SUSTAINABILITY IN DEBATE

SUSTENTABILIDADE EM DEBATE



EDITORIAL

When nature no longer warns us

ARTICLES *VARIA*

Oil exploration and the management of coastal protected areas from an environmental justice perspective

Assessing municipal solid waste management plans through an SDG adherence index: an evidence-based approach

Representation and participatory water management: a portrait of the State Councils in 2024

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The Andean chakra as a socioecological system of Buen Vivir for food sovereignty

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Editorial

When nature no longer warns us

Carlos Hiroo Saito, Marcel Bursztyn, Cristiane Barreto, Patrícia Mesquita and Cristiana Dobre

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Warnings about the limits of human action on the natural environment are nothing new. Rachel Carson drew attention to the diffuse, cumulative effects of agrochemicals, while the report to the Club of Rome quantified the incompatibility between exponential growth and a finite material base. The 1992 Rio de Janeiro Conference enshrined the precautionary principle, allowing action to be taken before there is full certainty that a risk is unavoidable. Since then, warnings have grown more precise and better substantiated, even if the action they call for keeps being deferred. This gap between knowledge and action is what defines the present moment, and it is playing out across the planet.

It is worth distinguishing between two kinds of problems that the sustainability literature often lumps together. The first is the scarcity of natural resources and the erosion of livelihoods, whose economic toll always falls hardest on the most vulnerable. The second concerns extreme climate events, and this is where things have changed: no longer latent threats unevenly spread between rich and poor countries, they are now concrete, simultaneous events unfolding across several continents at once. Nature, it seems, is sending more than mere signals that further degradation of the natural environment can no longer be sustained.

If, as early as the start of 2026, the United Nations University's Institute for Water, Environment and Health was already declaring a state of Global Water Bankruptcy, we may soon find ourselves declaring a Global Climate Bankruptcy too.

The summer of 2026 in the northern hemisphere, marked by lethal heatwaves and large-scale wildfires across two continents, adds at least four new findings to what we already knew:

- extreme events are no longer a statistical exception but part of the new climate normal;
- income and infrastructure offer far less protection than previously assumed;
- the fallout spreads well beyond the affected region, crossing borders and oceans;
- degradation is now outpacing the institutional response.

None of this will surprise regular readers of this journal. Bernal *et al.* (2022) and Oliveira *et al.* (2020) projected and then measured the impact of extreme heat on cardiovascular and respiratory mortality in Brazil. Fardin *et al.* (2023), studying a Brazilian mountain city plagued by recurring disasters, found that repeated exposure had not translated into any lasting preventive capacity. Soares (2017), working in southern Mexico, examined how vulnerability, gender and disaster risk intersect, and flagged similar concerns. These studies span nearly a decade and different settings, yet their conclusions echo one another. Situated case studies are not only local. It is precisely their empirical precision that makes them comparable.

It would be unfair to dwell only on the bad news. Adaptation, long treated as a fallback for the failure of mitigation, has earned its own place on the multilateral agenda, and vulnerability research now features prominently everywhere.

Politically, however, "managing consequences" still tends to win out over "managing causes". And this is not just a problem for the Global South. Much of Europe still has no structured plan for responding to heatwaves, despite one record-breaking summer after another, and Araújo *et al.* (2026) found comparable gaps in municipal climate plans when assessed through a public-health lens.

Lefèvre, Assis and Caldas (2025) offer an uncomfortable explanation. Public interest in climate spikes right after an event, then fades within weeks. The window for action opens and closes before any structural decision has time to mature. As Lindoso and Strapasson (2025) point out, adaptation and socio-environmental resilience call for the opposite rhythm. Institutional continuity and predictable funding are essential. We would add one more requirement to that list: environmental education and scientific literacy, as a way of turning that fleeting window into lasting, deliberate action.

Where public attention comes and goes, editorial continuity serves a purpose that goes beyond the academic one.

This editorial is a reminder of the moment we are living through. As extremes start hitting even countries that once considered themselves safe, acting urgently stops being an ethical duty toward others and becomes, for everyone, a matter of survival. Yet the underlying inequality persists. In every country, it is the poorest who die first from heat and lose everything in floods. More than three decades after Rio, we must admit that the precautionary principle has never really been applied to climate change anywhere. Stating a principle, it turns out, is far easier than putting it into practice.

How much longer will those in power keep just reacting to these consequences, instead of acting to prevent ever-greater tragedies? Species are at risk, and so are people. Prevention is not optional, and it is urgent; The evidence we now have leaves no room for claims of ignorance or for scepticism to guide our choices. The institutional framework needed still does not exist, and no single country or region will be able to build it alone. We urgently need to stop the climate crisis before it turns into a global climate bankruptcy a point of no return where regret would be futile, and far too late.

This issue of *Sustainability in Debate* brings together contributions that examine, at different scales and in different places, the gap between what we already know and what actually gets decided.

A first group of articles deals with the instruments that should anticipate harm. Jesus and Wernke analysed the management plans of coastal conservation units in Amapá in light of the licensing of the FZA-M-59 block in the Equatorial Margin, showing that the incorporation of environmental justice remains fragmented and poorly articulated with licensing, which limits the anticipatory capacity of governance. Leal *et al.* applied an SDG-adherence index to the municipal solid waste plans of 34 municipalities in Goiás and found that the highest scores are sustained by declarative elements rather than evidence of implementation. Costa *et al.* mapped the State and Federal District Water Resources Councils in 2024, identifying a predominance of public-sector representation, female under-representation and uneven functioning across the federal units.

Araújo, Silverwood-Cope, Branco and Ometto examined why scientific knowledge does, or does not, reach decision-making. The comparison between the Interministerial Commission on Global Climate Change and the Joint Committee on Climate Change between 1999 and 2009 shows that the former operated in a fragmented manner, with conceptual and symbolic uses of science, while the latter broadened scientific influence by connecting technical diagnoses to politically recognised problems.

A third set shows who bears the costs when scientific knowledge is slow to reach the decision-making level. Oliveira, Soares, Dávalos, Rocha, Sátiro and Silva. monitored soil quality in the Jacaré Curituba

Settlement Project, in Sergipe, between 2014 and 2022, and identified persistent salt and nutrient imbalances in the absence of adequate technical assistance. Silva and Guerrieri assessed residential distributed photovoltaic generation across 51 distribution utilities and found that consumers in the lowest consumption bracket have the worst economic performance under current rules, proposing an exemption from the availability cost for systems of up to 1.5 kW. Borille *et al.* analysed public perceptions of meat and deforestation in the Amazon and found that the group with lower purchasing power is more permissive regarding the consumption of products from deforested areas, while respondents perceived environmental legislation as robust yet ineffective.

Vecchietti, Schreiber and Viana investigated conscious consumption and the circular economy among secondary-school students and found that the perception of circularity is tied to material security: state-school students show a greater perception of risk regarding reuse. In this case, the barrier is material before it is cognitive.

Finally, two articles remind us that the response will not come from a single country or a single tradition of knowledge. Vargas-Chaves and Luna-Galván argued that Latin America built, through the Treaty of Tlatelolco, a path of institutional cooperation distinct from nuclear deterrence. Cachipuendo, Churuchumbi and Pilataxi analysed the Andean chakra as a socioecological system of Sumak Kawsay, concluding that its preservation requires intercultural public policies, along with recognition of the role of women, and longitudinal and comparative lines of research across the different locations of the Andean region.

Knowing exactly where the chain between evidence and decision breaks down is the first step toward acting before it is too late. And acting before it is too late is, today, the only form of precaution we have left.

Finally, this issue also marks Cristiane Barreto joining the journal's team of editors-in-chief.

Enjoy the read.

The Editors

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Editorial

Quando a natureza deixa de apenas avisar

Carlos Hiroo Saito, Marcel Bursztyn, Patrícia Mesquita, Cristiana Dobre e Cristiane Barreto

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Não é de hoje que alertas são lançados em relação aos limites da ação humana sobre o ambiente natural. Rachel Carson chamou a atenção para os efeitos difusos e cumulativos dos agroquímicos, e o relatório do Clube de Roma traduziu em números a incompatibilidade entre o crescimento exponencial e uma base material finita. A Conferência do Rio de Janeiro (1992) consagrou o princípio da precaução, que autoriza agir antes da certeza plena de que o risco é inevitável. De lá para cá, os alertas ganharam precisão e provas de materialidade, ao mesmo tempo que a ação por eles reclamada foi sendo postergada. É essa assimetria, entre conhecimento e ação que caracteriza o momento atual, e se manifesta em todo o planeta.

Aliás, convém distinguir duas ordens de problemas que a literatura sobre sustentabilidade frequentemente reúne sob o mesmo rótulo. A primeira é a escassez de recursos naturais e a deterioração dos meios de vida, cujos efeitos econômicos recaem sempre com mais força sobre as populações mais vulneráveis. A segunda é a dos eventos climáticos extremos, e é nela que reside a novidade: deixaram de ser ameaças latentes, desigualmente distribuídas entre países ricos e pobres, para se tornarem manifestações concretas e simultâneas em vários continentes. Parece que a natureza está enviando mais do que apenas sinais de que não é possível continuar a degradar e invadir o ambiente natural.

Se, já no início de 2026, a Universidade das Nações Unidas / Instituto para a Água, o Meio Ambiente e a Saúde anunciaram que atingimos o estado de Falência Hídrica Global, corremos o risco de, na sequência, virmos a decretar a Falência Climática Global.

O último verão do hemisfério norte, marcado por ondas de calor letais e por incêndios florestais de grande escala em dois continentes, acrescenta ao quadro conhecido pelo menos quatro constatações:

- os extremos deixaram de ser exceção estatística e passaram a integrar a normalidade climática;
- a proteção conferida pela renda e pela infraestrutura é bem menor do que se supunha;
- os efeitos se propagam muito além do território atingido, atravessando fronteiras e oceanos;
- a degradação ocorre mais rapidamente do que a resposta institucional.

Nada disso surpreende mais o leitor ou a leitora desta revista. Bernal *et al.* (2022) e Oliveira *et al.* (2020) projetaram e mensuraram os efeitos do calor extremo sobre a mortalidade cardiovascular e respiratória no Brasil. Fardin *et al.* (2023) mostraram, em uma cidade serrana brasileira com desastres recorrentes, que a repetição dos episódios não se converteu em capacidade preventiva instalada. Soares (2017), no sul do México, examinou a tríade vulnerabilidade, gênero e risco de desastre, e levantou inquietações convergentes. São edições distintas, ao longo de quase uma década, com estudos ancorados em territórios específicos e conclusões que se comunicam. Casos situados não são casos locais: é justamente por serem descritos com precisão empírica que se tornam comparáveis.

Seria injusto registrar apenas as más notícias. A adaptação, por décadas tratada como concessão ao fracasso da mitigação, ganhou estatuto próprio na agenda multilateral, e a produção científica sobre vulnerabilidade já está na ordem do dia em toda a parte.

No entanto, na esfera política, persiste a preferência pela "gestão de consequências" em detrimento da "gestão de causas". Convém insistir que esse não é um problema apenas do Sul Global. Boa parte dos países europeus segue sem um plano estruturado de resposta a ondas de calor, depois de sucessivos verões recordes, e Araújo *et al.* (2026) identificaram lacunas equivalentes em planos climáticos municipais avaliados pela ótica da saúde.

Lefèvre, Assis e Caldas (2025) ofereceram uma explicação incômoda para essa ausência ao verificarem que o interesse público pelo clima cresce logo após o evento e desaba poucas semanas depois. A janela de oportunidade abre e fecha antes que qualquer decisão estrutural amadureça. Como observaram Lindoso e Strapasson (2025), adaptação e resiliência socioambiental exigem o oposto desse ritmo, ou seja, permanência institucional e financiamento previsível. Nós adicionamos a essas necessidades uma outra, que é a educação ambiental e alfabetização científica como meio para transformar a janela de oportunidades numa ação consciente e duradoura.

Onde a atenção pública é intermitente, a permanência editorial cumpre uma função que não é apenas acadêmica.

Este editorial chama atenção para o momento em que vivemos. Quando os extremos passam a atingir também os países que se julgavam protegidos, a urgência de agir deixa de ser um imperativo ético em relação aos outros e passa a ser, para todos, uma questão de sobrevivência. A assimetria, no entanto, permanece: em qualquer país, são os mais pobres que morrem primeiro no calor e perdem tudo nas enchentes. Mais de três décadas depois da conferência do Rio, é preciso reconhecer que o princípio da precaução nunca chegou a ser efetivamente aplicado ao clima em lugar algum. Enunciar princípios revelou-se muito mais fácil do que incorporá-los às decisões.

Até quando os dirigentes e os detentores do poder vão se manter apenas reativos a tais consequências, sem agir preventivamente, evitando que estejamos expostos a tragédias cada vez maiores? Espécies da biodiversidade estão em risco, assim como os humanos. A prevenção é um imperativo e é urgente, porque a evidência acumulada já não autoriza a alegação de ignorância ou a conduta orientada pelo ceticismo. O arranjo institucional, no entanto, ainda não está elaborado, e não sairá de um único país ou região. É urgente estancarmos a crise climática para que ela não se transforme numa falência climática global, um ponto de não retorno em que o arrependimento pode ser inútil e insuficiente.

A presente edição de *Sustainability in Debate* reúne contribuições que examinam, em escalas e territórios distintos, a distância entre o que já sabemos e o que efetivamente se decide.

Um primeiro conjunto de artigos trata dos instrumentos que deveriam antecipar o dano. Jesus e Wernke analisaram os planos de manejo das unidades de conservação costeiras do Amapá diante do licenciamento do bloco FZA-M-59, na Margem Equatorial, e mostram que a incorporação da justiça ambiental permanece fragmentada e pouco articulada ao licenciamento, o que limita a capacidade antecipatória da governança. Leal *et al.* aplicaram um índice de aderência aos ODS aos planos municipais de resíduos sólidos de 34 municípios de Goiás e verificaram que as pontuações mais altas são sustentadas por elementos declarativos, não por evidências de implementação. Costa *et al.* retrataram os Conselhos Estaduais e Distrital de Recursos Hídricos em 2024, identificando preponderância do poder público, sub-representação feminina e funcionamento desigual entre as unidades da Federação.

Araújo, Silverwood-Cope, Branco e Ometto examinaram o porquê de o conhecimento científico chegar, ou não chegar, à decisão. A comparação entre a Comissão Interministerial de Mudança Global do Clima e a Comissão Mista sobre Mudanças Climáticas entre 1999 e 2009 mostra que a primeira operou de

forma fragmentada, com usos conceituais e simbólicos da ciência, enquanto a segunda ampliou a influência científica ao conectar diagnósticos técnicos a problemas politicamente reconhecidos.

Um terceiro conjunto mostra sobre quem recai os custos quando o conhecimento científico tarda a chegar ao nível decisório. Oliveira, Soares, Dávalos, Rocha, Sátiro e Silva acompanharam a qualidade do solo no Projeto de Assentamento Jacaré Curituba, em Sergipe, entre 2014 e 2022, e identificaram desequilíbrios de sais e nutrientes persistentes na ausência de assistência técnica adequada. Silva e Guerrieri avaliaram a geração distribuída fotovoltaica residencial em 51 concessionárias e identificaram que os consumidores de menor faixa de consumo têm o pior desempenho econômico sob as regras vigentes, propondo isenção do custo de disponibilidade para sistemas de até 1,5 kW. Borille *et al.* analisaram a percepção pública sobre carne e desmatamento na Amazônia e identificaram que o grupo de menor poder aquisitivo é mais permissivo quanto ao consumo de produtos provenientes de áreas desmatadas, ao mesmo tempo que os respondentes perceberam a legislação ambiental como robusta e inefetiva.

Vecchietti, Schreiber e Viana investigaram o consumo consciente e a economia circular entre estudantes do ensino médio e constataram que a percepção de circularidade está atrelada à segurança material: alunos da rede pública manifestam maior percepção de risco quanto ao reúso. A barreira, nesse caso, é material antes de ser cognitiva.

Por fim, dois artigos lembram que a resposta não virá de um único país nem de uma única tradição de conhecimento. Vargas-Chaves e Luna-Galván argumentaram que a América Latina construiu, por meio do Tratado de Tlatelolco, uma via de cooperação institucional distinta da dissuasão nuclear. Cachipuendo, Churuchumbi e Pilataxi analisaram a *chakra* andina como sistema socioecológico do *Sumak Kawsay*, concluindo que a sua preservação requer políticas públicas interculturais, além do reconhecimento do papel do gênero feminino e linhas de pesquisa longitudinais, e comparativas entre os diferentes locais da região andina.

Reconhecer exatamente onde a cadeia entre evidência e decisão se rompe é condição para agir antes. E agir antes é, hoje, a única forma de precaução que ainda nos resta.

Por último, este número marca também a entrada de Cristiane Barreto no corpo de editores-chefe da revista.

Boa leitura.

Os Editores

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Oil exploration and the management of coastal protected areas from an environmental justice perspective

Exploração petrolífera e gestão de unidades de conservação costeiras sob a perspectiva da justiça ambiental

Silvia Cristina de Jesus [1]

Ana Vitória Wernke [2]

[1] *PhD in Environmental Sciences, Professor, Federal University of São Carlos, São Carlos, SP, Brazil*
E-mail: silvia.jesus@ufscar.br

[2] *PhD in Architecture and Urbanism, Professor, Latin American Faculty of Social Sciences, São Paulo, SP, Brazil*
E-mail: anawernke@flacso.org.br

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ABSTRACT

This article examines whether the management plans of federal coastal protected areas in the state of Amapá, Brazil, are aligned with environmental policy guidelines in the context of offshore oil exploration in the Equatorial Margin. Using a qualitative documentary analysis guided by the analytical dimensions of environmental justice (procedural, distributive, epistemic, and differential exposure to risk), the study evaluated management plans as preventive instruments of environmental governance by examining participatory mechanisms, recognition of traditional knowledge, distribution of risks and benefits, and references to vulnerable groups. The licensing process of block FZA-M-59 was analysed to assess the articulation between territorial planning and environmental licensing. The results indicate that, although management plans recognise ecological integrity and sociocultural presence, the incorporation of environmental justice dimensions remains fragmented and weakly integrated with licensing processes. This disconnect limits the anticipatory capacity of protected area governance in contexts of high ecological sensitivity and socioenvironmental vulnerability.

Keywords: Equatorial Margin. Protected areas management. Offshore oil exploration. Coastal governance. Traditional communities.

RESUMO

Este artigo examina se os planos de manejo das unidades de conservação federais costeiras localizadas no estado do Amapá, Brasil, estão alinhados às diretrizes das políticas ambientais no contexto da exploração petrolífera offshore na Margem Equatorial. Por meio de uma análise documental qualitativa orientada pelas dimensões analíticas da justiça ambiental (procedimental, distributiva, epistêmica e

exposição diferencial ao risco), o estudo avaliou os planos de manejo como instrumentos preventivos de governança ambiental, examinando os mecanismos de participação, o reconhecimento dos conhecimentos tradicionais, a distribuição de riscos e benefícios, e as referências a grupos vulneráveis. O processo de licenciamento do bloco FZA-M-59 foi analisado para avaliar a articulação entre o planejamento territorial e o licenciamento ambiental. Os resultados indicam que, embora os planos de manejo reconheçam a integridade ecológica e a presença sociocultural, a incorporação das dimensões da justiça ambiental permanece fragmentada e pouco integrada aos processos de licenciamento. Essa desconexão limita a capacidade antecipatória da governança das unidades de conservação em contextos de elevada sensibilidade ecológica e vulnerabilidade socioambiental.

Palavras-chave: *Margem Equatorial. Gestão de unidades de conservação. Exploração petrolífera offshore. Governança costeira. Comunidades tradicionais.*

1 INTRODUCTION

The Brazilian Equatorial Margin, encompassing the coastal stretch between the states of Amapá and Rio Grande do Norte, has emerged as a new strategic frontier for offshore oil exploration, namely activities conducted in the marine environment and on the continental shelf (Marta-Almeida *et al.*, 2026). Despite the high socio-environmental sensitivity of this region, characterised by rich biodiversity, extensive wetlands, estuarine systems, and overlaps with traditional territories, the expansion of large-scale extractive projects has advanced into areas under the direct or indirect influence of federal protected areas, including the Cabo Orange National Park (CONP), the Maracá-Jipioca Ecological Station (MJES) and the Lago Piratuba Biological Reserve (LPBR).

The environmental licensing process of block FZA-M-59, located in the *Foz do Amazonas* Basin, has become one of the most emblematic cases in recent debates on oil exploration along the Brazilian Equatorial Margin. The initial denial of the license by the Brazilian Institute of the Environment and Renewable Natural Resources (Ibama) in 2023, grounded in gaps in oceanographic and ecological data, weaknesses in the Environmental Impact Assessment (EIA), and shortcomings in emergency response planning, sparked broad public and institutional debate. The process subsequently underwent technical reviews and reassessments, culminating in the issuance of an Operating License in 2025 for exploratory drilling. This trajectory underscores the tensions between environmental public policies, national energy expansion strategies, and the challenges of marine and coastal environmental governance, particularly in ecologically sensitive and socially vulnerable territories.

Management plans constitute a central category of territorial planning instruments within Brazilian environmental governance, assuming a key role in territorial governance and risk prevention. By establishing guidelines for land and resource use and for the protection of conserved areas, based on conservation objectives and ecological zoning, these instruments are designed to structure decision-making processes and anticipate socio-environmental conflicts in protected territories (ICMBio, 2018). However, the effectiveness of these instruments depends on their periodic updating, alignment with sectoral public policies, and, above all, the incorporation of participatory mechanisms and the recognition of local and traditional knowledge, especially in regions with a strong presence of traditional populations (Ruano-Chamorro; Gurney; Cinner, 2022).

Environmental justice provides an analytical framework for examining how environmental planning incorporates participation, recognition of different knowledge systems, and the distribution of environmental risks among social groups (Acselrad, 2010; Fraser, 1998; Schlosberg, 2007). In coastal Amazonian contexts, these dimensions are particularly relevant because protected areas overlap with territories occupied by traditional communities whose livelihoods depend directly on coastal and marine ecosystems (Soares, 2024).

This article examines whether the management plans of federal protected areas along the coast of Amapá are aligned with environmental policy guidelines for offshore oil exploration in the Brazilian Equatorial Margin. Specifically, it evaluates whether these management plans function as preventive environmental governance instruments through the incorporation of environmental justice principles. To this end, it analyses the extent to which the plans recognise participatory mechanisms, territorial vulnerabilities, traditional knowledge, and differential exposure to socio-environmental risks, as well as their potential contribution to environmental licensing and decision-making processes. The study focuses on the role of management plans as strategic planning instruments, examining their capacity to support preventive environmental governance and provide information relevant to licensing processes under conditions of environmental uncertainty, without assessing the environmental impacts of offshore oil exploration itself.

2 METHODOLOGY

2.1 STUDY AREA

The study area comprises three federal protected areas located along the coast of Amapá State, in northern Brazil: Cabo Orange National Park (CONP), Maracá-Jipioca Ecological Station (MES), and Lago Piratuba Biological Reserve (LPBR) (Figure 1). These protected areas are part of a region considered to have high socio-environmental sensitivity, situated at the northernmost extent of the Brazilian Equatorial Margin, near the mouth of the Amazon River and the border with French Guiana. The region is characterised by extensive coastal and estuarine ecosystems that support high biodiversity and sustain the livelihoods of traditional coastal communities (Magris; Marta-Almeida; Lentini, 2026).

