003	60,915
AP	2.211	2.114	2,252	2.201	2.215	2,063	2.121	2,200	1,808	1,797	1,883
AM	14,927	15,920	16,894	16,417	17,356	15,224	15.110	15,337	13,778	14,045	15,250
BA	150,038	149,206	150,809	152,381	148,685	148,421	151,200	154,451	149,977	153,078	163.216
CE	83,264	83,933	85,256	87,968	86,172	80.320	78,599	78,832	75,657	76,702	79,487
DF	18,347	19,604	18,655	18,508	17,898	17,264	17.107	16,944	16,888	16,976	18,075
ES	57,945	56,725	58,460	59,443	58,380	54,445	56,520	57,296	57,241	54,877	57,837
GO	187,519	197,327	207,694	211,507	206,538	202.714	209,775	208,629	205,540	210,753	219,903
MA	37,160	36,326	34,911	35.106	33,940	33,743	32,621	32,997	31,723	34,278	35,775
MG	475,747	469,056	484,864	483.049	478,466	470,751	477,149	478,911	473,034	477,521	504,691
MS	116,552	123,598	125,232	127,280	126,837	127,501	126,059	128,972	128,036	133,695	137,643
MT	145,770	147,097	157,825	159,524	157,709	156,925	168,849	175,410	179,901	182,782	190,698
PA	77,170	79,622	81,223	84,382	84,563	82,424	86,542	87,984	82,279	86.108	93,728
PB	48,306	46,784	48,014	48,072	46,229	45,220	44,742	44,859	43,333	44,423	43,647
PE	155,208	146,208	145,606	150,076	140,495	137,895	138,844	137,960	133,815	133,255	142,912
PI	17,291	18,509	18,207	19,207	19,080	17,655	18,331	20,322	19,745	18,980	21,479
PR	315,579	303,663	326,718	334.355	334,440	316.173	329.330	327,158	332.026	347,818	361,057
RJ	90,670	91,839	89,175	90,680	88,195	82,691	80,680	78,514	76,326	73,931	75,499
RN	41,298	40,268	41,258	40,947	40,329	40,157	40.181	40,156	37,844	38,184	40,926
RO	25,661	27,540	28,366	29,215	29,669	28,936	32,066	32,396	32,277	32,252	31,947
RR	2,044	2,278	2,563	2,598	2,627	2,704	2,466	2,649	2,972	3.183	3,678
RS	236.051	227,982	233,942	237,499	238,520	236,559	234,864	237,773	234,158	241,035	250,747
SC	216,755	203.244	222.803	225,139	220.237	218.901	228,603	230,870	237,167	251,292	262,853
SE	31,273	31.014	29,676	31,284	29,662	28,162	27,548	27,285	24,838	26,470	29,343
SP	946,770	941,926	930,786	908,866	901,644	861,741	876,563	858.043	853,523	852,294	872,445
TO	23,553	25.181	26,641	28,777	30,040	30,058	29,669	30,039	29,272	31,448	33,579

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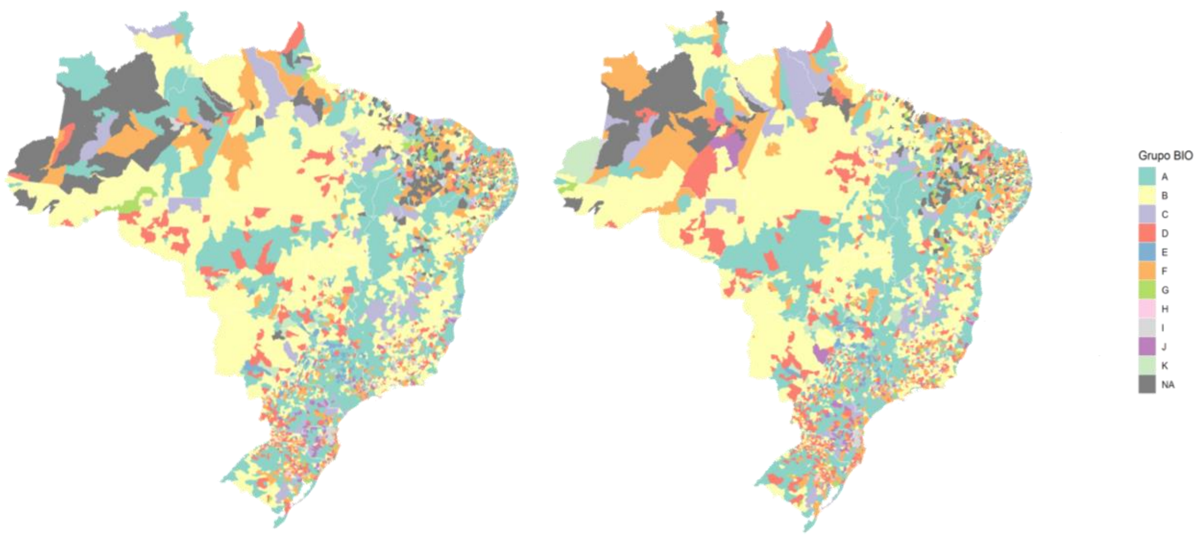
BR	**3,625,635**	**3,588,953**	**3,659,361**	**3,666,339**	**3,619,389**	**3,517,167**	**3,580,427**	**3,575,191**	**3,533,994**	**3,601,059**	**3,755,372**

Source: prepared by the author, based on the inventory 12/31 (RAIS) 2011-2021, 2025.