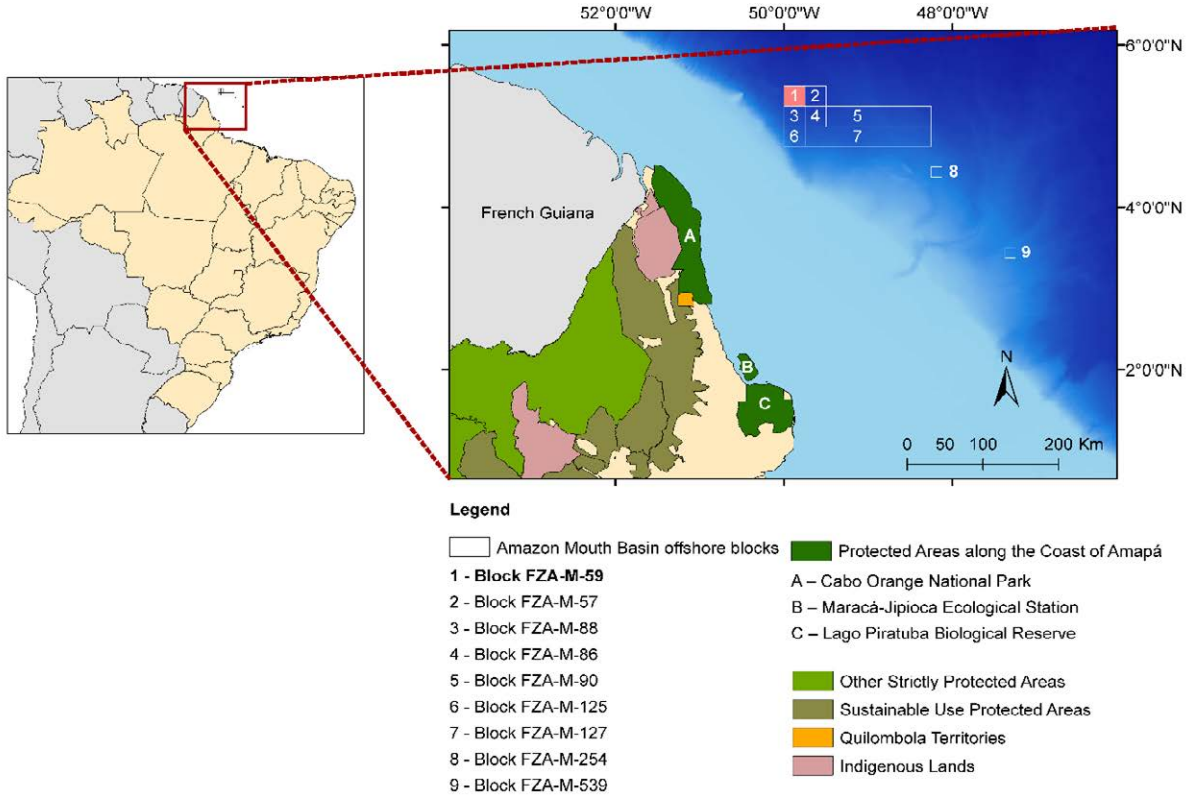

Figure 1 – Location of the study area

Source: Author's own elaboration (2026).

The management plans of these protected areas provide comprehensive socio-economic diagnoses of their surrounding areas, highlighting the presence of traditional communities, including riverine populations, artisanal fishers, and quilombola communities, whose livelihoods are closely linked to coastal and marine ecosystems. The documented economic activities include artisanal fishing, the harvesting of natural products under traditional management practices, and family-based agriculture, reflecting predominantly subsistence-oriented livelihoods (ICMBio, 2010, 2017, 2021).

The study area comprises extensive coastal and estuarine ecosystems that support high biodiversity and sustain traditional communities, making it one of the most socio-environmentally sensitive sectors of the Brazilian Equatorial Margin (Cerqueira; Silva, 2026; Magris; Marta-Almeida; Lentini, 2026). This ecological complexity coexists with increasing exposure to offshore oil-related pressures, as oil transport and dispersion are strongly influenced by wind forcing, tides, river discharge, and the North Brazil Current, which control cross-shelf connectivity and shoreline contamination pathways (Borges *et al.*, 2026). The vulnerability of this coupled coastal-marine system became evident during the 2019–2020 oil spill, which affected extensive portions of the Brazilian coastline and caused widespread ecological and socioeconomic impacts on mangroves, reef-associated habitats, fisheries, and coastal communities despite the relatively small volume of oil released (Borges *et al.*, 2026; Soares *et al.*, 2022).

2.2 METHODOLOGICAL PROCEDURES

This study adopts a qualitative documentary analysis approach (Bowen, 2009), guided by theoretical categories derived from the field of environmental justice. As technical and legal instruments for the management of protected areas, management plans play a central role in defining use zones, biodiversity protection strategies, and articulation with territorial public policies. The management plans of CONP (ICMBio, 2010), MJES (ICMBio, 2017), and LPBR (ICMBio, 2021) were analysed. In addition, the technical opinion that supported the denial of the environmental license for block FZA-M-59 by Ibama (2023a) was examined as a complementary source, serving as a reference for identifying risks, institutional gaps, and governance challenges relevant to the analysis of the management plans. The "Methodological Guidelines for the Preparation of Management Plans for Federal Protected Areas" (ICMBio, 2018) were adopted as an analytical benchmark, particularly regarding territorial integration, participatory management, and the incorporation of preventive approaches in response to external pressures and threats.

The documents were analysed based on the presence, absence, or ambiguity of elements related to the core dimensions of environmental justice, with the aim of identifying patterns, gaps, and contradictions in institutional discourses and proposals, as well as examining how these instruments incorporate principles of socio-environmental justice in the context of the proposed oil exploration in the Equatorial Margin. The analysis was structured around four analytical dimensions derived from the environmental justice literature (Acselrad, 2010; Fraser, 1998; Schlosberg, 2007; Schroeder *et al.*, 2008), operationalised through the indicators presented in Table 1. Each management plan was systematically coded according to these dimensions, allowing the identification of patterns, documentary gaps, and differences among the analysed management plans.

Table 1 – Operational indicators used for environmental justice analysis

Dimension	*Operational indicators*	*Documentary evidence*
Procedural justice	Participatory councils, consultations, workshops, communication channels	Participation mechanisms, stakeholder engagement, governance arrangements

Dimension	*Operational indicators*	*Documentary evidence*
Distributive justice	Risks, benefits, restrictions, compensation measures	Environmental impacts, zoning, conflict, risk allocation
Epistemic justice	Recognition of traditional/local knowledge	References to traditional knowledge, local knowledge, co-management, participatory diagnosis
Differential exposure	Vulnerable groups, cumulative risks, spatial exposure	Sensitive areas, vulnerable communities, proximity to risk sources

Source: Author's own elaboration (2026).

3 CONCEPTUAL FOUNDATIONS OF ENVIRONMENTAL JUSTICE APPLIED TO THE STUDY

The federal protected areas located along the coast of the state of Amapá are embedded in a geographical and social context marked by traditional communities (artisanal fishers, riverine populations, and Indigenous peoples) whose livelihoods depend directly on coastal and marine ecosystems (Chelala; Amazonas, 2025; Renck *et al.*, 2026). These communities maintain sustainable resource-use practices transmitted across generations but face land tenure insecurity, limited institutional representation, and socioeconomic vulnerability, which increase their exposure to external pressures (Silva *et al.*, 2022). Large-scale infrastructure and offshore oil projects may affect these territories through environmental impacts, access restrictions, changes in fishing dynamics, and intensified territorial conflicts (Duarte *et al.*, 2025; Magris; Marta-Almeida; Lentini, 2026; Renck *et al.*, 2026).

Environmental justice has expanded beyond the assessment of unequal distributions of environmental risks to encompass the institutional arrangements through which governance is designed and implemented. In coastal and marine contexts, this perspective also includes ecological distribution conflicts affecting traditional communities whose livelihoods depend directly on natural resources (Martínez-Alier, 2018), as well as participatory governance, recognition of traditional knowledge, and institutional capacity to address cumulative socio-environmental pressures, consistent with broader discussions on collective governance of common-pool resources (Ostrom, 2009). Management plans are therefore understood as conservation and governance instruments, capable of identifying vulnerabilities, anticipating socio-environmental conflicts, and supporting environmental decision-making.

Although the protected areas analyzed belong to the strict protection category which, under the Brazilian National System of Protected Areas (SNUC – Law No. 9,985/2000), prohibits permanent human occupation and the direct use of natural resources (Brasil, 2000), all the management plans examined acknowledge the historical and current presence of traditional communities in their surrounding zones and, in some cases, even within the original boundaries of the protected areas. This contradiction reflects what Diegues (2008, p. 55) terms the “modern myth of untouched nature,” according to which conservation would only be viable through the separation of society and nature, disregarding traditional and sustainable forms of territorial occupation and resource use. Accordingly, the extent to which management plans recognise local knowledge and participation varies among the protected areas analysed.

Against this background, the four dimensions of environmental justice (procedural, distributive, epistemic, and differential exposure to risks) provide the analytical framework adopted in this study to examine whether management plans incorporate participation, equitable risk distribution, local

knowledge, and differentiated territorial vulnerabilities into environmental governance. The following subsection discusses how these dimensions are reflected in the management plans examined in this study.

4. RESULTS AND DISCUSSION

4.1 DIMENSIONS OF ENVIRONMENTAL JUSTICE IN MANAGEMENT PLANS

4.1.1 PROCEDURAL JUSTICE

All three management plans analysed recognise social participation as a guiding principle for protected area governance. However, participation is implemented unevenly and remains predominantly consultative, with limited provision for continuous or deliberative engagement throughout the management cycle. This pattern is consistent with studies showing that participatory governance in protected areas often provides limited influence over environmental decision-making (Olaya-Restrepo; Schiavetti; Barbeitos, 2022; Ruano-Chamorro; Gurney; Cinner, 2022).

In the Management Plan of CONP, participation is promoted through Participatory Planning Workshops, stakeholder consultations, and a Consultative Council including Indigenous, quilombola, and local representatives. The plan also adopts adaptive management based on monitoring and periodic review. Nevertheless, decision-making remains consultative, without permanent co-management arrangements, reflecting a common limitation in protected area governance (Holland, 2017).

The MJES Management Plan adopts participatory planning, parity-based Consultative Council meetings, Open Meetings, and fishing agreements with local communities, integrating public contributions into the territorial diagnosis and zoning. These instruments strengthen dialogue and transparency but do not substantially reduce existing power asymmetries, reinforcing the argument that procedural justice depends on the effective incorporation of local priorities into governance (Renck *et al.*, 2026).

Among the analysed protected areas, LPBR presents the strongest procedural dimension, combining Participatory Planning Workshops, public meetings, a Consultative Council, working groups, and Terms of Commitment with traditional communities, including Vila Sucuriju. Although these mechanisms broaden participation and negotiated resource management, decision-making remains primarily consultative, in line with recommendations for collaborative environmental governance (Bennett *et al.*, 2025).

According to the Brazilian National Register of Protected Areas (CNUC), the three protected areas analysed have formally established Management Councils (Brasil, 2025). However, the management plans provide limited guidance on communication strategies, community outreach, and long-term engagement, restricting opportunities for effective participation by traditional populations. This finding supports critiques that formal participatory arrangements may reproduce existing inequalities when they are not accompanied by genuine opportunities for influence and co-management (Acselrad, 2010; Fraser, 1998; Holland, 2017; Schroeder *et al.*, 2008).

The licensing process for block FZA-M-59 reveals similar limitations. Official records do not indicate communication strategies specifically designed for potentially affected traditional communities. Although Ibama disseminated institutional information (Ibama, 2023b) and Petrobras reported meetings, public hearings, and a Social Communication Plan (Notícias, 2024), the available documentation does not allow assessing the extent to which these initiatives effectively reached traditional communities or enabled meaningful participation. Consequently, this study does not infer

legal non-compliance with Brazilian licensing requirements. Rather, it highlights that compliance with formal participatory procedures does not necessarily ensure effective engagement or the incorporation of local perspectives into environmental decision-making, a distinction that is central to procedural and epistemic environmental justice.

4.1.2 DISTRIBUTIVE JUSTICE

The management plans analysed include sections identifying pressures and threats to protected ecosystems. However, they give limited attention to how the risks and benefits associated with conservation and large-scale extractive projects are distributed among the different social groups that occupy and use these territories.

Within the scope of the CONP Management Plan, distributive justice is addressed indirectly. The plan emphasises environmental benefits, such as biodiversity protection, climate regulation, and hydrological maintenance, and mentions initiatives with potential local socio-economic gains. However, socio-environmental costs and restrictions disproportionately affect traditional, riverine, Indigenous, and quilombola populations, and conflicts related to fishing, buffalo ranching, and historical mining are not explicitly linked to distributive inequality (Jesus, 2026). This emphasis on collective conservation benefits, with limited consideration of differentiated social costs, reflects a pattern identified in protected area governance (Acselrad, 2010; Diegues, 2008).

In the MJES Management Plan, distributive justice is more explicit but not systematically articulated. The plan acknowledges both ecological benefits, seen by coastal communities as essential for fish stock maintenance, and unevenly imposed restrictions, such as limits on anchorage and competition with industrial fleets. Costs and environmental impacts are recognised as socially uneven, yet no compensatory mechanisms are defined. Similar patterns have been documented in studies showing that small-scale fishing communities often bear disproportionate conservation and development costs despite limited influence over marine resource governance (Cioffi; Gruber Sansolo, 2022; Reis-Filho; Hatje; Barros, 2024).

In the LPBR, distributive justice is more complex. The reserve generates collective environmental benefits but lacks mechanisms to secure territorial rights or socio-economic security for traditional populations. Land conflicts and economically dominant activities, such as extensive buffalo ranching, disproportionately affect residents, while hydroelectric developments on the Araguari River transfer additional environmental risks. Consequently, environmental pressures accumulate in communities with limited political and economic capacity, a pattern widely discussed in the environmental vulnerability literature (Adger, 2006).

Overall, the management plans tend to frame conservation benefits as collective goods, whereas the associated costs and restrictions fall disproportionately on historically vulnerable coastal communities. Environmental justice studies have documented similar inequalities in the distribution of environmental burdens among politically marginalised groups (Adger, 2006; Chemhuru, 2019; Fraser, 1998) and reinforce the need for closer articulation between environmental planning, energy planning, and territorial governance in areas subject to expanding extractive activities.

4.1.3 EPISTEMIC JUSTICE

Epistemic justice, understood in this study as the complementary integration of different knowledge systems into environmental management rather than their equivalence, manifests unevenly across the management plans analysed. Scientific and regulatory knowledge remain central to environmental licensing and protected area management, while local and traditional knowledge may contribute to

contextual understanding of socio-environmental dynamics and adaptive governance strategies (Eyraud *et al.*, 2023; Schlosberg, 2007). While all plans acknowledge the presence of traditional populations, the extent to which their knowledge informs diagnoses and management strategies differs substantially.

In the Management Plan of the MJES, epistemic justice is reflected in the integration of local knowledge into the territorial diagnosis, using regional terminology and residents' accounts to interpret environmental processes such as lake salinisation and fluvial changes. A section on the "Community Perspective" records local views of the island as a space of subsistence, shelter, and identity, indicating efforts to recognise local knowledge within management. This approach is consistent with studies showing that experiential knowledge strengthens environmental planning by improving the understanding of local ecological dynamics, particularly in coastal territories (Eyraud *et al.*, 2023; Silva *et al.*, 2022). However, local knowledge remains complementary rather than structuring, reflecting the persistence of technical-scientific approaches in protected area governance (Diegues, 2008; Schlosberg, 2007).

In the CONP Management Plan, epistemic justice is more limited. While the plan acknowledges sociocultural diversity and incorporates participatory surveys and cultural practices, these are mostly supplementary and do not structure management guidelines, which remain anchored in technical-scientific frameworks. This configuration reflects broader discussions emphasising that recognising local knowledge alone does not ensure its effective incorporation into environmental governance (Eyraud *et al.*, 2023; Schlosberg, 2007).

In the LPRB, epistemic justice is robust and systematic. Local knowledge guides ecological understanding and management strategies, with participatory tools such as perception mapping and recognition of selective traditional fishing practices. The plan legitimises local cosmologies and promotes participatory monitoring, integrating community knowledge with scientific rigour, thereby reducing knowledge hierarchies while maintaining technical-administrative oversight.

Taken as a whole, the analysis reveals the predominance of a technical-scientific rationality that, while indispensable for environmental management, often remains disconnected from local sociocultural contexts. This pattern reproduces what Diegues (2008) describes as the "modern myth of untouched nature" in which environmental protection is conceived through the exclusion or marginalisation of traditional knowledge systems. Accordingly, uneven incorporation of local knowledge may reduce the capacity of management plans to anticipate socio-environmental risks and support adaptive governance (Eyraud *et al.*, 2023).

4.1.4 DIFFERENTIAL EXPOSURE TO ENVIRONMENTAL RISKS

While distributive justice addresses how environmental risks and benefits are socially allocated, differential exposure to environmental risks concerns the extent to which particular social groups experience greater vulnerability to environmental impacts because of their geographic location, dependence on natural resources, socioeconomic conditions, and limited institutional protection (Jesus, 2026). In coastal protected areas, this dimension is particularly relevant because cumulative pressures associated with climate change and large-scale extractive activities tend to affect traditional communities disproportionately (Duarte *et al.*, 2025; IPCC, 2022; Magris; Marta-Almeida; Lentini, 2026; Renck *et al.*, 2026).

In the MJES Management Plan, differential exposure to risks is highlighted by the combination of geographic vulnerability and the socioeconomic fragility of traditional coastal communities. Offshore oil and gas projects, mercury contamination from inland mining, inadequate sanitation, feral buffalo impacts, and climate change-related coastal erosion increase local populations' susceptibility, affecting food security and mobility. This combination of environmental and social stressors reflects cumulative

vulnerabilities already documented for Amazonian fishing communities, where environmental change directly affects livelihoods and food security (Renck *et al.*, 2026; Silva *et al.*, 2022).

In CONP, communities near mining areas, such as Vila Brasil, face higher exposure to mercury contamination than urban populations, exacerbated by infrastructure and institutional asymmetries. Major infrastructure projects, like Highway BR-156 and the Oiapoque River bridge, further intensify cumulative environmental and socioeconomic risks. These conditions illustrate how territorial inequalities amplify environmental exposure, a pattern also reported for the Brazilian Equatorial Margin under expanding infrastructure and extractive activities (Chelala; Amazonas, 2025; Duarte *et al.*, 2025).

The LPBR addresses differential exposure most explicitly. Traditional populations in Sucuriju, Paratu, and Araquiçaua are highly vulnerable due to dependence on coastal and estuarine ecosystems. Threats include freshwater scarcity, mercury contamination, and external developments such as hydroelectric dams on the Araguari River, whose licensing ignored the lower river course. The plan also recognises the reserve's sensitivity to potential oil spills associated with offshore exploration in the Brazilian Equatorial Margin, as well as environmental pressures related to buffalo ranching and soybean expansion that threaten floodplain grasslands and native açaí groves essential for local livelihoods. The convergence of these pressures reinforces concerns about cumulative risks in protected coastal ecosystems located near prospective offshore oil blocks (Duarte *et al.*, 2025; Magris; Marta-Almeida; Lentini, 2026).

Overall, although the management plans broadly follow the methodological guidelines of the Chico Mendes Institute for Biodiversity Conservation (ICMBio, 2018), they incorporate differential exposure to environmental risks unevenly and remain weakly articulated with environmental licensing processes. This limitation is particularly evident in the treatment of emerging pressures associated with offshore oil exploration in the Equatorial Margin and the proximity of protected areas to exploration blocks such as FZA-M-59. Consequently, the plans have limited capacity to anticipate cumulative risks and support precautionary environmental decision-making. Environmental justice research has documented that cumulative environmental burdens are frequently concentrated in politically and socioeconomically marginalised coastal communities (Adger, 2006; Chemhuru, 2019; Fraser, 1998; Jesus, 2026).

4.2 MANAGEMENT PLANS IN PREVENTIVE ENVIRONMENTAL GOVERNANCE: THE FZA-M-59 LICENSING PROCESS

The study uses the licensing process of block FZA-M-59 as a reference to discuss the preventive role of management plans in environmentally sensitive coastal territories, without assessing the licensing process itself. Management plans are expected to identify socio-environmental vulnerabilities, support the anticipation of cumulative pressures, and provide information capable of informing environmental decision-making (ICMBio, 2018). When weakly articulated with licensing processes, however, their contribution to preventive environmental governance becomes limited.

Environmental licensing generates technical information that can support the periodic revision of management plans through adaptive management (ICMBio, 2018). Conversely, management plans provide territorial information that may improve the identification of cumulative impacts and local vulnerabilities during licensing. The limited institutional integration between these instruments reduces their capacity to anticipate socio-environmental risks (Bennett *et al.*, 2025; Cioffi; Gruber Sansolo, 2022). Given the inherent uncertainties associated with offshore oil exploration, including accidental oil spills, changes in fishing dynamics, intensified maritime traffic, and cumulative pressures on coastal livelihoods, preventive environmental governance should be guided by both the prevention and precautionary principles throughout the licensing process (Duarte *et al.*, 2025; Unesco, 2005).

This complementarity should not be interpreted as implying equivalent roles for different knowledge systems. Environmental licensing necessarily relies on standardised scientific evidence capable of

supporting technically robust and legally defensible decisions. Local and traditional knowledge, in turn, contributes by identifying territorial dynamics, cumulative pressures, and socially relevant information that may not be captured through conventional technical studies (Eyraud *et al.*, 2023; Schlosberg, 2007). Their incorporation therefore complements scientific evidence by contributing contextual and territorial information, strengthening preventive governance without compromising methodological consistency or legal certainty.

Ibama's denial of the FZA-M-59 drilling license in 2023 highlighted insufficient environmental data, high ecological sensitivity, limitations in emergency response capacity, the absence of a Strategic Environmental Assessment of Sedimentary Areas, and uncertainties regarding impacts on Indigenous peoples and traditional communities (Ibama, 2023a, 2023b). These issues are consistent with documentary gaps identified in the management plans, particularly regarding cumulative impacts, differentiated territorial vulnerabilities, and the articulation between conservation planning and environmental licensing. The subsequent approval of the license in 2025, following revisions to the Oiled Wildlife Protection and Response Plan and improvements in wildlife response infrastructure (Ibama, 2025a, 2025b), illustrates how preventive governance evolves through successive technical reviews. Nevertheless, the process also demonstrates the continuing need for stronger coordination between environmental licensing, protected area management, and sectoral policies in environmentally sensitive coastal territories. From a preventive governance perspective, management plans should provide strategic territorial information capable of supporting licensing decisions before cumulative pressures become more difficult to address.

Brazilian Bill No. 2,159/2021 was enacted as Ordinary Law No. 15,190/2025, renewing discussions on the balance between licensing efficiency, environmental safeguards, and public participation (Gomes; Braga, 2025). Meaningful public participation should be promoted whenever required by law or considered necessary by environmental authorities, particularly in licensing processes involving ecologically sensitive areas and traditional communities. These findings indicate that management plans and environmental licensing should operate as complementary instruments of preventive environmental governance, combining technical evidence with territorial knowledge to improve the anticipation of cumulative socio-environmental risks and support more informed environmental decision-making.

5 CONCLUSION

This article examined the coherence between the management plans of federal coastal protected areas in Amapá and Brazilian environmental policies in the context of offshore oil exploration in the Equatorial Margin. Based on documentary analysis guided by the dimensions of environmental justice, the study identified uneven incorporation of participatory mechanisms, differences in the recognition of local and traditional knowledge, and limited articulation between management planning and environmental licensing processes. The findings reveal differences in how environmental justice principles are incorporated across the analysed management plans, instead of pointing to structural failures in environmental governance. The documentary analysis shows that, although these instruments establish relevant normative commitments, consideration of public participation, local and traditional knowledge, and cumulative socio-environmental risks remains uneven across the planning documents. These documentary gaps may limit the preventive capacity of management plans, particularly in contexts where protected areas are increasingly exposed to multiple environmental pressures associated with large-scale infrastructure and offshore oil development.