Complementing Figure 1's intensity, Figure 2 qualifies the productive specialization of the bioeconomic core. In each municipality, the class with the highest number of formal ties in the RAIS is identified, where the BIO Group nomenclature follows the pattern in Table 3. Thus, this perspective reveals the chain that leads local employment, differentiates primary areas from agroindustrial processing areas, and serves as a bridge between the spatial distribution and the state trajectory in Table 3.

Figure 2: BIO predominance by municipality, formal ties, 2011 and 2021

(2011) **(2021)**



Note: The legend's logarithmic scale is crucial: it allows comparisons between metropolises and small municipalities within the same framework, but reduces visual contrasts between medium-sized sectors. Source: Prepared by the author, based on the December 31 inventory (RAIS) via Database | Grid: geobr / IBGE, 2025.

The 2011 cross-section shows a broad predominance of *A* and *B* in the interior of the country, with a strong presence in the Central-West and parts of the North and Northeast. This configuration of primary employment in the North and Northeast tends to reflect a production profile with greater aptitude for the primary segment, often associated with small properties and less technological development (Souza et al., 2023; Fernandes et al., 2024). In contrast, even in 2011, primary activities in the Central-West were already linked to large properties and greater technological development (Souza et al., 2023). *C* occupies portions of the Amazon and coastal stretches. However, the extensive forested areas in the Amazon have a low density of formal employment, which implies low economic exploitation of sociobiodiversity and the challenge of converting this natural wealth into formal economic wealth (Willerding et al., 2020; Oliveira et al., 2024).

In the South and in areas of the Southeast interior, an agro-industrial belt is observed anchored in *D* and *F*, in line with the consolidation of the agro-industrial segment in these regions, responsible for the majority of formal agribusiness jobs in mesoregions of Paraná, for example (Souza et al., 2023). While *E* is concentrated in the sugarcane axes, Zona da Mata of Pernambuco and Alagoas and the interior of São Paulo, reinforcing the historical importance of the Southeast in the production of bioenergy, ethanol, is pointed out in the literature as a reduction in carbon emissions by replacing gasoline (Muçouçah, 2009; Carbonell et al., 2021). *I* forms patches in the Agreste and northern backlands, *H* is organized in the southern tobacco corridor, *J* is fixed in the South with points in Espírito Santo and Bahia, *K* appears punctually. As observed by Lima and Pinto (2022), the Bioindustry, as a whole, although essential for value aggregation, still exhibited a more localized distribution in 2011.

In 2021, the opposition between "frontier primary" and "consolidated agroindustry" remains, albeit redesigned. *D* and *F* extend along logistics corridors in the South and Central-West, with a regional specialization in agro-industrial hubs with urban-industrial linkages (Souza et al., 2023). *A* and *B* are advancing in MATOPIBA and pockets of the North-Central region, consolidating the role of this agricultural frontier geared toward commodity production. The 14.1% growth in formal employment in the primary sector in this region, even from 2019 to 2021, demonstrates the dynamism and resilience of these frontier activities (Loayza, Reis, and Jesus, 2024). *C* remains associated with Amazonian and coastal areas, *J* consolidates in the South and radiates nuclei in the Center-South, *G* emerges in urban hubs with the beverage industry, reflecting the concentration of bioindustries and logistics functions in urban centers and the exploitation of agglomeration economies and supporting infrastructure (Souza et al., 2023; Oliveira et al., 2024). Finally, *E*, *I*, and *H* lose geographic extension in several microregions. One justification for the retraction of *E*, sugar, according to Muçouçah (2009), stems from the mechanization of sugarcane harvesting and industrial restructuring, processes that have reduced formal jobs in traditional sugarcane-growing states.

The indicator I_{po} quantifies the share of 100% bio-based employment in total formal employment. Between 2011 and 2021, Brazil maintained a level close to 8%, from 7.97% to 7.98%, with a U-shaped movement. A slight decline was observed until 2014, to 7.53%, followed by a continuous recovery until 2020, to 8.14%, and then leveling off in 2021. This level, while stable, indicates that bio-based activities, the Primary and Bioindustrial Segments, support a significant portion of formal employment, consistent with estimates that place the bioeconomy as responsible for approximately 20% of value generation in Brazil (Lima, Pinto, 2022).

Regionally, the Central-West region maintains high levels, the South remains above 10% in several states, and the Northeast exhibits heterogeneity, combining historically sugarcane-growing areas and agroindustrial hubs with states with a more diversified base. In 2021, the largest shares are concentrated in the Central-West: Mato Grosso, 21.33%, Mato Grosso do Sul, 20.33%, and Goiás, 14.30%, levels similar to or higher than those of 2011. This leadership reflects the region's consolidation as a dynamic hub of high-tech agribusiness and the expansion of the formal agribusiness labor market, in contrast to the decline observed in national agribusiness employment (Loayza, Reis, Jesus, 2024). In the South, Paraná, 11.41%, and Santa Catarina, 10.85%, maintain high levels, confirming the consolidation of the southern agro-industrial belt, in which the profile of formal links is concentrated in the agro-industrial and agro-services segments (Souza et al., 2023).