The analysis supports the usefulness of environmental justice as an analytical framework for examining environmental planning instruments in contexts characterised by institutional fragmentation and socio-environmental complexity. They also highlight opportunities to strengthen coordination between protected area planning and environmental licensing, improve communication with local communities,

and foster more systematic consideration of local and traditional knowledge and cumulative socio-environmental risks during future revisions of management plans. The study also suggests that greater integration between environmental planning and licensing processes may enhance the capacity of management plans to anticipate cumulative socio-environmental risks and support more informed decision-making in regions undergoing the expansion of offshore oil activities.

As this study is based exclusively on documentary analysis, it does not evaluate the implementation of management plans or the effectiveness of environmental licensing in practice. Future research may complement these findings through field-based investigations and stakeholder engagement.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

The authors used OpenAI, GPT-5.5-mini for language editing and stylistic polishing only. All scientific content, analysis, and intellectual input were developed and verified by the authors; we take full responsibility for the accuracy and integrity of the manuscript.

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Assessing municipal solid waste management plans through an SDG adherence index: an evidence-based approach

Avaliação de planos de gestão de resíduos sólidos urbanos por meio de um índice de aderência aos ods: uma abordagem baseada em evidências

Thomas Leonardo Marques de Castro Leal [1]

Thaynara Batista Reis [2]

Letícia Santos Borges [3]

José Gustavo Venâncio da Silva Ramos [4]

Marcela Leão Domiciano [5]

[1] PhD in Development and Environment, Professor, Department 2, Instituto Federal de Educação, Ciência e Tecnologia de Goiás, Goiânia, GO, Brazil
E-mail: thomas.leal@ifg.edu.br

[2] Undergraduate degree in Environmental and Sanitary Engineering, Instituto Federal de Educação, Ciência e Tecnologia de Goiás, Goiânia, GO, Brazil
E-mail: thaynarareisb@gmail.com

[3] Undergraduate degree in Environmental and Sanitary Engineering, Instituto Federal de Educação, Ciência e Tecnologia de Goiás, Goiânia, GO, Brazil
E-mail: leticia.borges@estudantes.ifg.edu.br

[4] Master's in Civil Engineering, Professor, Departamento 3, Instituto Federal de Educação, Ciência e Tecnologia de Goiás, Goiânia, GO, Brazil
E-mail: jose.ramos@ifg.edu.br

[5] PhD in Geotechnics, Professor, Department 3, Instituto Federal de Educação, Ciência e Tecnologia de Goiás, Goiânia, GO, Brazil
E-mail: marcela.domiciano@ifg.edu.br

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ABSTRACT

The objective of this study was to develop and apply an evidence-based Sustainable Development Goals (SDG) Adherence Index to evaluate Municipal Solid Waste Management Plans across 34

municipalities in Goiás, Brazil. The methodology combines literature review, expert-based weighting using the Rank Order Centroid (ROC) method, and a structured assessment of the evidence type (declarative, operational, and measurable). The results reveal substantial heterogeneity, with only 41% of the municipalities presenting adherence greater than 50%. Although the operational dimensions show higher adherence, the plans incorporate elements related to social integration and monitoring to a more limited extent. The findings highlight a structural mismatch between normative priorities and municipal planning capacity, indicating that compliance with Brazil's National Solid Waste Policy is necessary but insufficient for advancing the 2030 Agenda. High adherence scores are often driven by declarative elements rather than implementation-oriented evidence. The study contributes a replicable framework for evaluating policy instruments based on evidence quality, offering insights for improving municipal planning and supporting more effective sustainability governance.

Keywords: Solid Waste Management. Sustainable Development Goals. Policy Adherence. Municipal Planning. Environmental Governance.

RESUMO

O objetivo deste estudo foi desenvolver e aplicar um Índice de Aderência aos Objetivos do Desenvolvimento Sustentável (ODS) baseado em evidências para avaliar Planos Municipais de Gestão de Resíduos Sólidos em 34 municípios de Goiás, Brasil. A metodologia combina revisão bibliográfica, ponderação baseada em especialistas utilizando o método Rank Order Centroid (ROC) e uma avaliação estruturada do tipo de evidência (declarativa, operacional e mensurável). Os resultados revelam uma heterogeneidade substancial, com apenas 41% dos municípios apresentando aderência superior a 50%. Embora as dimensões operacionais apresentem maior aderência, os planos incorporam de forma mais limitada elementos relacionados à inclusão social e ao monitoramento. Os achados destacam um descompasso entre as prioridades atribuídas pelos especialistas e o conteúdo documental dos planos, indicando que a conformidade com a Política Nacional de Resíduos Sólidos brasileira é necessária, mas insuficiente para o avanço da Agenda 2030. Altos índices de aderência são frequentemente impulsionados por elementos declarativos em vez de evidências orientadas à implementação. O estudo contribui com um arcabouço replicável para a avaliação de instrumentos de políticas públicas com base na qualidade das evidências, oferecendo insights para aprimorar o planejamento municipal e apoiar uma governança da sustentabilidade mais eficaz.

Palavras-chave: *Gestão de Resíduos Sólidos. Objetivos de Desenvolvimento Sustentável. Cumprimento de Políticas. Planejamento Municipal. Governança Ambiental.*

1 INTRODUCTION

Municipal solid waste (MSW) management represents a critical global challenge, with approximately 2.1 billion tonnes generated annually worldwide (Unep, 2024). Inadequate waste management practices cause significant environmental and public health impacts, including water, air, and soil pollution, as well as increased risks of respiratory and psychosocial disorders (Mor; Ravindra, 2023). These challenges are particularly acute in developing countries, where institutional and infrastructure constraints hinder the implementation of effective waste management systems (Siddiqua; Hahladakis; Al-Attiya, 2022).

In Brazil, MSW generation reached 81 million tonnes in 2023, with approximately 7 million tonnes disposed of improperly (Abrema, 2024). Despite the existence of the National Solid Waste Policy (*Política Nacional de Resíduos Sólidos* – PNRS, in Portuguese), which establishes regulatory guidelines for waste management, 36.6% of municipalities still rely on improper disposal methods, such as open dumps and controlled landfills (IBGE, 2024). This situation highlights a persistent gap between formal regulatory frameworks and their effective implementation at the local level.

Municipal Integrated Solid Waste Management Plans (*Planos Municipais de Gestão Integrada de Resíduos Sólidos* – PMGIRS, in Portuguese) constitute the primary institutional instrument for operationalising PNRS guidelines at the municipal level. In addition to being legally required, these plans are a prerequisite for access to federal funding and financial incentives related to urban cleaning and waste management services (Brasil, 2010, 2022). However, the mere existence of these plans does not necessarily ensure their quality, consistency, or effectiveness in addressing broader sustainability challenges.

In parallel, the growing incorporation of the Sustainable Development Goals (SDGs) into public policies has reinforced the need for integrated and cross-sectoral approaches to waste management. Solid waste management is directly linked to multiple SDGs, particularly those related to health (SDG #3), sustainable cities (SDG #11), responsible consumption and production (SDG #12), and climate action (SDG #13), reflecting its inherently cross-cutting nature (Elsheekh *et al.*, 2021). Although previous studies suggest conceptual convergence between Brazilian environmental policies and the SDGs, major structural limitations, such as low waste sorting and collection rates, continue to hinder progress toward these goals (Dantas; Fontgalland, 2021; Martins; Borges; Zaneti, 2025).

Given the central role of municipalities in implementing both national policies and international commitments, adherence to the SDGs becomes a critical issue. However, the available assessment tools have important limitations. Instruments such as the Sustainable Cities Development Index (IDSC-BR) assess municipal performance based on SDG indicators but do not specifically examine how planning instruments, such as PMGIRS, incorporate elements associated with the SDGs (Wissmann; Backes, 2022). Moreover, the localisation and monitoring of the SDGs at the Brazilian municipal level are constrained by limitations in the availability, transparency, territorial disaggregation, and standardisation of public information, as well as by technical and institutional weaknesses in information systems (Lindoso *et al.*, 2021). These limitations reinforce the need for assessment procedures capable of distinguishing general references to the SDGs from operational and measurable evidence within municipal planning instruments

Likewise, guidelines developed by institutions such as the National Confederation of Municipalities (CNM) and the Local2030 Coalition provide normative guidance for SDG localisation but lack operational and quantitative mechanisms for assessing adherence at the plan level (CNM, 2017).

This reveals a specific methodological gap: the absence of structured and quantitative tools capable of systematically assessing the degree to which municipal solid waste management plans adhere to the SDGs while also considering the quality and strength of the underlying evidence. To address this gap, this study developed and applied an SDG Adherence Index structured around weighted indicators and evidence classification. The index was built through a literature review and expert-based weighting using the Rank Order Centroid (ROC) method and was applied to 34 municipalities in the state of Goiás, Brazil, to assess its analytical potential and empirical applicability.

2 METHODOLOGY

The methodology was divided into four stages. In the first stage, a document search was conducted in Google Scholar to map the relationships between the PNRS and the SDGs. The terms ("National Solid Waste Policy" OR "PNRS") AND ("Sustainable Development Goals" OR "SDGs") were combined. Studies in Portuguese published from 2015 onward were included, with no final-year limit. After screening by title and abstract, the full texts were assessed regarding their analysis of the relationship between the PNRS and the SDGs.

In the second stage, the weighting stage, 15 people with experience in the public, private, and self-employed sectors were invited to ensure a balanced sample. Due to its nature, this study was submitted

to the IFG Research Ethics Committee, linked to the National Health Council, and approved (CAAE: 88705925.9.0000.8082). Participants therefore signed the Informed Consent Form, agreeing to take part in the research. The questionnaire was divided into two parts. First, the experts were asked to rank the importance of the axes. Then, for each axis, they ranked the corresponding criteria. All axes and criteria are described in Table 2 in Results and Discussion (Section 3).

Among the experts interviewed, 26.7% work in direct public administration, 33.3% in private environmental consulting, and 40% in academia or as researchers, all with five or more years of experience in the solid waste sector. The diversity of participants was important for integrating different perspectives on the topic and perceptions from different sectors.

The Rank Order Centroid (ROC) method was used to aggregate the experts' individual preferences and generate a consensus ranking. The ROC method is particularly appropriate in contexts in which decision-makers provide preference rankings but do not express the relative intensity between criteria (Ahn, 2011). In these cases, ROC produces weight estimates that represent the expected value of preferences within the space of all possible distributions compatible with the ranking provided.

ROC performs well in terms of robustness, especially in situations of uncertainty or inconsistency in individual preferences, and is widely used as a reliable approximation when cardinal data are unavailable (Hatefi, 2023). Unlike methods based on pairwise comparisons, ROC has lower operational complexity and reduces the possibility of logical inconsistencies in responses, making it more suitable for applications with multiple criteria and a limited number of experts (Roszkowska, 2013). Equation 1 represents the ROC method, aggregating expert preferences and producing a consensus ranking from the different opinions.

$$W_k = \frac{1}{n}\sum_{i=k}^{n}\frac{1}{i} \qquad (1)$$

where is the total number of axes/criteria and is the ranking position.

In the third stage, PMGIRS or Municipal Basic Sanitation Plans (*Planos Municipais de Saneamento Básico* – PMSB, in Portuguese) from 34 municipalities in the state of Goiás were evaluated. The document universe was delimited based on the survey conducted by Borges *et al.* (2025), a study developed by the same authors that mapped all publicly available municipal solid waste management plans in the state. Thus, the municipalities were not selected because they had previously been included in that study; rather, the earlier survey was used to comprehensively identify existing plans available online. Using the same set of documents also enabled comparison between plan alignment with the PNRS, examined in the previous study, and alignment with the SDGs, assessed in the present research. It should be emphasised that the analysis is restricted to plan content and does not allow the effective implementation of the actions and policies described therein to be inferred.

This stage was conducted in four steps through technical content analysis of the plans and assignment of compliance scores to each defined criterion. The plans were analysed to identify how their content expressed the criterion being assessed. Once the content had been identified, it was evaluated in terms of evidence type and evidence strength, leading to the adherence score.

The dimensions "evidence type" and "evidence strength" play distinct and complementary analytical roles. Evidence type (declarative, operational, or measurable) characterises the nature of the information: whether it expresses an intention, describes an action, or presents quantitative data. Evidence strength (weak, moderate, or robust) assesses the degree of detail with which that information is presented in

the plan, considering the presence of concrete data, targets, or indicators. The combination of these two dimensions determines the score assigned to each criterion, as systematised in Table 1.

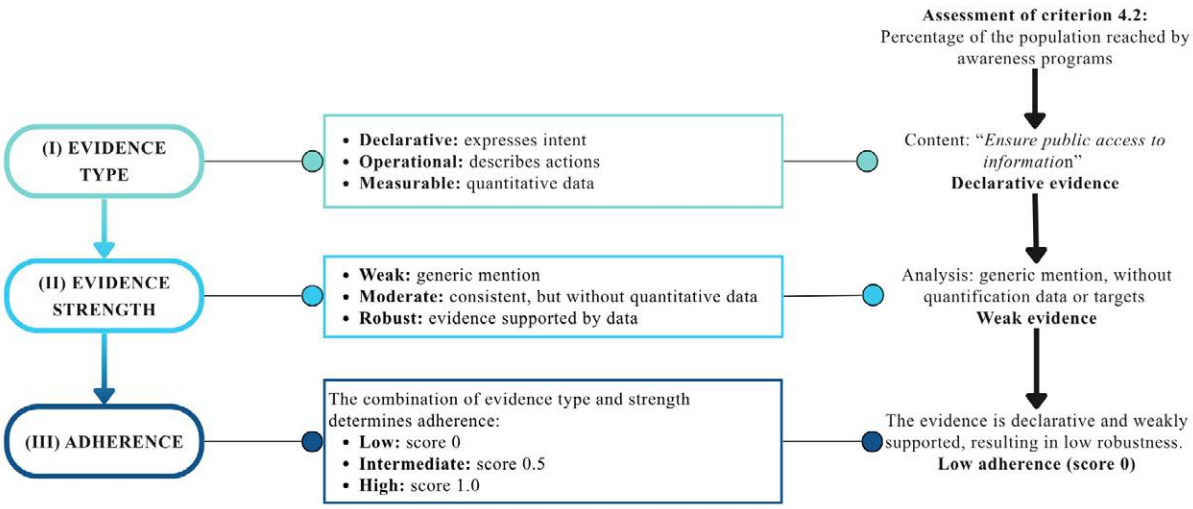

Figure 1 – Stages for evaluating evidence in municipal plans (PMGIRS/PMSB), applied to a sample criterion

Source: The authors.

The fourth and final step was the calculation of the Final Adherence Index (FAI), Equation 2, using a hierarchical weighting process that combines criterion scores and their respective weights. To allow comparison across different studies, this score was normalised as a percentage of alignment with the SDGs (from 0 to 100%).

$$FAI = \sum_{i=1}^{n} \left(W_i \sum_{j=1}^{m} (w_{ij} . s_{ij}) \right) \text{x } 100 \qquad (2)$$

where is the Final Adherence Index (%), is the weight of axis *i*, is the weight of criterion within axis , and is the adherence score.

Table 1 – Items used to assess municipal plan adherence to the SDGs

Evidence Type	*Evidence Strength*	*Description of the Combination*	*Adherence Level*	*Score*
Declarative	Weak	Generic mention of intent without specific actions or data	Low	0
Declarative	Moderate	Consistently expressed intent, but without concrete actions or data	Intermediate	0.5
Declarative	Strong	Intent supported by data, but only at the conceptual level	Intermediate	0.5
Operational	Weak	Description of generic actions without specifications or details	Intermediate	0.5
Operational	Moderate	Well-described and consistent actions, but without quantitative indicators	High	1
Operational	Strong	Specific actions with data monitoring and indicators	High	1

Evidence Type	*Evidence Strength*	*Description of the Combination*	*Adherence Level*	*Score*
Measurable	Weak	Presentation of generic data or data without clear context	Intermediate	0.5
Measurable	Moderate	Consistent quantitative data relevant to the SDGs	High	1
Measurable	Strong	Robust data with a clear methodology and monitoring guidelines	High	1

Source: The authors.

3 RESULTS AND DISCUSSION

3.1 CONCEPTUAL MAPPING

Previous studies that examined relationships between the PNRS and the SDGs were used as references for constructing the conceptual mapping (Cabral *et al.*, 2024; Farias *et al.*, 2022; Trigo *et al.*, 2023). Based on these references, the objectives and principles of the PNRS were systematically compared with the targets of the 2030 Agenda to identify thematic correspondences between the two frameworks. For example, the PNRS establishes as an objective the "non-generation, reduction, reuse, recycling, and treatment of solid waste, as well as the environmentally sound final disposal of rejects" (Brasil, 2010, art. 7, II), which corresponds to SDG target 12.5, aimed at reducing waste generation through prevention, reduction, recycling, and reuse. This procedure supported the structuring of the seven axes and 31 criteria used in subsequent stages of the research.

Figure 2 presents the conceptual mapping between the dimensions of the proposed index and the selected SDGs. This alignment was established based on thematic correspondence between each dimension, the SDG targets, and the literature reviewed in this study. The mapping does not imply direct measurement of SDG performance; rather, it indicates each dimension's potential contribution to specific targets.

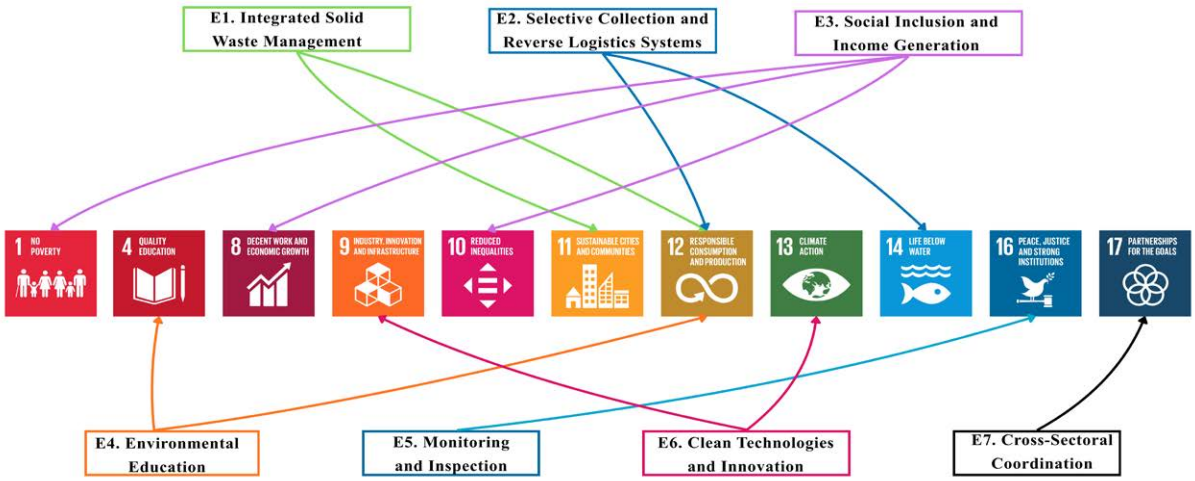

Figure 2 – Conceptual map linking the index axes and the SDGs

Source: The authors.

3.2 WEIGHTS OF AXES AND CRITERIA

Based on the experts' responses and the ROC method, a clear hierarchy of priorities was established for aligning PMGIRS/PMSB plans with the SDGs, as shown in Table 2. Axis E3 (Social Inclusion and Income Generation) received the highest weight, followed by E1 (Integrated Solid Waste Management), whereas E6 (Clean Technologies and Innovation) was considered the least relevant. This detailed hierarchy extended to the criterion level, revealing specific priorities within each thematic area.

The low relevance assigned to technological innovation should not be interpreted as a rejection of modernisation, but rather as a diagnosis of urgency: in the Brazilian context and in other Global South countries, technology without social inclusion tends to reproduce inequalities and remain unsustainable (Da Silva; Bolson, 2018; Marello; Helwege, 2018; Rutkowski; Rutkowski, 2015; Zisopoulos *et al.*, 2023). This perspective supports the view that waste management is primarily a human and institutional challenge, rather than strictly a technical or engineering problem (Gutberlet; Carenzo, 2020; Marshall; Farahbakhsh, 2013; Wilson; Velis; Rodic, 2013).

Table 2 – Expert weighting of axes and criteria

Axis	*Weight*	*Criteria*	*Weight*
E1. Integrated Solid Waste Management	0.228	1.1 Existence of waste-reduction initiatives/programs.	0.228
		1.2 Existence of waste-reuse initiatives/programs.	0.156
		1.3 Existence of environmentally sound final disposal for waste.	0.370
		1.4 Percentage of environmentally sound final disposal for waste (recycling, composting, etc.) above the national average.	0.073
		1.5 Percentage of environmentally sound final disposal for inert waste above the national average.	0.020
		1.6 Percentage of the population served by the conventional collection system above the national average.	0.109
		1.7 Existence of an environmentally sound final disposal method for inert waste (sanitary landfill, incineration).	0.044
E2. Selective Collection and Reverse Logistics Systems	0.156	2.1 Percentage of the population served by selective collection above the national average.	0.146
		2.2 Quantity of waste collected selectively above the national average.	0.270
		2.3 Existence of reverse logistics systems.	0.521
		2.4 Quantity of waste originating from the reverse logistics system above the national average.	0.063
E3. Social Inclusion and Income Generation	0.370	3.1 Reports the number of recyclable-material waste-picker cooperatives integrated into the waste management system.	0.146
		3.2 Percentage of recyclable waste sent to cooperatives.	0.521
		3.3 Income earned by recyclable-material waste pickers from the sale of recyclable materials.	0.270
		3.4 Existence of training and support programs for recyclable-material waste pickers.	0.063
E4. Environmental Education	0.073	4.1 Number of environmental education campaigns conducted with a focus on waste-related issues.	0.146
		4.2 Percentage of the population reached by awareness programs	0.270
		4.3 Existence of educational materials on waste management.	0.063
		4.4 Actions in schools through environmental education.	0.521

Axis	*Weight*	*Criteria*	*Weight*
E5. Monitoring and Regulatory Enforcement	0.109	5.1 Existence of periodic waste-management reports (transparency principle).	0.270
		5.2 Inspection plan for disposal and final-destination methods.	0.521
		5.3 Monitoring of the quantity of hazardous waste properly treated	0.063
		5.4 Monitoring of the percentage of hazardous waste properly treated.	0.146
E6. Clean Technologies and Innovation	0.020	6.1 Existence of composting or anaerobic digestion projects.	0.270
		6.2 Percentage of organic waste treated using clean technologies.	0.146
		6.3 Percentage of recyclable waste treated using clean technologies.	0.063
		6.4 Investment/incentives for actions and research into new waste final-destination technologies.	0.521
E7. Cross-Sectoral Coordination	0.044	7.1 Existence of public-private partnerships and joint waste-management actions or arrangements.	0.270
		7.2 Existence of signed sectoral agreements (municipalities).	0.146
		7.3 Civil society participation in waste-management committees or forums.	0.063
		7.4 Municipal government partnership with other agencies (Attorney General's Office, Public Defender's Office, etc.).	0.521

Source: The authors.

However, in the Brazilian context, infrastructure limitations, low selective collection coverage, and limited capacity for material recovery and treatment continue to constrain the performance of municipal waste-management systems (Cetrulo *et al.*, 2018; Oliveira; Klafke; Chaerki, 2021; Paes *et al.*, 2024; Rebehy *et al.*, 2023). Thus, the lower weight assigned to clean technologies and innovation does not mean that investments in sorting, composting, anaerobic digestion, and monitoring systems are dispensable. Rather, the result indicates that experts considered it more urgent to ensure social inclusion and strengthen integrated management, while technological modernisation should be articulated with these priorities. In the context of the municipalities in Goiás analysed, this interpretation is particularly relevant given the low level of operational and measurable evidence related to waste treatment and recovery.

The higher weight of Axis E3 (Social Inclusion and Income Generation) reflects the priority assigned by experts. However, municipalities perform more poorly precisely on this axis and achieve higher results in dimensions with lower weights. This divergence between normative priority and plan content is discussed in the following section.

The analysis of Axis E1 (Integrated Solid Waste Management) illustrates the operational and regulatory pressures that influence the relative importance of certain themes. The New Legal Framework for Sanitation (Law N. 14,026/2020) introduced strict universalisation and economic-financial sustainability targets, pressuring managers to address the most visible aspects of urban waste (Brasil, 2020). However, studies show that indicators such as recyclable-material recovery rates, effective selective-collection coverage, and inclusion of recyclable-material waste pickers generally remain low even after structured plans are implemented (Cetrulo *et al.*, 2018; Oliveira; Klafke; Chaerki, 2021). This suggests that regulatory compliance, even when framed as integrated management, often results in an institutional checklist rather than substantial structural transformation (Berticelli; Pandolfo; Korf, 2016; Paes *et al.*, 2024).

3.3 INTERPRETATION OF RESULTS IN LIGHT OF SDG ADHERENCE

After the weighting stage, this study examines how the identified priorities are reflected in municipal planning practices. Figure 3 presents PMGIRS/PMSB adherence across municipalities and axes in relation to the SDGs, where 0% represents the lowest score and 100% the highest. The values shown are weighted results and should therefore be interpreted in light of the weights assigned during the expert-based weighting stage. This limitation is not restricted to the formulation of municipal plans. Empirical evidence indicates that public recognition of the environmental benefits of selective collection does not necessarily translate into willingness to finance or otherwise support the service, suggesting a gap between favourable environmental perceptions and effective participation (Feitosa *et al.*, 2018).

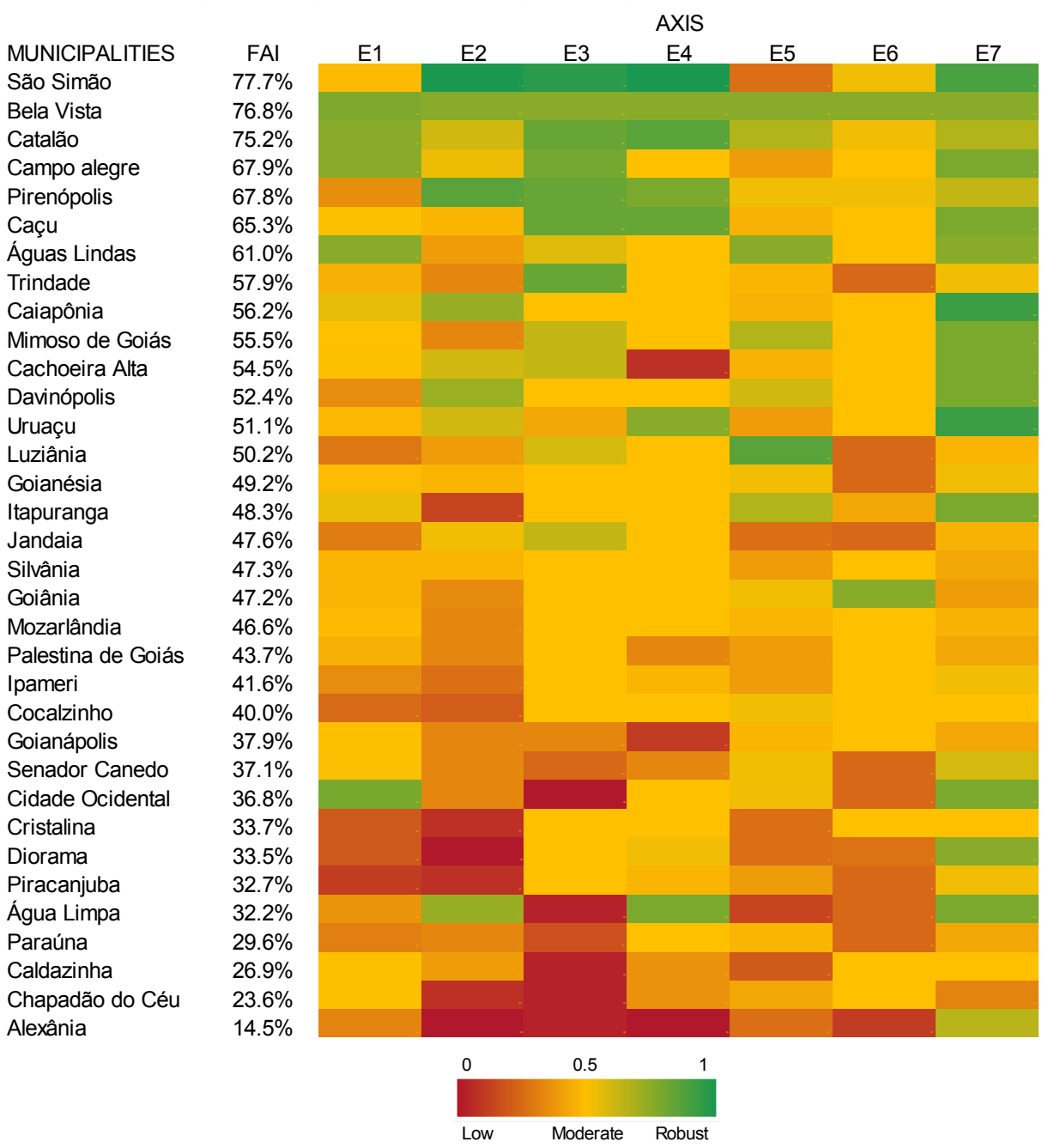

Figure 3 – Overall PMGIRS/PMSB performance of each municipality across the axes

Source: The authors.

Of the 34 PMGIRS/PMSB plans analysed, only 14 (41.2%) reached adherence levels above 50%, indicating that most plans do not consistently incorporate elements associated with the SDGs. This result highlights both the limited structural dissemination of these guidelines and strong heterogeneity across municipalities.

The conceptual mapping between the index dimensions and the selected SDGs (Figure 2) provides an analytical lens for interpreting municipal performance beyond the internal structure of the index. Rather than treating each dimension as an isolated component, this framework allows a broader understanding of how the observed strengths and weaknesses reflect systemic sustainability challenges associated with the 2030 Agenda.

Regarding Axis E1 (Integrated Solid Waste Management), aligned with SDGs 11 and 12, the results indicate relatively higher performance across all municipalities. This reflects the prioritisation of operational aspects, such as waste-collection coverage and environmentally sound disposal, which are strongly driven by regulatory requirements. By contrast, Axis E2 (Selective Collection and Reverse Logistics Systems), associated with SDGs 12 and 14, shows consistently low adherence levels. Low adherence on this axis indicates that the plans incorporate or detail elements related to material recovery and the structuring of reverse logistics only to a limited extent.

Regarding Axis E3 (Social Inclusion and Income Generation), linked to SDGs 1, 8, and 10, despite being the dimension with the highest weight, it shows one of the lowest performance levels. This finding reinforces a structural mismatch between normative priorities and the effective planning capacity of municipal plans. Axis E4 (Environmental Education), associated with SDGs 4 and 12, shows moderate performance. Municipal plans frequently include awareness campaigns and educational initiatives, particularly in schools.

Axis E5 (Monitoring and Inspection), linked to SDG 16, shows consistently low adherence across municipalities. The plans provide limited documentary evidence regarding monitoring systems, inspection mechanisms, and data disclosure. In turn, Axis E6 (Clean Technologies and Innovation), associated with SDGs 9 and 13, shows low and highly variable performance. The results indicate limited incorporation in plan content of actions, targets, and indicators related to composting, anaerobic digestion, and other treatment technologies.

Axis E7 (Cross-Sectoral Coordination), aligned with SDG 17, shows the highest adherence levels. However, this result should be interpreted cautiously, as it may reflect declarative or formal commitments rather than the existence of effective coordination mechanisms.

3.4 CRITICAL ANALYSIS OF PMGIRS/PMSB ADHERENCE

The results by axis (Figure 3) reveal a discrepancy between the normative hierarchy and empirical performance: E3, which has the greatest weight, is among the worst-performing axes, whereas E7, which has the lowest weight, shows the best results. Because the Final Adherence Index is a weighted sum, high scores on less-prioritised axes may partially compensate for deficits in critical dimensions. This is the compensability problem of composite indices (Greco *et al.*, 2019; OECD, 2008). The aggregate value should therefore be interpreted together with the axis-level profile, because similar index values may result either from balanced performance or from scores concentrated in predominantly declarative dimensions.

Comparison with adherence to the PNRS (Borges *et al.*, 2025) shows a positive but non-linear relationship. Pirenópolis and Bela Vista de Goiás perform well under both frameworks, whereas Mozarlândia and Piracanjuba combine higher legal compliance with only moderate SDG adherence. This indicates that

operational PNRS requirements do not ensure incorporation of broader sustainability dimensions, which are often supported only by declarative commitments.

Municipal size likewise does not explain performance: São Simão outperforms Goiânia and Senador Canedo, suggesting that resources and scale do not ensure greater adherence (Choi, 2021; Koop *et al.*, 2017). Local capacity combines administrative, fiscal, and political-institutional dimensions that may not evolve jointly (Aguiar; Lima, 2019). Integrated governance and cross-sectoral coordination therefore tend to be more decisive for socio-environmental planning (Paes; Oliveira, 2021; Rebehy *et al.*, 2023; Siman *et al.*, 2023).

The high adherence of E7 appears to derive mainly from expressions such as "partnerships," "shared responsibility," and "social participation," often without institutional, financial, or operational detail. This reveals a gap between discursive alignment and implementation capacity (Yan; Ramesh, 2026; Ye; Gao; Wu, 2024). By contrast, E5 and E6 require procedures, infrastructure, targets, and indicators, which explains their lower adherence and greater dependence on operational and measurable evidence.

In E3, low-to-moderate performance does not represent documentary shortcomings alone. The low-to-moderate performance of Axis E3 does not represent only a documentary weakness. The effective inclusion of waste pickers depends on income, infrastructure, formal agreements, continuity of activities, and adequate occupational and health conditions. Waste pickers commonly remain embedded in contexts of social vulnerability in which socioeconomic, educational, and occupational factors affect their quality of life (Vasconcelos *et al.*, 2018). Without these mechanisms, plans may reproduce social exclusion and environmental injustice (Da Silva; Bolson, 2018; Ferreira, 2024; Silva; Araújo; van Elk, 2024; Zon *et al.*, 2020). Although declarative commitments exist, structured programs, institutional arrangements, and income or participation indicators are rare. This pattern maintains a technocratic approach centred on logistics, with limited integration of waste pickers and cooperatives (Buch *et al.*, 2021; Cabral *et al.*, 2024).

The contrast between E1 and E3 reinforces this interpretation. Even among municipalities with lower overall performance, collection, disposal, and infrastructure receive more attention than inclusion and income generation. Thus, relatively high E1 results, such as those observed in Cidade Ocidental and Caldazinha, may reflect the provision of urban cleaning services without productive inclusion of waste pickers (Galdino *et al.*, 2024; Madureira; Candiani, 2025). This gap is especially relevant because these workers contribute to the circular economy, decent work, and SDGs 8, 11, and 12 (Alves; Costa, 2025).

Axis E5 shows low adherence and an almost complete absence of indicators, monitoring systems, and reporting mechanisms, limiting policy evaluation and learning (Elsheekh *et al.*, 2021; Rashed, 2025). Axis E2 records the lowest average, indicating weakness in selective collection and integration with reverse logistics. This limitation reduces material recovery and social inclusion and hinders progress toward SDG 11 (Martins; Borges; Zaneti, 2025). Although the plans mention reverse logistics and shared responsibility, operational mechanisms and measurable targets are lacking (Barbosa; Gonçalves; Simões, 2025; Santiago, 2024).

4 CONCLUSIONS

The SDG Adherence Index identifies how elements of the 2030 Agenda are incorporated into and supported by documentary evidence in PMGIRS/PMSB plans. Its application to 34 municipalities in Goiás showed that PNRS compliance is necessary but does not ensure SDG alignment, because the two frameworks represent distinct dimensions. The results compare plans and axes without allowing isolated inferences regarding legal compliance, overall quality, institutional capacity, or implementation.

Only 41% of the municipalities exceeded 50% adherence. E3 (Social Inclusion and Income Generation), the highest-weighted axis, showed low performance, while E7 (Cross-Sectoral Coordination) concentrated

the highest scores. This indicates that plans incorporate governance principles mainly in declarative form but struggle to translate them into operational and measurable mechanisms. Municipal size also did not determine performance: smaller municipalities outperformed larger centres, suggesting a greater influence of institutional capacity, governance, and political commitment.

The results must be interpreted in light of four limitations: the weights reflect the composition of the expert sample; the public availability of plans may favour more transparent municipalities; document analysis does not demonstrate implementation; and the additive structure permits compensation across axes. Thus, a low score means lower documentary incorporation of elements associated with the SDGs, not non-compliance with the PNRS or low municipal capacity.

Future research should expand and diversify the expert sample, test alternative aggregation methods (including non-compensatory approaches), apply the index in other regions, and integrate implementation indicators with plan content.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

The authors used ChatGPT (GPT-5.6 Thinking, OpenAI) for language editing and stylistic polishing only. All scientific content, analysis, and intellectual input were developed and verified by the authors; the authors take full responsibility for the accuracy and integrity of the manuscript.

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Avaliação de planos de gestão de resíduos sólidos urbanos por meio de um índice de aderência aos ODS: uma abordagem baseada em evidências

Assessing municipal solid waste management plans through an SDG adherence index: an evidence-based approach

Thomas Leonardo Marques de Castro Leal [1]

Thaynara Batista Reis [2]

Letícia Santos Borges [3]

José Gustavo Venâncio da Silva Ramos [4]

Marcela Leão Domiciano [5]

[1] Doutorado em Desenvolvimento e Meio Ambiente, Professor, Departamento 2, Instituto Federal de Educação, Ciência e Tecnologia de Goiás, Goiânia, GO, Brasil
E-mail: thomas.leal@ifg.edu.br

[2] Graduação em Engenharia Ambiental e Sanitária, Instituto Federal de Educação, Ciência e Tecnologia de Goiás, Goiânia, GO, Brasil
E-mail: thaynarareisb@gmail.com

[3] Graduação em Engenharia Ambiental e Sanitária, Instituto Federal de Educação, Ciência e Tecnologia de Goiás, Goiânia, GO, Brasil
E-mail: leticia.borges@estudantes.ifg.edu.br

[4] Mestrado em Engenharia Civil, Professor, Departamento 3, Instituto Federal de Educação, Ciência e Tecnologia de Goiás, Goiânia, GO, Brasil
E-mail: jose.ramos@ifg.edu.br

[5] Doutorado em Geotecnia, Professor, Departamento 3, Instituto Federal de Educação, Ciência e Tecnologia de Goiás, Goiânia, GO, Brasil
E-mail: marcela.domiciano@ifg.edu.br

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ARTICLE - VARIA

RESUMO

O objetivo deste estudo foi desenvolver e aplicar um Índice de Aderência aos Objetivos do Desenvolvimento Sustentável (ODS) baseado em evidências para avaliar Planos Municipais de Gestão

de Resíduos Sólidos em 34 municípios de Goiás, Brasil. A metodologia combina revisão bibliográfica, ponderação baseada em especialistas utilizando o método *Rank Order Centroid (ROC*) e uma avaliação estruturada do tipo de evidência (declarativa, operacional e mensurável). Os resultados revelam uma heterogeneidade substancial, com apenas 41% dos municípios apresentando aderência superior a 50%. Embora as dimensões operacionais apresentem maior aderência, os planos incorporam de forma mais limitada elementos relacionados à inclusão social e ao monitoramento. Os achados destacam um descompasso entre as prioridades atribuídas pelos especialistas e o conteúdo documental dos planos, indicando que a conformidade com a Política Nacional de Resíduos Sólidos brasileira é necessária, mas insuficiente para o avanço da Agenda 2030. Altos índices de aderência são frequentemente impulsionados por elementos declarativos em vez de evidências orientadas à implementação. O estudo contribui com um arcabouço replicável para a avaliação de instrumentos de políticas públicas com base na qualidade das evidências, oferecendo *insights* para aprimorar o planejamento municipal e apoiar uma governança da sustentabilidade mais eficaz.

Palavras-chave: Gestão de Resíduos Sólidos. Objetivos de Desenvolvimento Sustentável. Cumprimento de Políticas. Planejamento Municipal. Governança Ambiental.

ABSTRACT

The objective of this study was to develop and apply an evidence-based Sustainable Development Goals (SDG) Adherence Index to evaluate Municipal Solid Waste Management Plans across 34 municipalities in Goiás, Brazil. The methodology combines literature review, expert-based weighting using the Rank Order Centroid (ROC) method, and a structured assessment of the evidence type (declarative, operational, and measurable). The results reveal substantial heterogeneity, with only 41% of the municipalities presenting adherence greater than 50%. Although the operational dimensions show higher adherence, the plans incorporate elements related to social integration and monitoring to a more limited extent. The findings highlight a structural mismatch between normative priorities and municipal planning capacity, indicating that compliance with Brazil's National Solid Waste Policy is necessary but insufficient for advancing the 2030 Agenda. High adherence scores are often driven by declarative elements rather than implementation-oriented evidence. The study contributes a replicable framework for evaluating policy instruments based on evidence quality, offering insights for improving municipal planning and supporting more effective sustainability governance.

Keywords: *Solid Waste Management. Sustainable Development Goals. Policy Adherence. Municipal Planning. Environmental Governance.*

1 INTRODUÇÃO

A gestão de resíduos sólidos urbanos (RSU) representa um desafio global crítico, com geração anual de aproximadamente 2,1 bilhões de toneladas em todo o mundo (Unep, 2024). Práticas inadequadas de gestão de resíduos geram impactos ambientais e de saúde pública significativos, incluindo poluição da água, do ar e do solo, bem como aumento dos riscos de distúrbios respiratórios e psicossociais (Mor; Ravindra, 2023). Esses desafios são particularmente acentuados em países em desenvolvimento, onde as limitações institucionais e de infraestrutura dificultam a implementação de sistemas eficazes de gestão de resíduos (Siddiqua; Hahladakis; Al-attiya, 2022).

No Brasil, a geração de RSU atingiu 81 milhões de toneladas em 2023, com aproximadamente 7 milhões de toneladas descartadas de forma inadequada (Abrema, 2024). Apesar da existência da Política Nacional de Resíduos Sólidos (PNRS), que estabelece diretrizes regulatórias para a gestão de resíduos, 36,6% dos municípios ainda dependem de métodos de descarte inadequados, como lixões a

céu aberto e aterros controlados (IBGE, 2024). Esse cenário evidencia uma lacuna persistente entre os marcos regulatórios formais e sua implementação efetiva em nível local.

Os Planos Municipais Integrados de Gestão de Resíduos Sólidos (PMGIRS) e os Planos Municipais de Saneamento Básico (PMSB) constituem o principal instrumento institucional para operacionalizar as diretrizes das PNRS em nível municipal. Além de serem legalmente exigidos, esses planos também são pré-requisito para o acesso a recursos federais e incentivos financeiros relacionados a serviços de limpeza urbana e gestão de resíduos (Brasil, 2010, 2022). Contudo, a mera existência desses planos não garante necessariamente sua qualidade, consistência ou eficácia no enfrentamento de desafios mais amplos de sustentabilidade.

Em paralelo, a crescente incorporação dos Objetivos de Desenvolvimento Sustentável (ODS) nas políticas públicas reforçou a necessidade de abordagens integradas e intersetoriais para a gestão de resíduos. A gestão de resíduos sólidos está diretamente ligada a múltiplos ODS, particularmente aqueles relacionados à saúde (ODS 3), cidades sustentáveis (ODS 11), consumo e produção responsáveis (ODS 12) e ação climática (ODS 13), refletindo sua natureza inerentemente transversal (Elsheekh *et al.*, 2021). Embora estudos anteriores sugiram convergência conceitual entre as políticas ambientais brasileiras e os ODS, importantes limitações estruturais, como baixas taxas de coleta seletiva, continuam a dificultar o progresso em direção a esses objetivos (Dantas; Fontgalland, 2021; Martins; Borges; Zaneti, 2025).

Dado o papel central dos municípios na implementação tanto de políticas nacionais quanto de compromissos internacionais, aderir aos ODS torna-se uma questão crítica. No entanto, as ferramentas de avaliação disponíveis apresentam limitações importantes. Instrumentos como o Índice de Desenvolvimento Sustentável das Cidades (IDSC-BR) avaliam o desempenho municipal com base em indicadores dos ODS, mas não examinam especificamente como instrumentos de planejamento, como os PMGIRS, incorporam elementos associados aos ODS (Wissmann; Backes, 2022). Além disso, a localização e o monitoramento dos ODS no nível municipal brasileiro são limitados por lacunas de disponibilidade, transparência, desagregação e padronização das informações públicas, bem como por restrições técnicas e institucionais dos sistemas de informação (Lindoso *et al.*, 2021).

Da mesma forma, as diretrizes desenvolvidas por instituições como a Confederação Nacional de Municípios (CNM) e a *Association of Flemish Cities and Municipalities* (VVSG) fornecem orientação normativa para a localização dos ODS, mas carecem de mecanismos operacionais e quantitativos para avaliar a aderência ao nível do plano (CNM, 2017; VVSG, 2019).

Isso revela uma lacuna metodológica específica: a ausência de ferramentas estruturadas e quantitativas capazes de avaliar sistematicamente o grau de aderência dos planos municipais de gestão de resíduos sólidos aos ODS, levando em consideração também a qualidade e a força das evidências subjacentes. Para abordar essa lacuna, este estudo desenvolveu e aplicou um Índice de Aderência aos ODS estruturado com base em indicadores ponderados e classificação de evidências. O índice é construído por meio de revisão bibliográfica e ponderação baseada na opinião de especialistas, utilizando o método *Rank Order Centroid* (ROC), e é aplicado a 34 municípios do estado de Goiás, Brasil, a fim de avaliar seu potencial analítico e aplicabilidade empírica. Enquanto a PNRS constitui um marco legal de cumprimento obrigatório pelos municípios, a Agenda 2030 funciona, no nível municipal, como um referencial voluntário de sustentabilidade. Portanto, o índice avalia a incorporação documental de elementos associados aos ODS, e não a conformidade legal, a qualidade global dos planos ou a implementação das ações previstas.

2 METODOLOGIA

A metodologia foi dividida em quatro etapas. Na primeira, realizou-se pesquisa documental no Google Acadêmico para mapear as relações entre PNRS e ODS. Foram combinados os termos (“Política Nacional de Resíduos Sólidos” OR “PNRS”) AND (“Objetivos de Desenvolvimento Sustentável” OR

"ODS"). Incluíram-se estudos em português publicados a partir de 2015, sem limite final. Após triagem por título e resumo, os textos completos foram avaliados quanto à análise da relação entre a PNRS e os ODS, gerando um mapeamento conceitual entre os dois documentos.

Na segunda etapa, houve a ponderação das dimensões identificadas na fase anterior. Foram 15 respondentes com experiência nos setores público, privado ou autônomo. Entre os especialistas entrevistados, 26,7% trabalham na administração pública direta, 33,3% em consultoria ambiental privada e 40% na área acadêmica ou como pesquisadores, todos com cinco ou mais anos de experiência no setor de resíduos sólidos. A diversidade dos participantes foi importante para integrar diferentes perspectivas sobre o tema, permitindo a integração de percepções de diferentes setores.

Devido à sua natureza, este estudo foi submetido ao Comitê de Ética em Pesquisa do IFG, vinculado ao Conselho Nacional de Saúde, e aprovado (CAAE: 88705925.9.0000.8082). Assim, os participantes assinaram o Termo de Consentimento Livre e Esclarecido (TCLE), concordando em participar da pesquisa. No questionário, os especialistas foram solicitados a classificar a importância das dimensões identificadas, divididas entre Eixos e Critérios. Essas dimensões estão descritas na Tabela 2, em Resultados e Discussão (Seção 3).