In the Southeast, Minas Gerais grew marginally, 10.10%, São Paulo fell to 6.50%, and Rio de Janeiro remained low, 2.00%. In the Northeast, the contrast is striking. Alagoas fell from 21.02% to 12.03%, Pernambuco fell from 9.54% to 8.87%, Ceará to 5.43%, and Paraíba to 6.78%. Bahia maintained a stable and upward trajectory, 7.15%, and Sergipe closed at 7.73%. The marked decline in Alagoas and the decline in São Paulo, according to Muçouçah (2009), tend to be directly associated with the restructuring of historical complexes, such as the sugar mill, and the mechanization of sugarcane harvesting, which, while contributing to reducing emissions, eliminates low-skilled jobs.

In the North, relative expansion was observed in Rondônia, from 7.31% to 10.68%, Tocantins, from 9.78% to 11.54%, and Pará, from 7.54% to 8.31%, while Amazonas and Amapá fluctuated at low levels. Roraima rose from 2.24% to 3.37%. The relative growth in these northern regions, together with the Central-West and part of the Northeast, converges with the trend of increasing green jobs, axes of the bioeconomy, above the national average in the period (Ansanelli et al., 2025). The low participation in states such as Amazonas and Amapá, in turn, reiterates that, despite the broad potential, the formal use of sociobiodiversity remains limited, and employment is concentrated in urban centers, such as Manaus.

The results in Table 5 reinforce the spatial interpretation. Primary specialization is growing in regions of the Center-North, such as MATOPIBA, which saw significant job growth in the primary sector and withstood the COVID-19 crisis, while agroindustrial processing is consolidating in the Center-South (Loayza, Reis, Jesus, 2024). Where sectors such as sugar and textiles lost traction, relative participation shrank, although organic employment remained significant in absolute terms. In short, the decade combined stability in the national weight of the formal bioeconomy with intra-regional rearrangements. There are gains in the southern agroindustrial axis and in the northern arc, and a reduction in centrality in some historical complexes in the Northeast and Southeast. This redesign of employment raises the question of whether wages follow (or not) the same direction, distinguishing territories where processing adds value from those where primary processing predominates.

Table 6 I_{rend} shows the fraction of the wage bill linked to the 100% bioeconomic basket in relation to total formal income. Nationally, the indicator remains stable, with a slight increase from 5.77% (2011) to 6.05% (2021) and a peak in 2020 (6.10%). This trajectory, combined with I_{po}, tends to indicate that the bioeconomy maintains a relative weight in formal labor income throughout the decade, with variations associated with sectoral restructuring and short-term shocks that affected economic segments differently (Machado et al., 2021; Lima, Pinto, 2022).

The highest levels are concentrated in the Center-West and South, with MT (18.33% in 2021), MS (16.73%) and GO (12.40%) maintaining high shares of state income from the bioeconomy; in the South, SC (9.10%), PR (9.23%) and RS (7.00%) maintain a prominent position. The largest increases occur in RO (+3.63%) and TO (+2.65%), followed by MS (+1.29%), PR (+0.72%), RS (+0.77%), MG (+0.64%), and GO/MT (+0.69/+0.75%), which are in line with agro-industrial densification in slaughter, dairy, and food, as well as with greater local value capture in processing, which reinforces employment-income links and sustains high levels in these states (Lima; Pinto, 2022; Souza et al., 2023). The literature warns that trajectories guided by biomass volume, without inclusive governance arrangements, can increase distributive asymmetries, a relevant point for interpreting the gains in the Central-West (Lima, 2022).

In the Southeast, Minas Gerais advanced to 7.60% and São Paulo fell to 5.48%, while Rio de Janeiro remained low (1.21%), reflecting a less intensive production structure in bio-based chains. This contrast is consistent with chains such as sugarcane, in which the lack of

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diversification into bioproducts and cascading use limits the effects on jobs and wages, reducing the relative weight when the sectoral cycle cools down, as is the case in São Paulo (Scheiterle et al., 2018) In the Northeast, BA grew to 5.29%, but AL fell from 16.30% to 8.67% (−7.63%), with declines also in PB (4.72%), PE (6.07%) and CE (4.03%). The situation is consistent with the shrinkage of traditional complexes and with qualification requirements that tend to concentrate “green” jobs in urban-industrial hubs, hindering regional diffusion (Muçouçah, 2009; Souza et al., 2023; Ansanelli et al., 2025).

North and borders: RO (8.10% in 2021) and TO (7.88%) registered significant gains, while PA fluctuated around 5%–5.3%. Evidence for 2020–2021 in MATOPIBA describes the creation of formal jobs, a change in the hiring profile, and greater female participation, which helps explain the increase in the share of the “bio” wage bill in the new frontiers, in line with the increases in RO and TO (Loayza, Reis, Jesus, 2024). At the same time, the spatial organization of the bioeconomy in the Amazon, with industrial concentration in capital cities and dispersed primary bases, limits linkages and territorial diffusion, which contributes to the stability observed in PA and to intraregional heterogeneities. The coexistence of a “plantation” hub and sociobiodiverse systems reinforces the need for policies that connect conservation, inclusion, and industrialization to sustain the indicator over time (Willerding et al., 2020; Ollinaho, Kröger, 2023; Moscow et al., 2024).