O método *Rank Order Centroid* (ROC) foi usado para agregar as preferências individuais dos especialistas, gerando uma ordenação consensual. O método ROC é particularmente indicado em contextos em que os tomadores de decisão fornecem classificações de preferências, mas não expressam a intensidade relativa entre os critérios (Ahn, 2011). Nesses casos, o ROC produz estimativas de peso que representam o valor esperado das preferências dentro do espaço de todas as distribuições possíveis compatíveis com a ordenação fornecida.

O ROC apresenta bom desempenho em termos de robustez, especialmente em situações de incerteza ou inconsistência nas preferências individuais, sendo amplamente utilizado como aproximação confiável quando não se dispõe de dados cardinais (Hatefi, 2023). Diferentemente de métodos baseados em comparações par a par, o ROC apresenta menor complexidade operacional e reduz a possibilidade de inconsistências lógicas nas respostas, sendo mais adequado para aplicações com múltiplos critérios e número limitado de especialistas (Roszkowska, 2013). A equação 1 converte a posição de cada eixo ou critério na ordenação em um peso ROC. Os pesos obtidos para os especialistas foram posteriormente agregados para calcular os pesos finais apresentados na Tabela 2,

$$W_k = \frac{1}{n}\sum_{i=k}^{n}\frac{1}{i} \qquad (1)$$

em que é o total de eixos/critérios e é a posição de classificação.

Na terceira etapa, foram avaliados os planos PMGIRS/PMSB de 34 municípios do estado de Goiás. O universo documental foi delimitado com base no levantamento realizado por Borges *et al.* (2025), estudo desenvolvido pelos mesmos autores, que mapearam todos os planos municipais de gestão de resíduos sólidos disponíveis publicamente no estado. Assim, os municípios não foram selecionados por terem sido previamente incluídos naquele estudo; o levantamento anterior foi utilizado para identificar de forma abrangente os planos existentes e acessíveis *online*. A adoção do mesmo conjunto documental também possibilitou a comparação entre o alinhamento dos planos com a PNRS, examinado no estudo anterior, e seu alinhamento com os ODS, avaliado na presente pesquisa. Ressalta-se que a análise se restringe ao conteúdo dos planos e não permite inferir a efetiva implementação das ações e políticas neles previstas.

Esta terceira etapa foi conduzida em três passos, apresentados em sequência na Figura 1. As dimensões "tipo de evidência" e "força da evidência" desempenham papéis analíticos distintos e complementares. O tipo de evidência (declarativa, operacional ou mensurável) caracteriza a natureza da informação: se expressa uma intenção, descreve uma ação ou apresenta dados quantitativos. A força da evidência (fraca, moderada ou robusta) avalia o grau de detalhamento com que essa informação é apresentada no plano, considerando a presença de dados concretos, metas ou indicadores. A combinação dessas duas dimensões determinou a pontuação atribuída a cada Critério, conforme sistematizado na Tabela 1.

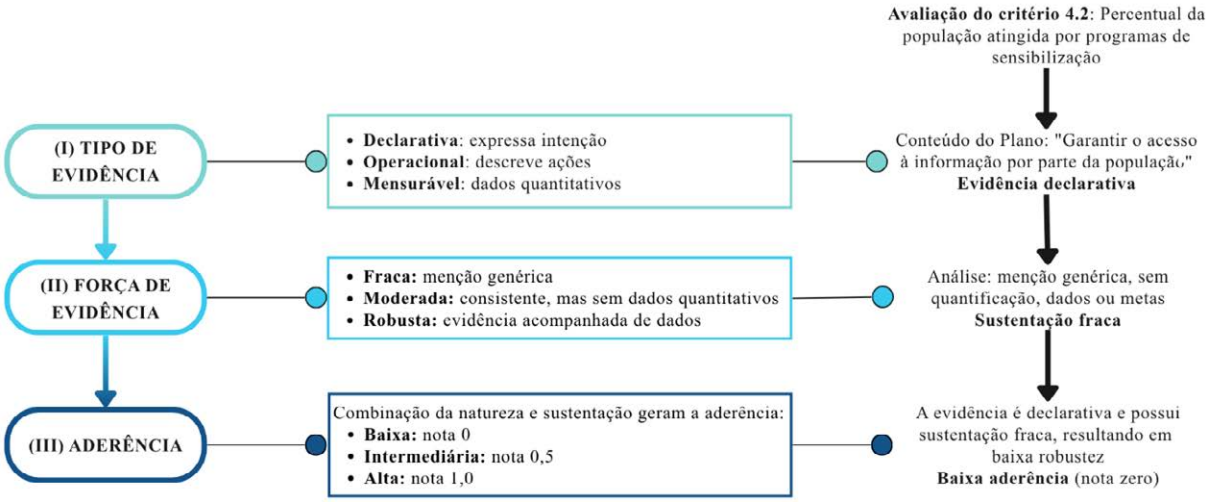

Figura 1 – Etapas de avaliação de evidências em planos municipais (PMGIRS/PMSB) com aplicação em um critério amostral

Fonte: Os autores.

O quarto e último passo foi o cálculo do Índice de Aderência Final (), equação 2, calculado por meio de um processo de ponderação hierárquica, combinando as pontuações dos critérios e seus respectivos pesos. Para permitir a comparação entre diferentes estudos, essa pontuação foi normalizada como uma porcentagem de alinhamento com os ODS (de 0 a 100%),

$$FAI = \sum_{i=1}^{n} \left(W_i \sum_{j=1}^{m} (w_{ij} . s_{ij}) \right) \text{ x } 100 \qquad (2)$$

em que é o Índice de Aderência Final (%), é o peso do eixo , é o peso do critério do eixo , e é o escore de aderência.

Tabela 1 – Itens de avaliação da aderência dos planos municipais aos ODS

Tipo de Evidência	*Força da Evidência*	*Descrição da Combinação*	*Nível da aderência*	*Nota*
Declarativa	Fraca	Menção genérica de intenção sem ações ou dados específicos	Baixa	0
Declarativa	Moderada	Intenção expressa de forma consistente, mas sem ações ou dados concretos	Intermediária	0,5

Tipo de Evidência	*Força da Evidência*	*Descrição da Combinação*	*Nível da aderência*	*Nota*
Declarativa	Forte	Intenção apoiada por dados, mas apenas em nível conceitual	Intermediária	0,5
Operacional	Fraca	Descrição de ações genéricas sem especificação ou detalhes	Intermediária	0,5
Operacional	Moderada	Ações bem descritas e consistentes, mas sem indicadores quantitativos	Alta	1
Operacional	Forte	Ações específicas com monitoramento de dados e indicadores	Alta	1
Mensurável	Fraca	Apresentação de dados genéricos ou dados sem contexto claro	Intermediária	0,5
Mensurável	Moderada	Dados quantitativos consistentes relevantes para os ODS	Alta	1
Mensurável	Forte	Dados robustos com metodologia clara e diretrizes de monitoramento	Alta	1

Fonte: Os autores.

3 RESULTADOS E DISCUSSÃO

3.1 MAPEAMENTO CONCEITUAL

Para realização do mapeamento conceitual, utilizaram-se os trabalhos encontrados na pesquisa documental. Os estudos anteriores que examinaram as relações entre a PNRS e os ODS foram: Cabral *et al.* (2024), Farias *et al.* (2022), e Trigo *et al.* (2023). A Figura 2 apresenta o mapeamento conceitual entre as dimensões do índice proposto e os ODS selecionados. Esse alinhamento foi estabelecido com base na correspondência temática entre cada dimensão, as metas dos ODS e a literatura revisada neste estudo. O mapeamento não implica a medição direta do desempenho dos ODS, mas, sim, uma contribuição potencial de cada dimensão para metas específicas.

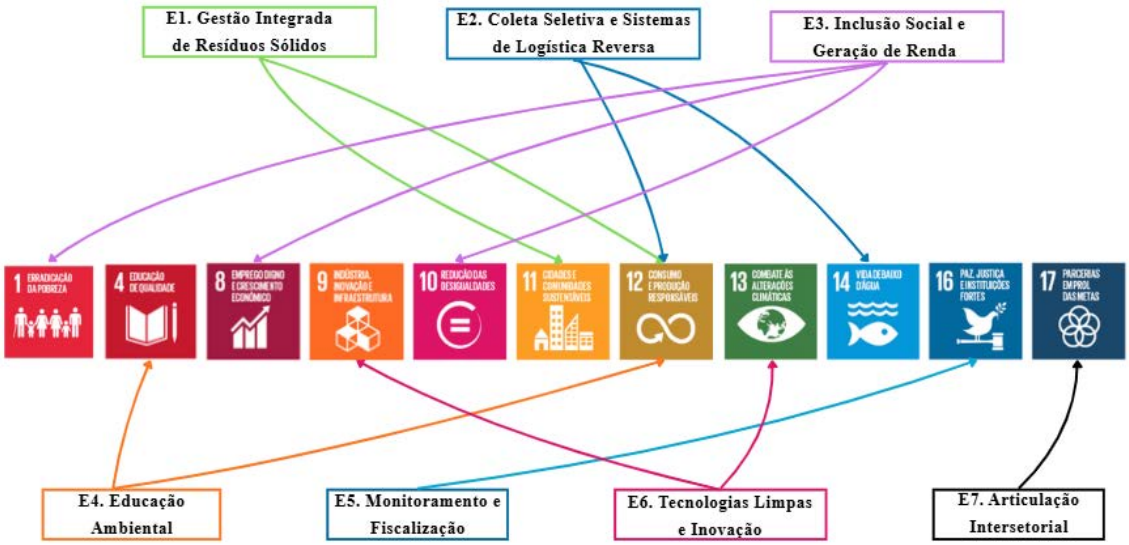

Figura 2 – *Mapa conceitual entre os eixos do índice e os ODS*

Fonte: Os autores.

Os objetivos e princípios da PNRS foram sistematicamente comparados com as metas da Agenda 2030, buscando-se identificar correspondências temáticas entre os dois referenciais. Por exemplo, a PNRS estabelece como objetivo a "não geração, redução, reutilização, reciclagem e tratamento dos resíduos sólidos, bem como disposição final ambientalmente adequada dos rejeitos" (Brasil, 2010, art. 7º, II), conteúdo que apresenta correspondência com a meta 12.5 dos ODS, voltada à redução da geração de resíduos por meio da prevenção, redução, reciclagem e reutilização. Esse procedimento fundamentou a estruturação de sete eixos, mostrados na Figura 2, e de 31 critérios, apresentados na Tabela 2.

3.2 PESOS DOS EIXOS E CRITÉRIOS

Com base nas respostas da amostra consultada, o método ROC produziu uma hierarquia de pesos que representa as preferências agregadas desses especialistas, apresentados na Tabela 2.

Tabela 2 – Ponderação de eixos e critérios pelos especialistas

Eixo	*Peso*	*Critérios*	*Peso*
E1. Gestão Integrada de Resíduos Sólidos	0,228	1.1 Existência de iniciativas/programas para redução de resíduos.	0,228
		1.2 Existência de iniciativas/programas para reutilização de resíduos.	0,156
		1.3 Existência de destinação final ambientalmente adequada para resíduos.	0,370
		1.4 Percentual de destinação final ambientalmente adequada para resíduos (reciclagem, compostagem, etc.) acima da média nacional.	0,073
		1.5 Percentual de destinação final ambientalmente adequada para resíduos inertes acima da média nacional.	0,020
		1.6 Percentual da população atendida pelo sistema de coleta convencional acima da média nacional.	0,109
		1.7 Existência de método de destinação final ambientalmente adequado para resíduos inertes (aterro sanitário, incineração).	0,044
E2. Coleta Seletiva e Sistemas de Logística Reversa	0,156	2.1 Percentual da população atendida pela coleta seletiva acima da média nacional.	0,146
		2.2 Quantidade de resíduos coletados seletivamente acima da média nacional.	0,270
		2.3 Existência de sistemas de logística reversa estruturados.	0,521
		2.4 Quantidade de resíduos provenientes do sistema de logística reversa acima da média nacional.	0,063
E3. Inclusão Social e Geração de Renda	0,370	3.1 Expressa o número de cooperativas de catadores de materiais recicláveis integradas ao sistema de gestão de resíduos.	0,146
		3.2 Percentual de resíduos recicláveis destinados às cooperativas.	0,521
		3.3 Renda dos catadores de materiais recicláveis obtida com a venda de materiais recicláveis.	0,270
		3.4 Existência de programas de capacitação e apoio para catadores de materiais recicláveis.	0,063
E4. Educação Ambiental	0,073	4.1 Número de campanhas de educação ambiental realizadas com foco em questões de resíduos.	0,146
		4.2 Percentual da população alcançado pelos programas de conscientização.	0,270
		4.3 Existência de materiais educativos sobre gestão de resíduos.	0,063
		4.4 Ações nas escolas por meio da educação ambiental.	0,521

Eixo	*Peso*	*Critérios*	*Peso*
E5. Monitoramento e Fiscalização	0,109	5.1 Existência de relatórios periódicos sobre gestão de resíduos (princípio da transparência).	0,270
		5.2 Plano de inspeção para métodos de descarte e destinação final.	0,521
		5.3 Monitoramento da quantidade de resíduos perigosos tratados adequadamente.	0,063
		5.4 Monitoramento do percentual de resíduos perigosos tratados adequadamente.	0,146
E6. Tecnologias Limpas e Inovação	0,020	6.1 Existência de projetos de compostagem ou biodigestão.	0,270
		6.2 Percentual de resíduos orgânicos tratados por tecnologias limpas.	0,146
		6.3 Percentual de resíduos recicláveis tratados por tecnologias limpas.	0,063
		6.4 Investimento/incentivo para ações e pesquisa de novas tecnologias para a destinação final de resíduos.	0,521
E7. Articulação Intersetorial	0,044	7.1 Existência de parcerias público-privadas, ações de gestão e/ou gestão de resíduos.	0,270
		7.2 Existência de convênios setoriais firmados (municípios).	0,146
		7.3 Participação da sociedade civil em comitês ou fóruns de gestão de resíduos.	0,063
		7.4 Parceria do governo municipal com outros órgãos (Procuradoria-Geral, defensoria pública, etc.)	0,521

Fonte: Os autores.

O Eixo E3 recebeu o maior peso, seguido pelo E1, enquanto o E6 recebeu o menor. Essa ordenação é dependente da composição da amostra e não deve ser interpretada como uma hierarquia universal dos eixos. A baixa relevância atribuída à inovação tecnológica não deve ser interpretada como uma rejeição da modernização, mas, sim, como um diagnóstico de urgência: no contexto brasileiro e em outros países do Sul Global, a tecnologia sem inclusão social tende a reproduzir desigualdades e a permanecer insustentável (Da Silva; Bolson, 2018; Marello; Helwege, 2018; Rutkowski; Rutkowski, 2015; Zisopoulos *et al.*, 2023). Essa perspectiva corrobora a visão de que a gestão de resíduos é, primordialmente, um desafio humano e institucional, e não estritamente um problema técnico ou de engenharia (Gutberlet; Carenzo, 2020; Marshall; Farahbakhsh, 2013; Wilson; Velis; Rodic, 2013).

Entretanto, no contexto brasileiro, limitações de infraestrutura, baixa cobertura da coleta seletiva e reduzida capacidade de recuperação e tratamento de materiais ainda restringem o desempenho dos sistemas municipais de gestão de resíduos (Cetrulo *et al.*, 2018; Oliveira; Klafke; Chaerki, 2021; Paes *et al.*, 2024; Rebehy *et al.*, 2023). Assim, o menor peso atribuído às tecnologias limpas e à inovação não significa que investimentos em triagem, compostagem, biodigestão e sistemas de monitoramento sejam dispensáveis. O resultado indica, antes, que os especialistas consideraram mais urgente assegurar a inclusão social e fortalecer a gestão integrada, devendo a modernização tecnológica ser articulada a essas prioridades. No contexto dos municípios goianos analisados, essa interpretação é particularmente relevante diante do baixo nível de evidências operacionais e mensuráveis relacionadas ao tratamento e à recuperação dos resíduos.

O maior peso do Eixo E3 (Inclusão Social e Geração de Renda) expressa a prioridade atribuída pelos especialistas. Contudo, os planos apresentam menor aderência documental justamente nesse eixo e resultados mais altos em dimensões de menor peso. Essa divergência entre prioridade atribuída pelos especialistas e conteúdo dos planos é discutida na seção seguinte.

A análise do Eixo E1 (Gestão Integrada de Resíduos Sólidos) ilustra as pressões operacionais e regulatórias que influenciam a importância relativa de certos temas. O Novo Marco Legal do Saneamento (Lei nº 14.026/2020) introduziu metas rigorosas de universalização e sustentabilidade econômico-financeira, pressionando os gestores a abordar os aspectos mais visíveis dos resíduos urbanos (Brasil, 2020). No entanto, estudos mostram que indicadores como taxas de recuperação de materiais recicláveis, cobertura efetiva da coleta seletiva e inclusão de catadores de materiais recicláveis geralmente permanecem baixos mesmo após a implementação de planos estruturados (Cetrulo *et al.*, 2018; Oliveira; Klafke; Chaerki, 2021). Isso sugere que a conformidade regulatória, mesmo quando enquadrada como gestão integrada, muitas vezes resulta em uma lista de verificação institucional em vez de uma transformação estrutural substancial (Berticelli; Pandolfo; Korf, 2016; Paes *et al.*, 2024).

3.3 INTERPRETAÇÃO DOS RESULTADOS À LUZ DA ADERÊNCIA AOS ODS

Após a etapa de ponderação, este estudo examinou como as prioridades identificadas se refletem nas práticas de planejamento municipal. A Figura 3 apresenta a aderência do PMGIRS/PMSB entre os municípios e eixos em relação aos ODS, onde 0% representa a pontuação mais baixa e 100% a mais alta. Os valores apresentados são resultados ponderados e, portanto, devem ser interpretados à luz dos pesos atribuídos durante a etapa anterior de ponderação baseada na opinião de especialistas.

Dos 34 PMGIRS/PMSB analisados, apenas 14 (41,2%) atingiram níveis de aderência acima de 50%, indicando que a maioria dos planos não incorpora consistentemente elementos associados aos ODS. Esse resultado destaca tanto a limitada disseminação estrutural dessas diretrizes quanto a forte heterogeneidade entre os municípios.

O mapeamento conceitual entre as dimensões do índice e os ODS selecionados (Figura 2) fornece uma lente analítica para interpretar o desempenho municipal além da estrutura interna do índice. Em vez de tratar cada dimensão como um componente isolado, essa estrutura proposta permite uma compreensão mais ampla de como os pontos fortes e fracos observados refletem os desafios sistêmicos de sustentabilidade associados à Agenda 2030.

Com relação ao Eixo E1 (Gestão Integrada de Resíduos Sólidos), alinhado aos ODS 11 e 12, os resultados indicam um desempenho relativamente maior em todos os municípios. Isso reflete a priorização de aspectos operacionais, como a cobertura da coleta de resíduos e o descarte ambientalmente adequado, que são fortemente impulsionados por requisitos regulatórios. Em contrapartida, o Eixo E2 (Coleta Seletiva e Sistemas de Logística Reversa), associado aos ODS 12 e 14, apresenta níveis de aderência consistentemente baixos. A baixa aderência nesse eixo indica que os planos incorporam ou detalham de forma limitada elementos relacionados à recuperação de materiais e à estruturação da logística reversa. Essa limitação não se restringe à formulação dos planos. Evidências empíricas indicam que o reconhecimento dos benefícios ambientais da coleta seletiva não necessariamente se converte em disposição para financiar ou apoiar concretamente o serviço, revelando uma possível distância entre percepção ambiental favorável e participação efetiva (Feitosa *et al.*, 2018).

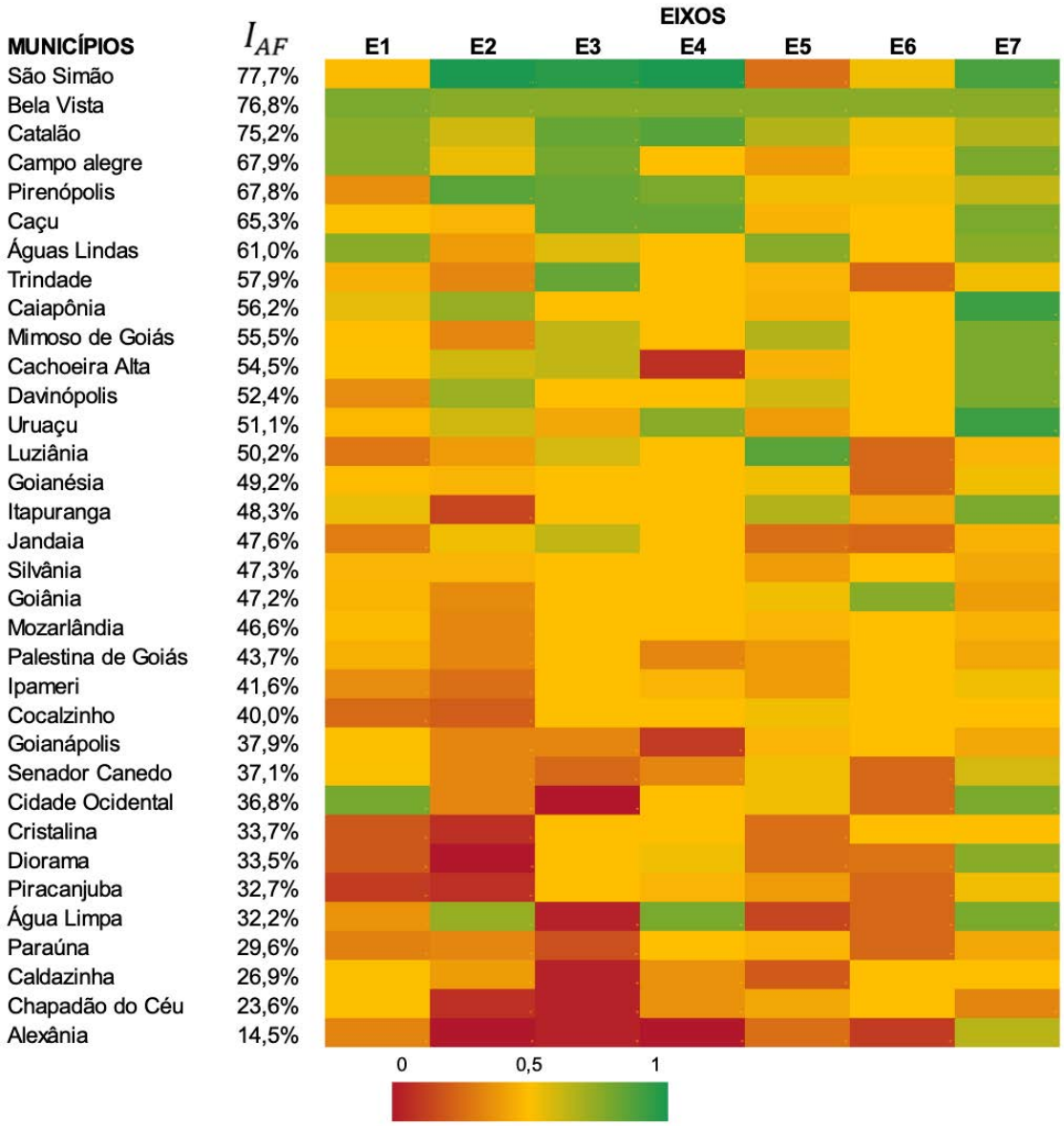

Figura 3 – Aderência documental dos PMGIRS/PMSB de cada município por eixo

Fonte: Os autores.

Em relação ao Eixo E3 (Inclusão Social e Geração de Renda), vinculado aos ODS 1, 8 e 10, apesar de ser a dimensão com maior peso, apresenta um dos níveis de desempenho mais baixos. Essa constatação reforça uma incompatibilidade estrutural entre as prioridades normativas e a menor incorporação documental desses elementos nos planos municipais. O Eixo E4 (Educação Ambiental), associado aos ODS 4 e 12, apresenta desempenho moderado. Os planos municipais frequentemente incluem campanhas de conscientização e iniciativas educacionais, principalmente nas escolas.