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Table 5: Formal ties in bioeconomy segments in relation to total formal ties (I_{po}), in each state, between 2011 and 2021

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
I_{po} **AC**	5.08%	4.82%	4.77%	4.99%	5.24%	5.87%	5.64%	5.45%	5.02%	4.70%	4.50%
I_{po} **AL**	21.02%	19.56%	17.28%	15.02%	14.66%	14.93%	14.16%	12.78%	11.72%	12.63%	12.03%
I_{po} **AP**	1.86%	1.73%	1.79%	1.67%	1.84%	1.68%	1.67%	1.67%	1.46%	1.50%	1.54%
I_{po} **AM**	2.57%	2.70%	2.71%	2.65%	2.95%	2.79%	2.72%	2.69%	2.53%	2.55%	2.48%
I_{po} **BA**	6.71%	6.69%	6.60%	6.51%	6.53%	6.95%	6.95%	7.01%	7.06%	7.29%	7.15%
I_{po} **CE**	6.07%	6.05%	5.84%	5.79%	5.72%	5.73%	5.52%	5.49%	5.36%	5.58%	5.43%
I_{po} **DF**	1.61%	1.68%	1.48%	1.42%	1.43%	1.40%	1.40%	1.45%	1.72%	1.49%	1.75%
I_{po} **ES**	6.50%	6.22%	6.21%	6.23%	6.41%	6.37%	6.56%	6.58%	6.62%	6.39%	6.36%
I_{po} **GO**	13.71%	13.83%	13.88%	14.10%	13.92%	14.20%	14.01%	13.98%	14.09%	14.74%	14.30%
I_{po} **MA**	5.70%	5.41%	5.01%	4.95%	4.88%	5.03%	4.75%	4.58%	4.55%	4.92%	4.61%
I_{po} **MG**	9.93%	9.65%	9.72%	9.68%	10.10%	10.36%	10.32%	10.23%	10.07%	10.28%	10.10%
I_{po} **MS**	19.69%	20.33%	20.00%	19.83%	20.05%	20.53%	20.10%	20.35%	20.35%	21.33%	20.33%
I_{po} **MT**	20.71%	19.97%	20.13%	20.05%	19.94%	20.65%	21.35%	21.20%	21.82%	22.20%	21.33%
I_{po} **PA**	7.54%	7.68%	7.33%	7.47%	7.65%	7.96%	8.31%	8.22%	7.93%	8.34%	8.31%
I_{po} **PB**	8.09%	7.71%	7.54%	7.32%	7.16%	7.37%	7.19%	7.20%	7.12%	7.46%	6.78%
I_{po} **PE**	9.54%	8.74%	8.40%	8.61%	8.55%	8.86%	8.89%	8.76%	8.89%	9.12%	8.87%
I_{po} **PI**	4.71%	4.74%	4.38%	4.44%	4.38%	4.24%	4.24%	4.69%	4.64%	4.74%	5.03%
I_{po} **PR**	10.98%	10.17%	10.64%	10.73%	10.94%	10.69%	11.11%	10.87%	11.02%	11.70%	11.41%
I_{po} **RJ**	2.12%	2.10%	1.98%	1.99%	2.03%	2.04%	2.04%	1.99%	2.02%	2.06%	2.00%
I_{po} **RN**	7.13%	6.92%	6.87%	6.64%	6.79%	7.03%	7.03%	6.99%	6.67%	7.12%	6.97%
I_{po} **RO**	7.31%	7.62%	7.81%	7.92%	8.42%	8.67%	9.40%	9.59%	9.65%	9.82%	10.68%
I_{po} **RR**	2.24%	2.44%	2.79%	2.78%	2.74%	2.88%	2.46%	2.71%	3.02%	3.23%	3.37%
I_{po} **RS**	8.23%	7.80%	7.76%	7.82%	8.15%	8.36%	8.30%	8.38%	8.41%	8.88%	8.75%
I_{po} **SC**	10.86%	9.93%	10.37%	10.18%	10.25%	10.41%	10.71%	10.54%	10.62%	11.10%	10.85%
I_{po} **SE**	8.15%	8.05%	7.39%	7.60%	7.44%	7.47%	7.14%	7.10%	7.27%	7.51%	7.73%
I_{po} **SP**	7.19%	6.94%	6.73%	6.54%	6.70%	6.65%	6.79%	6.58%	6.63%	6.71%	6.50%
I_{po} **TO**	9.78%	10.26%	10.39%	10.48%	11.01%	11.45%	10.56%	10.67%	10.97%	12.09%	11.54%

I_{po} **BR**	**7.97%**	**7.70%**	**7.61%**	**7.53%**	**7.68%**	**7.80%**	**7.90%**	**7.82%**	**7.89%**	**8.14%**	**7.98%**

Source: prepared by the author, based on the inventory 12/31 (RAIS) 2011-2021, 2025.

Table 2: Share of wages from bioeconomy segments in relation to total income (I_{rend}), in each state, between 2011 and 2021

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
I_{rend} **AC**	2.52%	2.36%	2.45%	2.50%	2.74%	3.41%	3.25%	2.96%	2.60%	2.26%	2.19%
I_{rend} **AL**	16.30%	15.10%	13.03%	11.11%	10.83%	11.14%	10.36%	9.36%	8.37%	8.73%	8.67%
I_{rend} **AP**	0.93%	0.86%	0.87%	0.79%	0.87%	0.98%	1.08%	0.76%	0.64%	0.67%	0.75%
I_{rend} **AM**	1.82%	1.99%	1.96%	1.91%	2.06%	2.00%	1.97%	1.90%	1.70%	1.76%	1.76%
I_{rend} **BA**	4.72%	4.77%	4.80%	4.61%	4.60%	4.88%	4.87%	4.96%	5.01%	5.25%	5.29%
I_{rend} **CE**	4.59%	4.57%	4.53%	4.38%	4.30%	4.40%	4.20%	4.10%	3.95%	4.08%	4.03%
I_{rend} **DF**	0.69%	0.78%	0.75%	0.72%	0.51%	0.52%	0.51%	0.51%	0.59%	0.51%	0.63%
I_{rend} **ES**	4.41%	4.20%	4.27%	4.24%	4.29%	4.36%	4.53%	4.52%	4.48%	4.56%	4.52%
I_{rend} **GO**	11.71%	11.91%	12.17%	12.27%	12.01%	12.24%	12.06%	11.73%	11.82%	12.42%	12.40%
I_{rend} **MA**	4.19%	4.11%	4.10%	4.24%	3.96%	3.99%	3.77%	3.61%	3.49%	3.71%	3.67%
I_{rend} **MG**	6.96%	7.00%	7.21%	7.11%	7.34%	7.62%	7.66%	7.58%	7.45%	7.66%	7.60%
I_{rend} **MS**	15.44%	16.61%	16.58%	16.42%	16.51%	17.11%	16.45%	16.60%	16.21%	17.34%	16.73%
I_{rend} **MT**	17.58%	17.08%	17.34%	17.40%	17.29%	17.56%	18.25%	18.31%	18.44%	19.04%	18.33%
I_{rend} **PA**	5.12%	5.21%	4.91%	4.96%	5.09%	5.29%	5.65%	5.29%	4.96%	5.17%	5.34%
I_{rend} **PB**	5.50%	5.37%	5.39%	5.20%	5.12%	5.29%	5.04%	4.98%	4.84%	4.99%	4.72%
I_{rend} **PE**	6.73%	6.15%	5.85%	6.01%	5.99%	6.26%	6.14%	6.00%	6.04%	6.15%	6.07%
I_{rend} **PI**	3.33%	3.42%	3.26%	3.17%	3.11%	2.97%	2.96%	3.24%	3.26%	3.33%	3.69%
I_{rend} **PR**	8.51%	7.88%	8.22%	8.36%	8.53%	8.41%	8.77%	8.53%	8.63%	9.50%	9.23%
I_{rend} **RJ**	1.32%	1.32%	1.23%	1.26%	1.29%	1.33%	1.31%	1.28%	1.25%	1.25%	1.21%
I_{rend} **RN**	4.23%	4.09%	4.08%	3.93%	4.09%	4.23%	4.25%	4.18%	3.91%	4.11%	4.17%
I_{rend} **RO**	4.47%	4.81%	5.08%	5.19%	5.62%	5.89%	6.53%	6.81%	6.90%	6.71%	8.10%
I_{rend} **RR**	1.28%	1.48%	1.68%	1.68%	1.66%	1.53%	1.20%	1.27%	1.43%	1.54%	1.74%
I_{rend} **RS**	6.23%	5.98%	5.98%	6.06%	6.35%	6.63%	6.54%	6.52%	6.55%	6.93%	7.00%
I_{rend} **SC**	9.13%	8.32%	8.68%	8.45%	8.47%	8.58%	8.77%	8.66%	8.76%	9.22%	9.10%
I_{rend} **SE**	4.64%	4.55%	4.21%	4.30%	4.41%	4.33%	4.14%	4.07%	4.43%	4.47%	4.82%

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I_{rend} **SP**	5.87%	5.81%	5.74%	5.60%	5.63%	5.73%	5.68%	5.42%	5.55%	5.70%	5.48%
I_{rend} **TO**	5.23%	6.04%	6.77%	6.41%	6.76%	7.33%	6.79%	6.84%	6.90%	8.07%	7.88%
I_{rend} **BR**	**5.77%**	**5.69%**	**5.69%**	**5.62%**	**5.69%**	**5.86%**	**5.91%**	**5.79%**	**5.86%**	**6.10%**	**6.05%**

Source: prepared by the author, based on the inventory 12/31 (RAIS) 2011-2021, 2025.