O Eixo E5 (Monitoramento e Fiscalização), vinculado ao ODS 16, mostra uma aderência consistentemente baixa entre os municípios. Os planos apresentam evidências documentais limitadas sobre sistemas de monitoramento, mecanismos de inspeção e divulgação de dados. Por sua vez, o Eixo E6 (Tecnologias Limpas e Inovação), associado aos ODS 9 e 13, apresenta um desempenho baixo e altamente variável. Os resultados indicam uma incorporação limitada, no conteúdo dos planos, de ações, metas e indicadores relacionados à compostagem, biodigestão e outras tecnologias de tratamento.

Por sua vez, o Eixo E7 (Articulação Intersetorial), alinhado ao ODS 17, apresenta os níveis mais altos de aderência. No entanto, esse resultado deve ser interpretado com cautela, pois pode refletir compromissos declarativos ou formais, em vez da existência de mecanismos de coordenação eficazes.

3.4 ANÁLISE CRÍTICA DA ADERÊNCIA AO PMGIRS/PMSB

Os resultados por eixo (Figura 3) evidenciam uma discrepância entre a hierarquia de pesos derivada das preferências dos especialistas e o desempenho empírico: o E3, de maior peso, está entre os piores resultados, enquanto o E7, de menor peso, apresenta os melhores. Como o Índice de Aderência Final é uma soma ponderada, pontuações altas em eixos menos prioritários podem compensar parcialmente déficits em dimensões críticas. Trata-se do problema da compensabilidade dos índices compostos (Greco *et al.*, 2019; OECD, 2008). Assim, o valor agregado deve ser interpretado com o perfil por eixo, pois índices semelhantes podem resultar de desempenhos equilibrados ou de pontuações concentradas em dimensões predominantemente declarativas.

A comparação com a aderência à PNRS (Borges *et al.*, 2025) mostra relação positiva, mas não linear. Pirenópolis e Bela Vista de Goiás obtêm bons resultados nos dois referenciais, enquanto Mozarlândia e Piracanjuba combinam maior conformidade legal com aderência apenas moderada aos ODS. Isso indica que requisitos operacionais da PNRS não garantem a incorporação de dimensões mais amplas de sustentabilidade, muitas vezes sustentadas apenas por compromissos declarativos.

O porte municipal tampouco explica o desempenho: São Simão supera Goiânia e Senador Canedo. Esse fato sugere que recursos e escala não asseguram maior aderência (Choi, 2021; Koop *et al.*, 2017), pois a capacidade local combina dimensões administrativas, fiscais e político-institucionais, que podem não evoluir conjuntamente (Aguiar; Lima, 2019). Governança integrada e coordenação intersetorial tendem, portanto, a ser mais determinantes para o planejamento socioambiental (Paes; Oliveira, 2021; Rebehy *et al.*, 2023; Siman; Yamane; Dutra, 2023).

A elevada aderência do E7 parece decorrer sobretudo de expressões como "parcerias", "responsabilidade compartilhada" e "participação social", frequentemente sem detalhamento institucional, financeiro ou operacional. Isso revela distância entre alinhamento discursivo e capacidade de implementação (Yan; Ramesh, 2026; Ye; Gao; Yu, 2024). Em contraste, E5 e E6 exigem procedimentos, infraestrutura, metas e indicadores, o que explica sua menor aderência e maior dependência de evidências operacionais e mensuráveis.

No E3, o desempenho baixo a moderado não representa apenas deficiência documental. A inclusão efetiva dos catadores depende de renda, infraestrutura, acordos formais, continuidade das atividades e condições adequadas de trabalho e saúde. A literatura mostra que esses trabalhadores permanecem inseridos em contextos de vulnerabilidade social, nos quais fatores socioeconômicos, educacionais e ocupacionais afetam diretamente sua qualidade de vida (Vasconcelos; Guimarães; Zaneti, 2018). Sem mecanismos capazes de enfrentar essas dimensões, os planos podem reproduzir exclusão social e injustiça ambiental (Da Silva; Bolson, 2018; Ferreira, 2024; Silva; Araújo; van Elk, 2024; Zon *et al.*, 2020). Embora existam compromissos declarativos, são raros programas estruturados, arranjos institucionais e indicadores de renda ou participação. Esse padrão mantém uma abordagem tecnocrática, centrada na logística, com integração limitada de catadores e cooperativas (Buch *et al.*, 2021; Cabral *et al.*, 2024).

O contraste entre E1 e E3 reforça essa interpretação. Mesmo entre municípios de menor desempenho geral, coleta, destinação e infraestrutura recebem maior atenção do que inclusão e geração de renda. Assim, resultados relativamente altos no E1, como em Cidade Ocidental e Caldazinha, podem refletir a prestação do serviço de limpeza urbana, sem integração produtiva dos catadores (Galdino *et al.*, 2024; Madureira; Candiani, 2025). Essa lacuna é especialmente relevante porque esses trabalhadores contribuem para a economia circular, o trabalho decente e os ODS 8, 11 e 12 (Alves; Costa, 2025).

O E5 apresenta baixa aderência e quase ausência de indicadores, sistemas de monitoramento e mecanismos de reporte, limitando a avaliação e o aprendizado das políticas (Elsheekh *et al.*, 2021; Rashed, 2025). O E2 registra a menor média, indicando menor incorporação, nos planos, de elementos relacionados à coleta seletiva e à integração com a logística reversa. Essa limitação reduz a recuperação de materiais e a inclusão social, além de dificultar o avanço do ODS 11 (Martins; Borges; Zaneti, 2025). Embora os planos mencionem logística reversa e responsabilidade compartilhada, faltam mecanismos operacionais e metas mensuráveis (Barbosa; Gonçalves; Simões, 2025; Santiago, 2024).

4 CONCLUSÕES

O Índice de Aderência aos ODS identifica como elementos da Agenda 2030 são incorporados e sustentados documentalmente nos PMGIRS/PMSB. Sua aplicação a 34 municípios de Goiás mostrou que a conformidade com a PNRS é necessária, mas não garante alinhamento aos ODS, pois os dois referenciais representam dimensões distintas. Os resultados comparam planos e eixos, sem permitir inferências isoladas sobre conformidade legal, qualidade global, capacidade institucional ou implementação.

Apenas 41% dos municípios superaram 50% de aderência. O E3 (Inclusão Social e Geração de Renda), de maior peso, apresentou baixo desempenho, enquanto o E7 (Articulação Intersetorial) concentrou as maiores pontuações. Isso indica que os planos incorporam princípios de governança sobretudo de modo declarativo, mas têm dificuldade para convertê-los em mecanismos operacionais e mensuráveis. O porte municipal também não determinou o desempenho: municípios menores superaram centros maiores, sugerindo maior influência da capacidade institucional, da governança e do compromisso político.

Os resultados devem ser interpretados considerando quatro limitações: (i) os pesos refletem a composição da amostra de especialistas, o que pode causar um viés de subjetividade; (ii) a disponibilidade pública dos planos pode favorecer municípios mais transparentes; (iii) a análise documental não comprova implementação; e (iv) a estrutura aditiva permite compensação entre eixos. Assim, pontuação baixa significa menor incorporação documental de elementos associados aos ODS, não descumprimento da PNRS ou baixa capacidade municipal.

Pesquisas futuras devem ampliar e diversificar a amostra de especialistas, testar métodos alternativos de agregação, inclusive não compensatórios, aplicar o índice em outras regiões e integrar indicadores de implementação ao conteúdo dos planos.

DECLARAÇÃO SOBRE O USO DE INTELIGÊNCIA ARTIFICIAL

Os autores utilizaram o ChatGPT (GPT-5.6 Thinking, OpenAI) exclusivamente para revisão linguística e aprimoramento estilístico. Todo o conteúdo científico, as análises e as contribuições intelectuais foram desenvolvidos e verificados pelos autores, que assumem total responsabilidade pela precisão e integridade do manuscrito.

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Representation and participatory water management: a portrait of the State Councils in 2024

Representatividade e gestão participativa das águas: um retrato dos Conselhos Estaduais e Distrital em 2024

Andréa Paula de Carestiato Costa [1]

Thiago Gil Barreto Barros [2]

Daniela Nogueira Soares [3]

[1] *Master's in Community Psychosociology and Human Ecology, Graduate student, Programme in Management and Regulation of Water Resources, University of Brasília, Brasília, DF, Brazil*
E-mail: acarestiato@gmail.com

[2] *Master's in Forest Sciences, Graduate student, Programme in Management and Regulation of Water Resources, University of Brasília, Brasília, DF, Brazil*
E-mail: thiagogilbarros@gmail.com

[3] *PhD in Sociology, Professor, Programme in Management and Regulation of Water Resources; Researcher, Center for Sustainable Development, University of Brasília, Brasília, DF, Brazil*
E-mail: danielanogueiracds@gmail.com

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ABSTRACT

The composition and functioning of Water Resources State Councils (CRHED) should reflect the decentralised and participatory aspects of the Brazilian national water resources policy. The absence of a national database on the CRHED, however, hinders social scrutiny and consideration of the current characteristics of the Brazilian Water Resources Management System - SINGREH. This study examined stakeholder participation in 27 CRHEDs, identifying the prevalence of the public sector (44%) over water resource users (21%) and civil society organisations (26%). It also examined gender information, the number of meetings, and the approval of deliberations throughout 2024, pointing to an underrepresentation of women (28%) and an uneven level of functioning among federal states. The importance of producing data on a regular basis is highlighted, allowing the monitoring of the CRHED in relation to their effectiveness and adherence to the principles and foundations of water policy in Brazil.

Keywords: Water. Governance. Collegiate body. Participation.

RESUMO

A composição e o funcionamento dos Conselhos de Recursos Hídricos dos Estados e do Distrito Federal – CRHED – deveriam refletir o caráter descentralizado e participativo da Política Nacional de Recursos Hídricos. A ausência de uma base de dados nacional sobre os CRHED, contudo, dificulta o escrutínio social e a reflexão sobre o perfil do Sistema Nacional de Gerenciamento de Recursos Hídricos – SINGREH. Este estudo avaliou a participação dos segmentos da sociedade em 27 CRHED, identificando a preponderância do poder público (44%) sobre os usuários de recursos hídricos (21%) e a sociedade civil (26%). Foram analisadas informações sobre gênero, quantidade de reuniões e a produção de deliberações em 2024, que apontaram uma sub-representação feminina (28%), e um funcionamento desigual entre as unidades da Federação. Destaca-se a importância da produção de dados com regularidade para o monitoramento dos CRHED em relação ao seu efetivo funcionamento e aos princípios e fundamentos da política das águas.

Palavras-chave: *Recursos hídricos. Governança. Colegiado. Participação.*

1 INTRODUCTION

The Water State and Federal District Councils (CRHED), created by the Federal Law nº 9.433/1997, which established the Brazilian National Water Policy (Brasil, 1997), are normative, advisory, and deliberative governance bodies within the framework of the Brazilian National Water Management System (SINGREH). They are present in almost all federal states, except the northern state of Acre, comprising representatives of the public sector, water users, and civil society organisations (CSOs).

Its role is to deliberate on their respective State Water Policy, to monitor the implementation of state water plans, promote coordination with other sectoral policies, arbitrate conflicts regarding water use and ensure social participation in water management (Brasil, 1997). The latter depends directly on the effective representation of each of the three above-mentioned groups of stakeholders.

The CRHED coordinates with the National Water Council (CNRH) and with the River Basin Committees (CBH), forming the network of water governance bodies within the scope of the SINGREH. In some federative units, public Water Funds and Water Agencies also form part of the State Water Management System (SEGRHI).

The governance of CRHED has frequently been the subject of technical and administrative reports. The effort to understand how their structure, composition, and dynamics can either foster or undermine their role as collegiate bodies for participatory water management remains an underexplored area, and further specific studies are needed to shed light on the historical evolution of their activities, as well as their impacts and contributions. Among the various implications of this scarcity of scientific production on the CRHED, such as historical series on their establishment, composition and functioning, the absence of national comparative studies may hinder the formulation of guidelines for their institutional strengthening, the measurement of the impact of their activities, as well as the pursuit of greater legitimacy and social representativeness of these collegiate bodies, with particular emphasis on the condition of gender (dis)parity within the CRHED.

The highly dynamic nature of the State Water Councils renders the analysis of their composition and representativeness, as well as of their deliberative effectiveness, a particularly complex object of study. The absence of a national and unified database, together with the scarcity of publications addressing these aspects, reveals a field of research that remains insufficiently explored. Néris (2021) addresses social participation in water management regarding São Paulo's CRHED, highlighting how CSOs influence the Council's decisions and render management more legitimate and democratic, despite facing challenges such as the predominance of economic interests and the unequal composition of the collegiate bodies.

Almost two decades ago, Tundisi and Matsumara-Tundisi (2008) had already emphasised the importance of a systemic and predictive approach to water governance, considering river basins as a framework for integrating biogeophysical, economic and social processes, which could constitute an effective management instrument for addressing local, regional and national problems on the basis of a consolidated database.

Thus, as an up-to-date portrait of the institutional reality, the present study seeks to contribute to an understanding of how the CRHED are currently operating and which challenges are emerging, particularly the identification of asymmetries within water governance and participation, thereby providing elements to help overcome knowledge gaps and broaden the academic debate. In addition, a one-year survey may serve as a baseline for longitudinal studies (Minayo; Deslandes; Gomes, 2024, p. 79), establishing a benchmark that may be compared with subsequent years and enabling the identification of trends, advances or setbacks.

Accordingly, the objective of this article is to characterise the composition, the stakeholders' representation and the conditions of participation, including women's participation, in Brazilian CRHED, analysing how these aspects affect the effectiveness of these collegiate bodies in fostering democratic and participatory water governance.

2 METHODOLOGICAL PROCEDURES

The present study was based on a documentary analysis of the implementation and functioning of the CRHED in Brazil, using scientific articles and academic publications, as well as management reports produced within the SINGREH, as sources of information. The bibliographic review of articles, dissertations, and theses primarily associated with the CRHED and, complementarily, with participation, governance, and gender within the SINGREH covered the period from 2000 to 2025, drawing on Brazilian works written in Portuguese.

In addition to a comprehensive literature review article concerning CREHDs (Marcondes; Moreira, 2021), a search for the term "Conselhos Estaduais de Recursos Hídricos" (State Water Councils) was conducted on the ResearchGate[1] and Google Scholar[2] platforms, yielding few results. Due to this limitation, the scope of bibliographic research was expanded to include the whole SINGREH as an element of the review, thereby allowing new bibliographic sources to be incorporated into the article's analytical effort. The results are presented and interpreted in the following section, considering the literature on participation, governance, and gender within SINGREH.

A particularly relevant data source was a technical report from the Brazilian National Water and Basic Sanitation Agency (ANA) on the Program for Consolidating the National Pact for Water Management (Progestão) (ANA, 2020). The report, titled "Establishment of the Status Report on State Water Resources Councils – Phase 1 – Diagnosis of State Water Resources Councils" (ANA, 2025a), systematised data from 2024, except for Alagoas State, for which 2023 data were used. Supplementary information was gathered through direct consultation of the websites of the water management agencies within the state governments of Acre (2025), Rio de Janeiro (2025), Rio Grande do Sul (2025), and Roraima (2025).

The systematised information included the following categories:

- Number of Technical Committees within the State Council;
- Number of Council members in accordance with their internal regulations;
- Number of women and men full members of the Council;

- Number of members by group of stakeholders: CSOs, municipal public authorities, state public authorities, water users, and others;
- Term of office of Council members in years;
- Number of Council plenary meetings planned;
- Number of Council plenary meetings held;
- Number of Council deliberations approved.

The systematised data comprises Table 1, which served as the basis for a qualitative analysis of water governance practices and processes across the various Brazilian federal units (FU), 26 States: Acre (AC), Alagoas (AL), Amazonas (AM), Amapá (AM), Bahia (BA), Ceará (CE), Espírito Santo (ES), Goiás (GO), Maranhão (MA), Minas Gerais (MG), Mato Grosso do Sul (MS), Mato Grosso (MT), Pará (PA), Paraíba (PB), Pernambuco (PE), Piauí (PI), Paraná (PR), Rio de Janeiro (RJ), Rio Grande do Norte (RN), Rondônia (RO), Roraima (RR), Rio Grande do Sul (RS), Sergipe (SE), Santa Catarina (SC), São Paulo (SP) and Tocantins (TO), plus the Federal District (DF).

Table 1 – Systematised data on State and District Water Councils

FU	Year.	No. Technical Committees	No. Members	No. Women	No. Men	No. CSO Members	No. State Members	No. Municipal Members	No. Users Members	No. Other Members	Term of office	No. Meetings planned	No. Meetings held	No. Deliberations approved
AC	2024	1	10	4	6	1	3	1	3	2	2	1	1	1
AL	2023	n/i	25	5	20	2	8	2	6	7	2	4	4	2
AM	2024	15	39	12	23	11	13	2	9	0	2	6	7	2
AP	2024	2	33	4	13	6	18	1	3	4	3	4	2	2
BA	2024	5	27	7	20	9	8	1	9	0	4	4	4	3
CE	2024	0	24	5	19	3	12	1	4	4	2	4	5	6
DF	2024	1	28	7	16	10	14	0	4	0	2	4	2	3
ES	2024	4	30	8	18	10	8	2	10	0	2	6	5	6
GO	2024	1	18	6	12	5	6	1	6	1	2	4	4	13
MA	2024	5	18	6	12	4	7	1	4	2	3	6	7	9
MG	2024	3	36	8	28	9	9	9	9	0	2	n/i	4	25
MS	2023	3	24	12	12	8	8	0	8	0	3	3	2	2
MT	2024	6	36	19	17	12	12	0	12	0	2	6	7	16
PA	2024	4	21	5	16	6	8	2	5	0	4	4	3	3
PB	2024	3	27	2	25	9	10	1	5	0	2	4	4	2
PE	2024	4	32	9	23	7	6	4	9	6	3	4	4	4
PI	2024	4	27	2	25	11	16	3	2	0	2	4	4	2
PR	2024	4	35	11	24	5	19	3	5	2	4	2	2	11
RJ	2024	7	32	14	17	9	5	3	9	6	3	6	6	10
RN	2024	2	32	6	23	6	10	0	6	4	2	2	3	7
RO	2024	1	30	5	6	15	4	0	3	5	2	5	5	8
RR	2024	n/i	18	n/i	n/i	4	8	2	6	2	2	6	6	n/i
RS	2024	8	22	5	17	0	13	0	0	9	2	6	3	32
SE	2024	n/i	19	6	13	3	5	3	3	1	3	4	2	2
SC	2024	4	20	6	14	10	10	0	0	0	0	2	3	2

FU	Year.	No. Technical Committees	No. Members	No. Women	No. Men	No. CSO Members	No. State Members	No. Municipal Members	No. Users Members	No. Other Members	Term of office	No. Meetings planned	No. Meetings held	No. Deliberations approved
SP	2024	7	33	5	28	5	11	11	6	5	2	3	3	14
TO	2024	3	26	11	39	7	13	0	2	0	3	4	4	12

Source: The authors.

2.1 STUDY LIMITATIONS

This study presents limitations associated with the nature of the collected secondary data, which depend on the regularity and updating of state and district databases and SINGREH reports. Specific information gaps were identified, such as the absence of gender data for the state of Roraima (RR).

Furthermore, given the quantitative and descriptive nature of this analysis, focused on the base year 2024, the adopted methodology does not allow for a qualitative assessment of the content and impact of the Resolutions published by the CHRED, nor does it permit measuring the actual political influence or the degree of effective engagement of each actor in the plenary sessions.

3 RESULTS AND DISCUSSION

The regulation governing the CNRH — Decree No. 11,960 of March 21, 2024 (Brazil, 2024) — introduces, in its latest version, a more balanced representation for civil society. This is essential for fostering transparency and participatory democracy, thereby strengthening water management by including voices that had previously been absent or unrecognised in this sphere. Notable among the recent changes to the CNRH's composition are the following (Art. 3, XXV): seven members of the CSOs, of which one is from indigenous peoples' organisations, one from traditional communities' organisations, and one from a national organisation representing municipalities.

Regarding women's participation, Matos (2024, p. 3) states that:

> Over the past few decades, the international agenda regarding women's rights and gender equality has evolved significantly, driven by social movements and by global conferences, declarations, and multilateral commitments involving diverse actors such as the United Nations, non-governmental organisations, and governments. Various studies highlight that gender relations define the distinct roles, responsibilities, values, and power dynamics to which men and women are subject
>
> (*author translation*).

However, according to ANA (2022), analyses of SINGREH's governance bodies indicate an underrepresentation of women in management positions within the water and sanitation sector, although participation in internal divisions — which tend to be more technical in nature — may vary. Yet, ANA's latest comprehensive report on the Current Situation of Water Resources (2025b) does not address the gender breakdown of the System's representatives as the 2022 edition did; consequently, the debate regarding the proportion of men and women in SINGREH's collegiate bodies has weakened and lost the relevance it had previously attained. Thus, there was a premature interruption of what could have become a time series capable of guiding the formulation of inclusion and gender equity policies within SINGREH.

The opportunity to access 2024 data proved to be a unique chance to provide a contemporary assessment of the subject and potentially broaden perspectives on participation, governance, and

gender inclusion, considering the scientific literature review. Marcondes and Moreira (2021) also conducted a bibliographic survey on Water Councils covering the period from 2000 to 2020, identifying 65 studies and demonstrating that most research focused on regional or state-level experiences, lacking analysis at the national level. This gap was addressed by the comprehensive national study led by Matos, Dias and Carrieri (2022) and the work by Vitória (2023).

Over the past six years, more specific analyses regarding CRHEDs have emerged —related to research and to human resource development for integrated water management, focusing on themes such as governance, participation, and gender (Matos, 2024; Matos, Dias, and Carrieri, 2022; Néris, 2021; Vitória, 2023). These analyses suggest the existence of institutional weaknesses which, combined with regional inequalities and a scarcity of academic information, may constrain the debate on water governance.

Widening the scope of analysis to encompass the set of actors within the SINGREH, contributions from authors on the challenges of representation, governance, and participation across various governance bodies, including state councils, were identified. Specialised literature has examined this topic from diverse perspectives, seeking to understand not only the formal presence of social actors in these spaces but, above all, the quality, depth, and effectiveness of such participation.

These studies reveal that, although CRHED represents a significant institutional advance, its ability to promote substantive participation remains in dispute. Particularly, with the research of Matos, Dias and Carrieri (2022) in the context of the series "Retratos de Governanças das Águas" by the Federal University of Minas Gerais – UFMG, a first quantitative framework of basin organizations and their members in Brazil was obtained, with chapters dedicated to the role of CREHD, to the issue of gender in water management and to gender participation and violence, in addition to addressing methodological aspects on the need for gender disaggregated data.

Furthermore, Matos, Dias, and Carrieri (2022) present results within a national scope, focusing on the socioeconomic profile of the representatives. They emphasise gender as a primary characteristic before examining data disaggregated by age, education level, academic background, and income. The study also analysed gender representation based on whether members held full or alternate seats on the governance bodies, highlighting the quality of women's participation in these CHRED forums. It is worth noting that, despite employing a different approach than the present article, the study yielded comparative results similar to those found when considering gender-disaggregated data in both investigations.

The literature on participation in water management governance bodies reveals a field marked by tensions between institutional advances and the persistence of structural inequalities (Table 2).

Table 2 – Participation in the State and Federal District Water Resources Councils (CRHED)

Authors	*Participation definition*	*Main focus*	*Core diagnosis*	*CSO role*
Abers and Jorge (2005)	Decentralisation and participatory approaches	Creation of committees and councils	Councils created more out of institutional necessity than social demand.	Civil society late appearance and with less political weight.
Almeida and Tatagiba (2012)	Arena of contestation and reproduction of inequalities	Management councils	Councils reproduce internal social hierarchies.	Representation does not guarantee deliberative power.