In short, the I_{po} is close to 8% over the decade and the I_{rend} is around 6%, with a slight increase until 2021. Where there is agro-industrial density (Southeast/South/Central-West), the I_{rend} advances relatively more; in primary or restructuring areas (part of the Northeast), the share of income grows less than that of employment, which reinforces the agenda of bioproduct diversification and cascading use. In this way, the spatial reconfiguration of the formal labor market in the bioeconomy, marked by the advance of primary specialization in regions such as MATOPIBA and the Arco Norte, in contrast with the consolidation of agro-industrialization in the Center-South, raises important questions for Brazil's climate and social agenda. The debate is timely in the context of COP30 in Belém, in the heart of the Amazon (Brazil, 2024a). In this setting, the National Bioeconomy Strategy, instituted in June 2024, sets guidelines aimed at reducing inequalities with a focus on regional development and on the inclusion of women and youth in bioeconomy value chains (FAO, 2024; Brazil, 2024a, 2024b).

A joint reading of employment and income reinforces this orientation. There is a gap in primary areas, in which the income participation index, I_{rend}, grows less than the employment participation index, I_{po}. This mismatch indicates the need to implement the objectives of the National Bioeconomy Strategy and of the ABC+ Sectoral Plan, 2020 to 2030, with emphasis on inclusive regional development. ABC+ seeks to foster adaptation to climate change and mitigation of greenhouse gases, GHG, while strengthening Technical Assistance and Rural Extension and professional training for the adoption of Sustainable Production Systems, Practices, Products and Processes, such as bioinputs and agroforestry systems (Brazil, 2021; Brazil, 2024a, 2024b). The expansion of practices such as the restoration of degraded pastures and integration systems, Crop, Livestock and Forest Integration and Agroforestry Systems, which are central targets of ABC+, increases resilience and contributes to GHG mitigation. It also creates room for productive diversification and for increases in employment and income among rural producers, especially in vulnerable regions (Brazil, 2021).

Based on this diagnosis, employment and income dynamics provide a concrete reference to articulate cross-cutting policies. Among the instruments, the Brazilian Sustainable Taxonomy, proposed to guide government and private activities, can direct green finance capital to territories and groups of activities with greater capacity to add value and reduce asymmetries. In this way, the bioeconomy advances in a fair and equitable manner, consistent with Brazil's sustainable development commitments and with the targets of its Nationally Determined Contribution (Brazil, 2021, 2023b, 2025). To understand where this employment and this income are formed, Table 7 breaks down the 100 percent BIO core by BIO groups, macroregions and profiles of employment relationships.

At the sectoral level, there is a shift toward processing. Slaughter and meat products, including dairy and fishery products, increased their share by 21.4%, and other food products increased by 12.4%. Manufacture of pulp, paper, and paper products remained close to its initial level, down 2.0%, with a slight gain in relative share. In contrast, declines were recorded in Sugar manufacturing and refining, down 36.8%; Biofuel manufacturing, down 18.6%; Tobacco product manufacturing, down 30.1%; and Textile product manufacturing, down 20.0%. In the primary sector, there was a decline in Agriculture, including agricultural support and post-harvest, down 11.7%; and Forestry production, fishing, and aquaculture, down 23.2%. This movement, visible in Figures 1 and 2, explains cases where I_{po} remains elevated while the I_{rend} advances more slowly, the diffusion of employment in the BIO base does not automatically convert into wage mass, which tends to grow where the chains are organized as value networks, with cascading use and diversification of bioproducts (Scheiterle et al., 2018; File; Pinto, 2022; Souza et al., 2023).

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Table 3: Profile of formal BIO ties by selected characteristics, Brazil, 2011–2021

Variable	2011		2021		Relative change in number of observations 2011–2021 (%)
	Number of observations	Percentage %	Number of observations	Percentage %	
BIO Group					
A - Agriculture, including agricultural support and post-harvest	1,815,205	28.58	1,602,812	26.94	-11.70
B - Livestock, including support	823.007	12.96	788.106	13.25	-4.24
C - Forestry production, fishing and aquaculture	280,350	4.41	215.207	3.62	-23.24
D - Slaughter and meat products, including dairy and fishery products	865,679	13.63	1,051,026	17.67	21.41
E - Sugar manufacturing and refining	575,307	9.06	363,746	6.11	-36.77
F - Other food products	864,282	13.61	971,325	16.33	12.39
G - Beverage manufacturing	187,829	2.96	161,423	2.71	-14.06
H - Manufacture of tobacco products	42,724	0.67	29,879	0.5	-30.07
I - Manufacture of textile products	435.105	6.85	348,163	5.85	-19.98
J - Manufacture of pulp, paper and paper products	245,387	3.86	240,578	4.04	-1.96
K - Biofuel production	217,142	3.42	176,668	2.97	-18.64
Region					
North	262.122	4.12	292,739	4.92	11.68
North East	1,126,422	17.73	950,664	15.98	-15.60
South	2,786,862	43.87	2,360,819	39.68	-15.29
Southeast	1,315,918	20.72	1,403,587	23.59	6.66
Midwest	860,693	13.55	941.124	15.82	9.34
Characteristics of the individual					
Sex					
Masculine	4,812,977	75,77	4,434,607	74.54	-7.86
Feminine	1,539,040	24,23	1,514,326	25.46	-1.61
Age					
10 to 14 years old	371	0.01	548	0.01	47.71
15 to 17 years old	55,152	0.87	36,538	0.61	-33.75
18 to 24 years old	1,380,371	21.73	1,101,940	18.52	-20.17
25 to 29 years old	1,172,940	18.47	927,576	15.59	-20.92
30 to 39 years old	1,860,090	29.28	1,702,304	28.62	-8.48
40 to 49 years old	1,193,879	18.8	1,277,224	21.47	6.98
50 to 64 years old	651,233	10.25	833,847	14.02	28.04
65 years or older	37,958	0.6	68,952	1.16	81.65

Race color					
Whites and yellows	3,433,912	54.06	2,438,067	40.98	-29.00
Black and brown people	2,589,978	40.77	2,640,628	44.39	1.96
Others	328.127	5.17	870,238	14.63	165.21
Education					
Illiterate	171,162	2.69	98,750	1.66	-42.31
Up to 5th inc.	881,744	13.88	465,737	7.83	-47.18
5th co fund	761,137	11.98	343,038	5.77	-54.93
6. The 9. Fund	1,034,819	16.29	681,493	11.46	-34.14
Fund compl	939,617	14.79	723,167	12.16	-23.04
Average incomp	582,293	9.17	610,650	10.26	4.87
Average complete	1,654,536	26.05	2,557,010	42.98	54,55
Incomp . Sup.	113,172	1.78	122,941	2.07	8.63
Sup. Comp	209,463	3.3	340.376	5.72	62.50
Master's degree	3130	0.05	4,285	0.07	36.90
Doctorate	944	0.01	1,486	0.02	57.42
Bond time					
Up to 2.9 months	755,186	11.89	575.301	9.67	-23.82
3.0 to 5.9 months	1,152,403	18.14	930,870	15.65	-19.22
6.0 to 11.9 months	1,315,673	20.71	1,004,592	16.89	-23.64
12.0 to 23.9 months	1,004,250	15.81	875,890	14.72	-12.78
24.0 to 35.9 months	518,474	8.16	526,226	8.85	1.50
36.0 to 59.9 months	608.107	9.57	594,686	10	-2.21
60.0 to 119.9 months	592,398	9.33	760.701	12.79	28.41
120.0 months or more	405,526	6.38	680,667	11.44	67.85
Contracted time					
Up to 12 hours	8,888	0.14	95,835	1.61	978.25
1 to 3 pm	806	0.01	3,679	0.06	356.45
4 to 8 pm	23,100	0.36	55,141	0.93	138.71
9:30 pm to 9:30 pm	39,118	0.62	60,458	1.02	54,55
31 to 40 hours	121,819	1.92	213.315	3.59	75.11
41 to 44 hours	6,158,286	96.95	5,520,505	92.8	-10.36

Source: prepared by the author, based on the inventory 12/31 (RAIS) 2011 and 2021, 2025.

Territorially, the total number of formal bioindustry links in Brazil fell by 6.35%, with losses in the South (-15.3%) and Northeast (-15.6%) and gains in the North (+11.7%), Central-West (+9.3%), and Southeast (+6.7%). This trend is consistent with the internalization of agroindustry in the Central-West, the consolidation of processing hubs in the Southeast, and the expansion of northern fronts aligned with agriculture and processing niches. Evidence from 2020–2021 in MATOPIBA reports the creation of formal positions and changes in the hiring profile, in line with the expansion observed in border states; in the Amazon, the concentration of bioindustries in capital cities and the dispersion of primary bases limit territorial linkages, which helps to understand stabilizations in part of the North and intraregional heterogeneities (Willerding et al., 2020; Loayza, Reis, Jesus, 2024; Moscow et al., 2024; Queiroz-Stein et al., 2024)

The employment profiles indicate demographic and occupational restructuring. Female participation increases from 24.23% to 25.46%, and the age structure shifts to higher groups, with reductions in the 18–24 age group (−20.2%) and 25–29 age groups (−20.9%), relative stability in the 30–39 age group (−8.5%), and expansion in the 40–49 age group (+7.0%), 50–64 age group (+28.0%), and 65+ age group (+81.6%). This pattern is consistent with industrial and logistical relationships that require stable teams and specific qualifications, a recurring feature in bio-industrial activities and green occupations, where training and coordination requirements raise entry barriers and favor regions with a coordinated urban-industrial and agro-industrial base (Muçouçah, 2009; Souza et al., 2023; Ansanelli et al., 2025).

In terms of race/color, "White and Asian" participation decreased from 54.06 to 40.98%, "Black and Brown" increased from 40.77 to 44.39%, and "Others (Indigenous, unidentified, or unknown)" increased from 5.17 to 14.63%. Regarding education, there was a clear increase in qualifications. There was a decline in all age groups up to elementary school, a strong increase in the number of people with completed high school from 26.05 to 42.98%, and an increase in the number of people with completed higher education from 3.30 to 5.72%. Regarding the length of time in formal employment, the results were 60–119.9 months (+28.4 %) and 120 months or more (+67.9%). The set indicates accumulation of specific capital and organizational learning in bio plants and firms, consistent with processes of industrial densification, standardization of routines and greater technical complexity of regional production arrangements (Lima; Pinto, 2022; Souza et al., 2023; Ansanelli et al., 2025).