Source: The authors.

The governance approach proposed by Abers and Keck (2013) shifts the focus from participation as a norm to participation as a practice. The authors demonstrated that authority within these councils is constructed by networks of actors who mobilise technical, political, and relational resources. However, this construction is marked by inequalities: major users and government institutions maintain a central position, while civil society faces structural weaknesses. These authors show that participation in these governance bodies tends to be formal rather than deliberative, characterised by civil society's limited capacity to exert influence and significant variation across states — particularly regarding transparency and access to information (Table 3).

Table 3 – Water Governance and councils

Authors	*Concept of Governance*	*Collegiate role*	*State-Users-CSO relations*	*Main tensions*
Jacobi *et al.* (2012)	Governance as multi-actor coordination	Coordination and decision-making bodies	Difficulty in coordinating between government sectors and levels	Material and informational barriers to qualified participation
Abers and Keck (2013)	Building "practical authority" in networks	Central arenas for negotiation	The State and large-scale users with significant technical capital versus civil society in a vulnerable position.	Asymmetry of resources and expertise
Abers and Tatagiba (2015)	Institutional activism and contestation within the State	Spaces of activism and conflict	Social actors try to influence decisions from within institutions	Structural limits on the influence of less powerful actors
Pires and Gomide (2015)	Governance as coordination and participation	Councils as instruments for democratic governance	The State needs to share power with society and users.	Resistance to opening up and to capture by organised interests
Matos, Dias and Carrieri (2022)	Governance with gender equity yields benefits for society.	Democratic governance in the reconfiguration of relations between State and society	Representation of collective interests in the political arena and in the definition of the public agenda	Modus operandi of the relationships between the actors involved
ANA (2022, 2025a and 2025b)	Governance as SINGREH indicator	The system's institutional nodes	Unequal relations between sectors and between regions	Institutional fragility in several states

Source: The authors.

The critique by Almeida and Tatagiba (2012) regarding management councils as political arenas helps us understand that SINGREH's collegiate bodies are not neutral spaces but rather settings where social inequalities are reproduced. This interpretive framework paves the way for incorporating gender analyses and demonstrates that women's participation in these councils is shaped by symbolic, material, and institutional barriers. The authors highlight that, even when women hold seats on these bodies, their influence is limited by factors such as the sexual division of labour, the undervaluing of their expertise, and the persistence of deliberative practices that privilege male voices. This perspective is confirmed, quantified, and contextualised by Matos, Dias, and Carrieri (2022) through their description of women's participation profiles based on gender-disaggregated data from the CRHEDs (Table 4).

Table 4 – Gender, equity and councils

Authors	*Gender approach*	*Findings about women's participation*	*Obstacles identified*	*Implications for equity in SINGREH*
Almeida and Tatagiba (2012)	Focus on internal inequalities, not gender	Councils reproduce social hierarchies	Structural inequalities (class, political capital)	Allow for a gender-based reading of these inequalities.
Abers and Keck (2013); Abers and Tatagiba (2015)	Power and networks are addressed, not gender	Show who accumulates practical authority (generally men in positions of power).	Technical capital, political networks, institutional position	Can show how these networks are gendered.
Matos, Dias and Carrieri (2022)	Gender as a central axis of analysis	Quantitative and qualitative gender profile with disaggregated socioeconomic data	Structural inequalities and differences in participation profiles and behavioural aspects by gender	Concept of participatory parity
ANA (2022, 2025a and 2025b)	Mentions women's participation in a descriptive manner.	Low female representation on some governance bodies	Lack of systematic data; absence of specific equity policies	Need to monitor and encourage greater participation by women

Source: The authors.

Integrating these perspectives reveals that participation in SINGREH's governance bodies is structured by multiple layers of inequality. While, on the one hand, these bodies represent an institutional advance by creating spaces for deliberation on water management, on the other, the effectiveness of such participation depends on conditions that are not yet fully guaranteed. Gender inequality, in particular, highlights that the democratisation of water management cannot be understood solely in terms of presence; rather, it must consider the actual distribution of voice, power, and influence. Thus, gender equity emerges not as a peripheral issue, but as a prerequisite for realising the promise of democratic water resource management (Phillips, 1995; Pitkin, 1967).

On the other hand, limitations revealed by the comparative analysis of sources include the restricted use of an intersectional approach and the failure to directly address gender as a theme. Significant temporal gaps between analyses are also evident, as are difficulties in tracking the dynamic nature of representation regarding issues such as participation and governance (Phillips, 1995; Pitkin, 1967). Finally, there are discontinuities in academic research — stemming from factors such as ideological setbacks, lack of funding, and lack of interest — which hinder the establishment of a solid foundation on the subject and undermine both institutional credibility and the development of solutions.

An analysis of data from Brazil's 27 subnational Water Councils (ANA, 2025a), presented in Table 1, revealed significant diversity among the variables of interest. Regarding the organisation of CHRED's work into Technical Committees (TCs), the councils organised themselves into 1 to 15 TCs, with an average of 4. As for membership size — as stipulated in their internal regulations — the councils comprised between 10 and 39 members (averaging 27), serving terms ranging from 2 to 4 years.

This information was broken down by gender, revealing an average composition of 72% men and 28% women across the CRHEDs. This variable also showed significant disparities among the states, which can be more clearly observed in Figure 1. While women hold only 7% of the seats on CHRED in Paraíba and Piauí, this number reaches 50% and 53% in Mato Grosso and Mato Grosso do Sul, respectively.

Regionally, the Center-West and North show higher female participation (42% and 32%, respectively), whereas the Southeast and South match the average (28%), and the Northeast falls below the average at 22%.

According to Nogueira (2023), gender inclusion is a necessary requirement — a condition — for the effectiveness of SINGREH regarding the democratisation of access and participation in decision-making. Gender inequality compromises effectiveness by limiting perspectives and solutions, and it restricts justice, given the simple fact that there are more women than men in Brazil (IBGE, 2023): 104.5 million women (51.5%) versus 98.5 million men (48.5%). Thus, SINGREH's role should be reinforced as an instrument not merely of a technical nature, but one of social justice (Phillips, 1995).

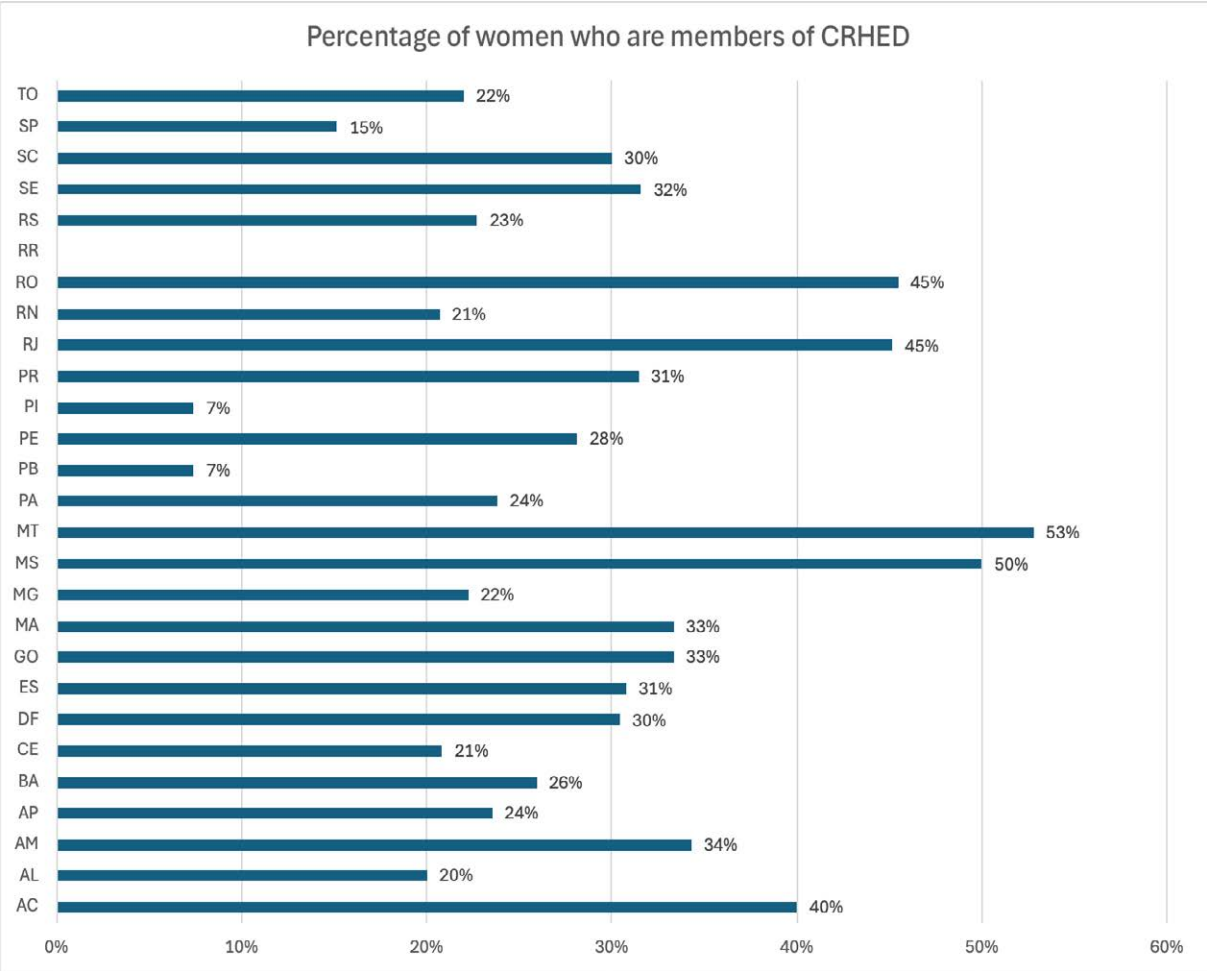

Figure 1 – Percentage of women who are full members of CRHED

Source: The authors.

Analysing the representation of stakeholder categories within the CRHEDs—specifically public authorities, water users, and civil society—it was identified that public authorities (state and municipal) held an average of 45% of the seats, while water users held 21% and civil society organisations held 27%. Interestingly, another 9% of the seats could not be categorised into the three aforementioned groups (Figure 2).

Comparing these figures with the provisions of CNRH Resolution No. 05/2000 (Brazil, 2000) — which establishes guidelines for the formation and operation of River Basin Committees (CBHs) — is revealing, even though these committees operate at a lower level within the SINGREH framework. The resolution

stipulates that public sector representatives must comprise no more than 40% of CBH members, CSOs must hold at least 20% of the seats, and institutions representing water users must account for exactly 40%. These percentages, set by the highest authority within SINGREH, reflect a concern for ensuring the participation of the water users — whose activities depend directly on water availability — and for balancing the roles of public authorities and CSOs. Specifically, the public sector's representation is capped at a level lower than that of the other two sectors to prevent government bodies from exerting total dominance over the CBHs' decisions.

Regarding the CRHEDs, however, it is observed that, at the state level, water policies have not reflected — or do not adhere to — this same concern. The data analysed in Figure 2 show that 16 of the 27 federal units have more than 40% of their members representing the public sector. It is worth noting that the "others" category also includes representatives from the federal government, which could raise this percentage even further. Municipal public authorities' representation is absent from the CRHEDs of MS, MT, RN, RO, RS, and SC (6 out of 26 federal units), as well as the Federal District (DF) itself.

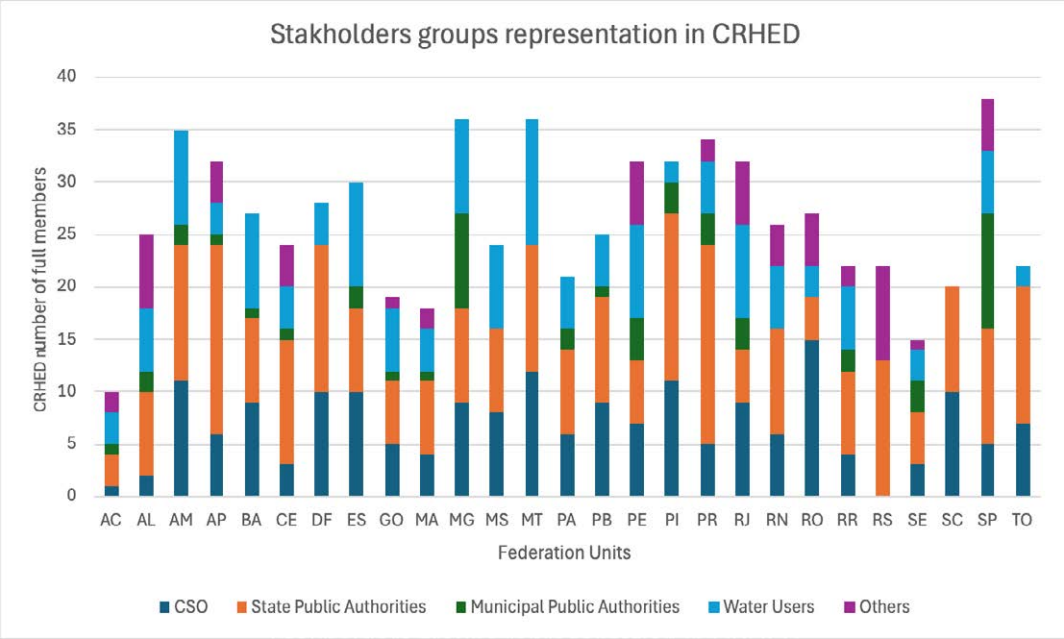

Figure 2 – Participation of groups of stakeholders in CRHEDs by federative unit

Source: The authors.

As Cesar, Luna, and Perkins (2020) point out, a successful transition from tragedy to solution regarding the management of common-pool resources in Brazil requires the consolidation of decentralised arenas in which the State acts as a facilitator rather than a hegemonic actor. The asymmetry observed in the 2024 data constrains the potential for self-organisation among water users and CSOs—elements the authors deem fundamental to the sustainability of environmental policies in the country. It is also worth noting that the current composition of the CNRH itself is highly unequal, with 70% of members representing public authorities, 16% representing water resource users, and 14% representing civil society organisations (Brazil, 2024).

Regarding CSO representation, eight of the 27 federal units fail to meet the 20% minimum threshold for full members in this segment—with the CRHED/RS surprisingly showing 0%. Although it could be argued that seven of the 20 seats in Rio Grande do Sul are allocated to CBHs, the leadership of these bodies does not necessarily represent CSOs within the basin, as the positions may also be held by representatives of public authorities or water users. Finally, regarding the Water Users category, on

average, only 21% of the seats on the CRHEDs are allocated to this group, and in none of the UFs do they account for more than 33% of the represented institutions. It is also worth noting that users have no direct representation in RS and SC, and represent less than 10% in AP, PI, and TO.

The regional asymmetries and the heavy concentration of seats held by public authorities within Brazilian Water Councils resonate with the international debate on the effectiveness of institutional arrangements. According to the OECD Principles on Water Governance (2015), the fragmentation of competencies and the lack of symmetry among actors create capacity gaps that undermine the implementation of integrated water policies. From the perspective of Ostrom's (1990) polycentric governance, sustainable management of common-pool resources requires that deliberative bodies operate with a genuine balance of power and autonomy across their constituent groups. When the government sector dominates the deliberative arena, mutual trust and the capacity to resolve local conflicts are weakened.

Data indicating the functioning of these Councils were also analysed — specifically the holding of meetings (both regular and extraordinary) and the number of resolutions published by the CRHED (Table 1). Although the average frequency of meetings was close to quarterly (3.9), limited activity was observed in some cases, with only one (AC) or two meetings (AP, DF, MS, PR, and SE) held during the year. From a regional perspective, CRHEDs in the Northeast, North, and Southeast regions managed, on average, to hold the planned number of meetings, whereas the Central-West and South regions fell slightly short.

Great dispersion was also observed regarding the production of deliberations, with emphasis on MG (25) and RS (32), while the AC published only 1 resolution, referring to the approval of the Progestão data, a requirement of the Program itself. In general, the CRHED in the North and Northeast regions produced 1 deliberation per meeting, in the Central-West, 2 deliberations per meeting, while those in the Southeast produced almost 3, and in the South, close to 5 deliberations per meeting. Despite the number of published deliberations, it is also necessary to analyse their content, specifically regarding their relevance for the effective management of state-owned water resources. This level of analysis, however, was not covered by the present work.

The analysis revealed striking differences among Brazilian regions. Regional disparities demonstrate that each state operates with distinct institutional capacities, social compositions, and deliberative dynamics. The Center-West region shows greater gender inclusion, with relatively high rates (DF ~30%, MS ~50%, MT ~53%). However, public authorities predominate, while CSOs and water users were less represented. In the Northeast, women's participation is extremely low, averaging around 22% across the region, with inferior values of just 7% in Paraíba and Piauí. There are institutional inconsistencies and limited social diversity, with states adhering to their schedules (BA, PE), while others show low output in terms of approved resolutions (PB, PI, and SE), revealing unequal administrative capacity. In the North, female participation ranged from 22% (TO) to 45% (RO), revealing a heterogeneity of active councils coexisting with those with low levels of activity (AP and TO), and — as seen in RR — there are extensive formal structures, such as 18 technical chambers, alongside low social inclusion.

In the Southeast region, characterised by robust structures and significant deliberative output, female participation averages 28%—with Rio de Janeiro (RJ) standing out at 45% and São Paulo (SP) showing low inclusion (15%), illustrating a gender balance disparity. In the South region, female participation is close to 30%, yet there are significant imbalances in deliberative output and low meeting frequency. Notably, Rio Grande do Sul (RS) accounts for 32 deliberations across just three meetings. From an operational standpoint, this scenario suggests a heavy agenda per session, raising the hypothesis of a concentrated deliberative dynamic — the qualitative depth of which warrants investigation in future studies — while Santa Catarina (SC) shows low regulatory output (2), and Paraná (PR) has few meetings (2) but a high number of deliberations (11).

Cases like RS — with only three meetings yet 32 resolutions — suggest a concentration of decisions within a few sessions and a lack of continuity in deliberations. In contrast, cases like AM — where many meetings take place but yield few resolutions — indicate low decision-making effectiveness. The data analysed corroborate previous findings pointing to significant variability in institutional capacities and inconsistency in meetings and resolutions (Vitória, 2023), as well as regional inequalities regarding CSO participation (Marcondes; Moreira, 2021) — specifically concerning gender representation, with women underrepresented by an average of 30% (ANA, 2022), and the predominance of public authorities in terms of stakeholders' categories representation (Marcondes; Moreira, 2021).

Furthermore, given that the administrative capacity of CRHEDs is a cornerstone of their effectiveness, the data indicates that many councils appear to face structural, operational, and staffing limitations that compromise their performance as governance bodies for water management. Another factor supporting this view is the limited number of technical committees in several states (AC, DF, GO), which may signal a lack of capacity for specialised analysis. Indeed, without TCs, councils must rely solely on the plenary session to address complex issues — such as water use permits, water body classification, and charging mechanisms — thereby overburdening members and diminishing the technical depth of decisions.

The findings of this study regarding the low frequency of plenary meetings and the regional disparity in the production of resolutions corroborate the analyses by Cesar, Luna, and Perkins (2019) concerning the empirical reality of common-pool resources in Brazil. The authors caution that the formal existence of committees or councils does not guarantee democratic management; if operational rules replicate old hierarchies or centralise decision-making within the state apparatus, regulatory effectiveness is compromised. Thus, the operational limitations identified in the CRHEDs demonstrate that the Brazilian institutional arrangement still faces severe bottlenecks in translating participatory rights into actual deliberative influence.

4 FINAL CONSIDERATIONS

It is evident that, in recent years, there has been an increase in scientific publications addressing specific topics such as CREHDs, gender equity in water policy, and even substantial changes in governance regulations at the national level. However, regarding gender equity, a notable gap exists in the debate and in-depth exploration of the subject within the analysed publications—whether focused on CREHDs or broadened to include SINGREH as a whole—highlighting the relevance and urgency of discussing this topic as a fundamental element of participation and governance.

Regarding the governance profile of the CRHEDs themselves, public sector dominance was observed across almost all councils, alongside relatively low participation from civil society organisations and water users. This marked imbalance favouring the public sector can limit the diversity of these collegiate bodies, creating conditions where State agendas prevail over balanced social agreements. Such disparities in representation and operational consistency can undermine the dynamism of participatory governance, distancing the councils from the decentralised model envisioned by legislation. A potential consequence of this distortion in representative dynamics — compounded by the lack of national standards and scientific support for evaluation and improvement — is the undermining of both the legitimacy and effectiveness of water policies, thereby failing to fulfil the Councils' role as participatory management bodies.

The underrepresentation of women in CRHED reinforces the exclusion of relevant social groups, weakening the Councils' decisions as they fail to represent the various stakeholders of SINGREH in a balanced manner. It is essential to recognise that gender inclusion is fundamental to fulfilling the democratic mission of the Brazilian National Water Policy; otherwise, there is a risk that the social inequalities prevalent in Brazilian society will be replicated within these Water Councils.

Compromised participation and representativeness, in turn, contribute to making governance less effective, manifesting as councils that—despite being formally constituted and meeting regularly—fail to fulfil their normative and deliberative mandates. This unbalanced deliberative output reveals two distinct operational weaknesses: on the one hand, the inefficiency resulting from frequent meetings that yield no practical outcomes; on the other, the risk of decision-making overload and superficial debate caused by an accumulation of agenda items.

Thus, the importance of producing and making available consistent data on a regular basis is reiterated, enabling the monitoring of variables relevant to the effective functioning of CREHDs — regarding both their legally assigned competencies and their adherence to the principles and foundations of water policy. Regarding regional disparities, the absence of a national governance standard — as called for by legislation — is also noted, hindering the integration and coordination of SINGREH.

Given that the formulation, approval, and implementation of public policies involve deliberate choices by political actors — translating and reproducing ideologies, priorities, interest-group pressures, and perceptions of social needs — it is crucial that bodies such as CREHDs incorporate these advances and perspectives more swiftly. At the same time, expanding academic output is essential to offset or prevent setbacks, such as the one regarding gender issues in the comprehensive Water Resources Situation Report 2025 (ANA, 2025b). CREHDs serve as relevant arenas for debate and the construction of governance; while participation exists within them, it remains unequal and asymmetrical. Therefore, it is necessary for CREHDs to increase the visibility of Water Policy, establish and expand channels for social oversight, and open their doors to new actors—however imperfectly—so that the National Water Resources Policy may truly become decentralised and participatory.

NOTES

1 | https://www.researchgate.net/

2 | https://scholar.google.com/?hl=pt-BR

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Sections of this manuscript were structured with the assistance of Microsoft 365 Copilot (version 2.20260722.19.0) to support data organisation and the creation of charts and tables. All results were subsequently reviewed, edited, and updated by the authors. We assume full responsibility for the final content and confirm that AI tools did not contribute to the conceptual development, data interpretation, or conclusions.