In the contracted workday, 41–44 hours remain dominant, but their share falls from 96.95 to 92.80 %, with the expansion of reduced formats, such as up to 12 hours (+978%) and 31–40 hours (+75.1%). Although a minority, these modalities signal a reorganization of shifts, outsourcing of stages, and the growth of auxiliary services. Analytically, the combination of higher qualifications, longer tenure, and contractual diversification is consistent with the agroindustrial densification of the Center-South and the stabilization of I_{rend} the I_{po}. Where the transition to transformation links and related services advances, the gap between employment and wages tends to narrow; where primary sectors persist in decline, the share of income grows less than the share of employment, reinforcing the need for innovation policies and governance arrangements focused on value, territorial diffusion, and social inclusion (Scheiterle et al., 2018; Lima, 2022; File; Pinto, 2022; Souza et al., 2023).

5. Conclusion

This study mapped the 100% BIO core of the Brazilian bioeconomy based on the RAIS (2011–2021), showing a stable share of formal employment around 8% and a wage bill close to 6% with a slight increase until 2021. These average stabilities, however, indicate territorial reconfiguration, with a greater relative weight in the Center-West and South (associated with agro-industrial densification) and losses in traditional complexes such as sugar in selected states in the Southeast and Northeast. In new frontiers, such as MATOPIBA, formal employment remained resilient in the 2020–2021 biennium, consistent with recent expansion, but with gaps between employment and income participation where processing is incipient. In the Legal Amazon and parts of the semiarid region, the combination of extensive primary production bases and the concentration of processing in a few urban centers persists, limiting local value capture.

The implications are direct for public policies and private strategies. Priority is given to bioindustrialization close to biomass sources, with cascading use, bioproduct diversification , and logistical integration; the adoption of verifiable targets and criteria anchored in IPO and IREND to guide territorial prioritization, credit, R&D, and public procurement; and the explicit differentiation between "plantation economy" arrangements and those based on sociobiodiversity, in order to avoid conceptual dilution in taxonomies and reinforce socio-environmental safeguards. Where there is a relevant primary base but little local transformation, the agenda should combine workforce qualification, financing solutions for fixed assets, and governance instruments that reduce coordination costs throughout the supply chains. In light of COP30, scheduled for Belém in 2025, strategies that position sociobiodiversity as a pillar of regional development in the Amazon, with innovation, social justice and respect for Indigenous peoples and local communities, gain prominence, in line with recent public policy guidelines.

The institutional framework provides instruments to make these directions operational. The National Bioeconomy Strategy, established by Decree No. 12,044 of 2024, sets guidelines for reducing inequalities with a focus on regional development, education and professional training, promotion of entrepreneurship and the creation of new jobs. Its effectiveness will depend on the National Bioeconomy Development Plan, which needs to direct financial and economic instruments to strengthen sociobiodiversity activities and family farming in regional complexes with lower average income. The Brazilian Sustainable Taxonomy, under development, should guide public and private actors committed to decent work and the reduction of regional asymmetries.

Incorporating the findings of this study into the targets of the ABC+ Plan, 2020 to 2030, which addresses adaptation and emissions mitigation through Sustainable Production Systems, Practices, Products and Processes and includes a valuation and recognition program, creates alignment among technology promotion, credit and finance. This alignment is especially relevant for territories such as the Arco Norte and MATOPIBA, which show employment growth and require value addition and decentralized industrialization to reduce the income deficit and advance economic, social and environmental sustainability. In the Amazon, accelerating green infrastructure and technical assistance, as set out under Axis I of the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon, Sustainable Productive Activities, is a precondition for converting the forest's socioeconomic base into higher value added green jobs.

Limitations of the findings include the 100% BIO core and the reliance on formal employment relationships captured by RAIS, which may underestimate dimensions of sociobiodiversity and informal employment. Furthermore, the analysis concluded in 2021, not capturing subsequent changes in the agroindustrial cycle or new sectoral public policies. These limitations do not invalidate the results, but they signal caution in extrapolation and indicate clear areas for further development.

For future research, it is recommended to integrate complementary sources that capture informal links and extract productive chains (e.g., regional input-output matrices, sectoral administrative records, and foreign trade data), measure productivity and technological diffusion of bioeconomy segments, and assess the sharing of benefits in sociobiodiversity chains. The systematic incorporation of traceability and territorial impact metrics will facilitate the monitoring of targets and comparison between bioeconomy modalities.

In short, the decade analyzed was not one of rupture, but rather of reallocation of the "where" and "how" employment and income are generated in the 100% BIO core: a lesser role for traditional complexes undergoing restructuring and a greater weight for bioindustries connected to logistics corridors and technologically advanced agricultural fronts. Transforming this movement into inclusive prosperity requires accelerating three vectors: (i) bioindustrialization with cascading use and diversification of bioproducts; (ii) qualification oriented toward the technical and digital skills required by the transformation and logistics links; and (iii) governance that aligns competitiveness, conservation, and benefit sharing. With goals supported by *IPO* and *IREND* and a focus on chains that combine innovation, traceability, and fair distribution, the bioeconomy can establish itself as an effective axis for generating decent work and reducing regional asymmetries, in line with the policy portfolio the country intends to showcase in Belém in 2025.

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