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Representatividade e gestão participativa das águas: um retrato dos Conselhos Estaduais e Distrital em 2024

Representation and participatory water management: a portrait of the State Councils in 2024

Andréa Paula de Carestiato Costa [1]

Thiago Gil Barreto Barros [2]

Daniela Nogueira Soares [3]

[1] Mestrado em Psicossociologia de Comunidades e Ecologia Humana, Mestranda, Gestão e Regulação de Recursos Hídricos, Universidade de Brasília, Brasília, DF, Brasil
E-mail: acarestiato@gmail.com

[2] Mestrado em Ciências Florestais, Mestrando, Gestão e Regulação de Recursos Hídricos, Universidade de Brasília, Brasília, DF, Brasil

E-mail: thiagogilbarros@gmail.com

[3] Doutorado em Sociologia, Professora, Programa de Mestrado Profissional em Gestão e Regulação dos Recursos Hídricos; Pesquisadora Plena, Centro de Desenvolvimento Sustentável, Universidade de Brasília, Brasília, DF, Brasil
E-mail: danielanogueiracds@gmail.com

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ARTICLE- VARIA

RESUMO

A composição e o funcionamento dos Conselhos de Recursos Hídricos dos Estados e do Distrito Federal – CRHED – deveriam refletir o caráter descentralizado e participativo da Política Nacional de Recursos Hídricos. A ausência de uma base de dados nacional sobre os CRHED, contudo, dificulta o escrutínio social e a reflexão sobre o perfil do Sistema Nacional de Gerenciamento de Recursos Hídricos – SINGREH. Este estudo avaliou a participação dos segmentos da sociedade em 27 CRHED, identificando a preponderância do poder público (44%) sobre os usuários de recursos hídricos (21%) e a sociedade civil (26%). Foram analisadas informações sobre gênero, quantidade de reuniões e a produção de deliberações em 2024, que apontaram uma sub-representação feminina (28%), e um funcionamento desigual entre as unidades da Federação. Destaca-se a importância da produção de dados com regularidade para o monitoramento dos CRHED em relação ao seu efetivo funcionamento e aos princípios e fundamentos da política das águas.

Palavras-chave: Recursos hídricos. Governança. Colegiado. Participação.

ABSTRACT

The composition and functioning of Water Resources State Councils (CRHED) should reflect the decentralised and participatory aspects of the Brazilian national water resources policy. The absence of a national database on the CRHED, however, hinders social scrutiny and consideration of the current characteristics of the Brazilian Water Resources Management System - SINGREH. This study examined stakeholder participation in 27 CRHEDs, identifying the prevalence of the public sector (44%) over water resource users (21%) and civil society organisations (26%). It also examined gender information, the number of meetings, and the approval of deliberations throughout 2024, pointing to an underrepresentation of women (28%) and an uneven level of functioning among federal states. The importance of producing data on a regular basis is highlighted, allowing the monitoring of the CRHED in relation to their effectiveness and adherence to the principles and foundations of water policy in Brazil.

Keywords: *Water. Governance. Collegiate body. Participation.*

1 INTRODUÇÃO

Os Conselhos de Recursos Hídricos dos Estados e do Distrito Federal (CRHED), criados pela Lei nº 9.433/1997, que instituiu a Política Nacional de Recursos Hídricos (Brasil, 1997), são órgãos colegiados normativos, consultivos e deliberativos que integram o Sistema Nacional de Gerenciamento de Recursos Hídricos (SINGREH). Eles estão presentes na quase totalidade das unidades federativas, com exceção do Acre, sendo compostos por representantes do poder público, dos usuários de água e da sociedade civil.

Sua função é deliberar sobre a Política Estadual de Recursos Hídricos de cada unidade da Federação, acompanhar a execução dos planos estaduais, promover a articulação com políticas setoriais, arbitrar conflitos pelo uso da água de domínio estadual e garantir a participação social na gestão (Brasil, 1997). Esta última depende diretamente da efetiva representatividade de cada um dos segmentos: poder público, usuários de água e sociedade civil.

Os CRHED se articulam com o Conselho Nacional de Recursos Hídricos (CNRH) e com os Comitês de Bacia Hidrográfica (CBH), conformando a rede de instâncias de governança hídrica do Brasil, no âmbito do Sistema Nacional de Gerenciamento de Recursos Hídricos – SINGREH. Em algumas unidades da Federação, também integram o Sistema Estadual ou Distrital de Gerenciamento de Recursos Hídricos (SEGRHI) os Fundos de Recursos Hídricos e as Agências de Água.

Na perspectiva da caracterização de sua governança, os CRHED têm sido objetos usuais de relatórios técnicos e administrativos, para além das constatações acerca de suas fragilidades. A busca pela compreensão de como sua estrutura, composição e dinâmica podem promover ou comprometer sua função como instância colegiada de gestão participativa da água, é ainda um aspecto pouco explorado por estudos específicos que possam lançar luz sobre o processo histórico da ação, impactos e contribuições oferecidas. Entre as diversas implicações dessa escassez de produção científica sobre os CRHED, como séries históricas de sua constituição, composição e funcionamento, a ausência de estudos comparativos nacionais pode dificultar a formulação de diretrizes para o seu fortalecimento institucional, a mensuração do impacto de sua atuação, bem como a busca por maior legitimidade e representatividade social desses colegiados, com destaque para a condição da (dis)paridade de gênero nos CRHED.

A natureza extremamente dinâmica dos Conselhos de Recursos Hídricos dos Estados e do Distrito Federal torna a análise da sua composição e representatividade, bem como de sua efetividade deliberativa, um objeto bastante complexo. A ausência de uma base de dados nacional e unificada, bem como a

escassez de publicações abordando tais aspectos, revela um campo de pesquisa ainda negligenciado. Néris (2021) trata da participação social na gestão hídrica no caso do CRHED de São Paulo destacando como as organizações da sociedade civil influenciam as decisões do Conselho e tornam a gestão mais legítima e democrática, embora enfrente desafios como a predominância de interesses econômicos e a composição desigual dos colegiados.

Há quase duas décadas, Tundisi e Matsumara-Tundisi (2008) já acentuavam a importância de uma abordagem sistêmica e preditiva na governança de recursos hídricos, considerando as bacias hidrográficas como um "desenho" para a integração de processos biogeofísicos, econômicos e sociais, o que poderia se constituir em efetivo instrumento de gestão para o enfrentamento dos problemas locais, regionais e nacionais, a partir de uma base de dados consolidada.

Assim, como um retrato atualizado da realidade institucional, o presente trabalho busca contribuir para a compreensão sobre como os CRHED estão funcionando no presente e quais desafios emergem, em especial, a identificação de assimetrias no âmbito da governança hídrica e da participação, fornecendo elementos para a superação de lacunas de conhecimento e ampliação do debate acadêmico. Além disso, um levantamento de um ano pode funcionar como linha de base para estudos longitudinais (Minayo; Deslandes; Gomes, 2024, p.79), criando-se um marco que poderá ser comparado com anos posteriores e viabilizando a identificação de tendências, avanços ou retrocessos.

Dessa forma, o objetivo deste artigo é caracterizar a composição, a representação dos segmentos e as condições da participação, inclusive das mulheres, dos CRHED brasileiros, analisando como tais aspectos impactam sobre a efetividade dessas instâncias colegiadas para uma governança democrática e participativa das águas.

2 MATERIAIS E MÉTODOS

O presente estudo teve por base a análise documental relativa à implementação e funcionamento dos CRHED no Brasil, tendo como fontes de informação artigos científicos e publicações acadêmicas, bem como relatórios de gestão produzidos no âmbito do SINGREH. A revisão bibliográfica de artigos, dissertações e teses associadas prioritariamente aos CRHED e, complementarmente, a participação, governança e gênero no SINGREH, cobriu o período de 2000 a 2025, a partir de trabalhos brasileiros em português.

Além de um artigo de revisão bibliográfica ampla relativo aos CRHED (Marcondes; Moreira, 2021), foi pesquisado o termo "Conselhos Estaduais de Recursos Hídricos" nas plataformas *ResearchGate*[1] e Google Acadêmico[2], obtendo-se poucos resultados. Em função dessa limitação, o escopo de pesquisa bibliográfica foi ampliado, de modo a considerar o SINGREH como elemento da revisão, o que permitiu agregar novas fontes bibliográficas ao esforço analítico deste artigo. Os resultados são apresentados e interpretados à luz da literatura sobre participação, governança e gênero do SINGREH na seção seguinte.

Uma fonte de dados de especial relevância foi o relatório técnico do Programa de Consolidação do Pacto Nacional pela Gestão das Águas – Progestão (ANA, 2020) "Estabelecimento do Relatório de Situação dos Conselhos Estaduais de Recursos Hídricos – 1ª Fase – Diagnóstico dos Conselhos Estaduais de Recursos Hídricos" (ANA, 2025a). Os dados sistematizados pela Agência Nacional de Águas e Saneamento Básico (ANA) tiveram como referência o ano-base de 2024, com exceção de Alagoas, para o qual foram utilizados dados de 2023. Foram coletadas informações complementares por meio de consulta direta aos sítios eletrônicos dos órgãos gestores nos governos estaduais de Acre (2025), Rio de Janeiro (2025), Rio Grande do Sul (2025) e Roraima (2025).

As informações sistematizadas contemplavam as seguintes categorias:

- Número de Câmaras Técnicas do Conselho;
- Número de membros do Conselho de acordo com o Regimento Interno;
- Número de mulheres e homens membros titulares do Conselho;
- Número de membros por segmento da sociedade civil, poder público municipal, poder público estadual, usuários, outros;
- Duração do mandato dos membros;
- Número de reuniões plenárias do Conselho previstas;
- Número de reuniões plenárias do Conselho realizadas;
- Número de deliberações do Conselho no ano.

Os dados tabulados compõem a Tabela 1, a partir da qual se desenvolveu análise qualitativa das práticas e processos de governança em recursos hídricos nas diferentes unidades federativas brasileiras.

Tabela 1 – Dados sistematizados de Conselhos Estaduais e Distrital

UF	Ano ref.	Nº Câmaras Técnicas	Nº membros RI	Nº Mulheres	Nº Homens	Nº Soc. Civil	Nº Poder Público Estadual	Nº Poder Público Municipal	Nº Usuários	Nº Outros	Duração do mandato em anos	Reuniões previstas no ano	Reuniões realizadas no ano	Deliberações no ano
AC	2024	1	10	4	6	1	3	1	3	2	2	1	1	1
AL	2023	n/i	25	5	20	2	8	2	6	7	2	4	4	2
AM	2024	15	39	12	23	11	13	2	9	0	2	6	7	2
AP	2024	2	33	4	13	6	18	1	3	4	3	4	2	2
BA	2024	5	27	7	20	9	8	1	9	0	4	4	4	3
CE	2024	0	24	5	19	3	12	1	4	4	2	4	5	6
DF	2024	1	28	7	16	10	14	0	4	0	2	4	2	3
ES	2024	4	30	8	18	10	8	2	10	0	2	6	5	6
GO	2024	1	18	6	12	5	6	1	6	1	2	4	4	13
MA	2024	5	18	6	12	4	7	1	4	2	3	6	7	9
MG	2024	3	36	8	28	9	9	9	9	0	2	n/i	4	25
MS	2023	3	24	12	12	8	8	0	8	0	3	3	2	2
MT	2024	6	36	19	17	12	12	0	12	0	2	6	7	16
PA	2024	4	21	5	16	6	8	2	5	0	4	4	3	3
PB	2024	3	27	2	25	9	10	1	5	0	2	4	4	2
PE	2024	4	32	9	23	7	6	4	9	6	3	4	4	4
PI	2024	4	27	2	25	11	16	3	2	0	2	4	4	2
PR	2024	4	35	11	24	5	19	3	5	2	4	2	2	11
RJ	2024	7	32	14	17	9	5	3	9	6	3	6	6	10
RN	2024	2	32	6	23	6	10	0	6	4	2	2	3	7
RO	2024	1	30	5	6	15	4	0	3	5	2	5	5	8
RR	2024	n/i	18	n/i	n/i	4	8	2	6	2	2	6	6	n/i
RS	2024	8	22	5	17	0	13	0	0	9	2	6	3	32
SE	2024	n/i	19	6	13	3	5	3	3	1	3	4	2	2
SC	2024	4	20	6	14	10	10	0	0	0	0	2	3	2

UF	Ano ref.	Nº Câmaras Técnicas	Nº membros RI	Nº Mulheres	Nº Homens	Nº Soc. Civil	Nº Poder Público Estadual	Nº Poder Público Municipal	Nº Usuários	Nº Outros	Duração do mandato em anos	Reuniões previstas no ano	Reuniões realizadas no ano	Deliberações no ano
SP	2024	7	33	5	28	5	11	11	6	5	2	3	3	14
TO	2024	3	26	11	39	7	13	0	2	0	3	4	4	12

Fonte: Elaborado pelos autores.

2.1 LIMITAÇÕES DO ESTUDO

Este trabalho apresenta limitações associadas à natureza dos dados secundários coletados, que dependem da regularidade e da atualização das bases de dados estaduais e distritais e dos relatórios do SINGREH. Identificaram-se lacunas pontuais de informação como a ausência de dados de gênero para o estado de Roraima.

Adicionalmente, por se tratar de um recorte essencialmente quantitativo e descritivo, focado no ano-base de 2024, a metodologia adotada não permite avaliar qualitativamente o conteúdo e o impacto das deliberações publicadas, tampouco mensurar a influência política real ou o grau de engajamento efetivo de cada ator nas plenárias.

3 RESULTADOS E DISCUSSÃO

A norma regulamentadora do CNRH, Decreto nº 11.960, de 21 de março de 2024 (Brasil, 2024), traz em sua última versão uma representação mais equilibrada para a sociedade civil, essencial para promover a transparência e a democracia participativa, fortalecendo a gestão dos recursos hídricos com a presença de vozes que até então não pertenciam ou não eram reconhecidas nesse âmbito. Entre as recentes inovações na composição do CNRH destacam-se (Art. 3º, XXV):

> [...] sete de organizações da sociedade civil de recursos hídricos, dos quais:
>
> d) um das organizações representativas dos **povos indígenas** com atuação em colegiados de recursos hídricos;
>
> e) um das organizações representativas das **comunidades tradicionais** com atuação em colegiados de recursos hídricos; e
>
> f) um de organização nacional de representação dos **Municípios** (Brasil, 2024) (grifo nosso).

Em relação à participação das mulheres, Matos (2024) afirma que:

> Ao longo das últimas décadas, a agenda de debates internacional sobre os direitos das mulheres e igualdade de gênero evoluiu de maneira significativa impulsionada pelos movimentos sociais, nas conferências globais, declarações e compromissos multilaterais que envolveram diversos atores, como as Nações Unidas, organizações não governamentais e governos. Diversos estudos destacam que as relações de gênero demarcam diferentes papéis, responsabilidades, valores e relações de poder aos quais homens e mulheres são submetidos (p. 3).

No entanto, segundo a ANA (2022), análises dos colegiados do SINGREH indicam uma sub-representação de mulheres em cargos de gestão no setor de águas e saneamento, embora a participação em divisões

internas, de perfil mais técnico, possa variar. O último relatório pleno, Conjuntura dos Recursos Hídricos da ANA (2025b), contudo, não aborda a estratificação de gênero dos representantes do Sistema como na edição anterior de 2022, e, dessa forma, o debate sobre proporção de homens e mulheres nos colegiados do SINGREH fica enfraquecido e perde a relevância que alcançou naquela ocasião. Assim, houve a interrupção prematura do que poderia ter se tornado uma série histórica capaz de orientar a formulação de políticas de inclusão e equidade de gênero no SINGREH.

A oportunidade de acesso a dados de 2024, fruto de levantamento realizado pela ANA a partir de sites dos CRHED e de relatórios de gestão, revelou-se oportunidade ímpar para um diagnóstico contemporâneo sobre o tema e o possível alargamento da percepção quanto à participação, governança e inclusão de gênero nesse âmbito *vis-à-vis* à discussão de revisão de literatura científica. Também Marcondes e Moreira (2021) promoveram um levantamento bibliográfico acerca dos Conselhos de Recursos Hídricos, considerando o período entre 2000 e 2020, que resultou na identificação de 65 trabalhos, e demonstrando que a maior parte das pesquisas se concentrou nas experiências regionais ou estaduais, sem trazer análises na esfera nacional. Essa lacuna foi mitigada pela abrangente pesquisa nacional liderada por Fernanda Matos (Dias; Carrieri, 2022) e a dissertação de Beatriz S. Vitória (2023).

Nos últimos seis anos, surgiram algumas análises mais específicas sobre os CRHED, relacionadas à pesquisa e à formação de recursos humanos para a gestão integrada de recursos hídricos, focadas em temas como governança, participação e gênero em recursos hídricos a exemplo de Matos (2024), Matos, Dias e Carrieri (2022), Néris (2021) e Vitória (2023). Tais análises indicam uma possível existência de fragilidades institucionais que, juntamente com as desigualdades regionais e a escassez de informação acadêmica, podem restringir o debate sobre a governança hídrica.

Ampliando-se o escopo de análise para o conjunto de atores do SINGREH, identificaram-se contribuições de autores que discutem os desafios de representação, governança e a participação em diferentes instâncias, incluindo os conselhos estaduais. De forma geral, a literatura especializada tem se debruçado sobre o tema sob diferentes perspectivas, buscando compreender não apenas a presença formal de atores sociais nesses espaços, mas sobretudo a qualidade, profundidade e efetividade dessa participação. O conjunto de estudos revela que, embora os CRHED representem um avanço institucional significativo, sua capacidade de promover participação substantiva permanece em disputa. Particularmente, com as pesquisas de Matos, Dias e Carrieri (2022) no contexto da série "Retratos de Governanças das Águas" pela Universidade Federal de Minas Gerais – UFMG, obteve-se um primeiro marco quantitativo de organismos de bacia e seus membros no Brasil, com capítulos dedicados ao papel dos CRHED, à questão de gênero na gestão dos recursos hídricos e à participação e violência de gênero, além de abordar aspectos metodológicos que envolvem a necessidade de dados desagregados por gênero.

Ademais, Matos, Dias e Carrieri (2022) apresentam os resultados em panorama nacional, com enfoque sobre a caracterização do perfil socioeconômico dos representantes, enfatizando aspectos com a referência inicial de gênero dos representantes, em seguida observando os dados desagregados por idade, escolaridade, formação e renda. O estudo analisou ainda a representação de gênero segregada com base na titularidade e suplência nos colegiados, com ênfase sobre a qualidade da participação das mulheres nessas instâncias em Conselhos Estaduais. Importante ressaltar que, embora com uma abordagem diferente da deste artigo, foi possível constatar resultados comparativos próximos aos encontrados quando se considera os dados desagregados por gênero em ambas as pesquisas. A literatura sobre participação nos colegiados de recursos hídricos revela um campo marcado por tensões entre avanços institucionais e persistência de desigualdades estruturais (Quadro 1).

Quadro 1 – Participação nos Conselhos de Recursos Hídricos dos Estados e do Distrito Federal (CRHED)

Autor(es)	*Como definem participação*	*Foco principal*	*Diagnóstico central*	*Papel da sociedade civil*
Abers e Jorge (2005)	Descentralização e participativas	Criação de comitês e conselhos	Conselhos criados mais por exigência institucional do que por demanda social	Sociedade civil entra tardiamente e com menor peso político
Almeida e Tatagiba (2012)	Arena de disputa e reprodução de desigualdades	Conselhos gestores em geral	Conselhos reproduzem hierarquias sociais internas	Representação não garante poder deliberativo

Fonte: Elaborado pelos autores.

A abordagem de governança proposta por Abers e Keck (2013) desloca o foco da participação como norma para a participação como prática. As autoras demonstraram que a autoridade nos conselhos é construída por redes de atores que mobilizam recursos técnicos, políticos e relacionais. Contudo, essa construção é marcada por desigualdades: grandes usuários e órgãos governamentais mantêm centralidade, enquanto a sociedade civil enfrenta fragilidades estruturais. Esses autores mostram que a participação nos colegiados tende a ser mais formal do que decisória, com baixa capacidade de influência da sociedade civil e forte variação entre estados, especialmente no que se refere à transparência e ao acesso à informação (Quadro 2).

Quadro 2 – Governança da água e conselhos

Autor(es)	*Conceito de governança*	*Papel dos colegiados*	*Relação Estado–usuários–sociedade civil*	*Principais tensões identificadas*
Jacobi *et al.* (2012)	Governança como articulação multiator	Instâncias de coordenação e deliberação	Dificuldade de articulação entre segmentos e níveis de governo	Barreiras materiais e informacionais à participação qualificada
Abers e Keck (2013)	Construção de "autoridade prática" em redes	Arenas centrais de negociação	Estado e grandes usuários com forte capital técnico; sociedade civil em posição frágil	Assimetria de recursos e expertise
Abers e Tatagiba (2015)	Ativismo institucional e disputa dentro do Estado	Espaços de ativismo e conflito	Atores sociais tentam influenciar decisões a partir de dentro das instituições	Limites estruturais à influência de atores menos poderosos
Pires e Gomide (2015)	Governança como coordenação e participação	Conselhos como instrumentos de governança democrática	Estado precisa compartilhar poder com sociedade e usuários	Resistência à abertura e captura por interesses organizados
Matos, Dias e Carrieri (2022)	Governança com equidade de gênero proporciona benefícios à sociedade	Governança democrática na reconfiguração das relações entre Estado e sociedade	Representação de interesses coletivos na cena política e na definição da agenda pública	Modus operandi das relações entre atores envolvidos
ANA (2022, 2025a, 2025b)	Governança como desempenho do SINGREH	Nós institucionais do sistema	Relações desiguais entre segmentos e entre regiões	Fragilidade institucional em vários estados

Fonte: Elaborado pelos autores.

A crítica de Almeida e Tatagiba (2012) aos conselhos gestores enquanto arenas políticas ajuda na compreensão de que os colegiados do SINGREH não são espaços neutros, mas instâncias nas quais se reproduzem desigualdades sociais. Essa chave interpretativa abre caminho para a incorporação de análises de gênero e demonstra que a participação das mulheres nos conselhos é atravessada por barreiras simbólicas, materiais e institucionais. A autora evidencia que, mesmo quando mulheres ocupam assentos nos colegiados, sua influência é limitada por fatores como divisão sexual do trabalho, a menor valorização de sua expertise e a reprodução de práticas deliberativas de privilegiar vozes masculinas. Essa perspectiva é confirmada, mensurada e qualificada por Matos, Dias e Carrieiri (2022) com a descrição do perfil de participação das mulheres baseado em dados desagregados de gênero nos CRHED (Quadro 3).

Quadro 3 – Gênero, equidade e conselhos

Autor(es)	*Como tratam gênero*	*Achados sobre participação feminina*	*Barreiras identificadas*	*Implicações para equidade nos colegiados SINGREH*
Almeida e Tatagiba (2012)	Não focam gênero, mas desigualdades internas	Indicam que conselhos reproduzem hierarquias sociais	Desigualdades estruturais (classe, capital político)	Abrem caminho para leitura de gênero como dimensão dessas desigualdades
Abers e Keck (2013); Abers e Tatagiba (2015)	Não tratam gênero, mas tratam poder e redes	Mostram quem acumula autoridade prática (em geral homens em posições de poder)	Capital técnico, redes políticas, posição institucional	Leitura de gênero pode mostrar como essas redes são generificadas
Matos, Dias e Carrieri (2022)	Gênero como eixo central de análise	Perfil quantitativo e qualitativo de gênero com dados socioeconômicos desagregados	Desigualdades estruturais, diferenças dos perfis de participação e aspectos comportamentais por gênero	Concepção de paridade da participação
ANA (2022, 2025a, 2025b)	Menciona participação de mulheres de forma descritiva	Baixa presença feminina em alguns colegiados	Falta de dados sistemáticos e ausência de políticas específicas de equidade	Necessidade de monitorar e induzir maior participação de mulheres

Fonte: Elaborado pelos autores.

A integração dessas perspectivas revela que a participação nos colegiados do SINGREH é estruturada por múltiplas camadas de desigualdade. Se, por um lado, os colegiados representam avanço institucional ao abrir espaços de deliberação sobre a água e recursos hídricos, por outro, a efetividade dessa participação depende de condições que ainda não estão plenamente asseguradas. A desigualdade de gênero, em particular, evidencia que a democratização da gestão hídrica não pode ser compreendida apenas em termos de presença, mas deve considerar a distribuição real de voz, poder e influência. Assim, a equidade de gênero emerge para além de um tema periférico, como condição para que a promessa de gestão democrática dos recursos hídricos se concretize (Phillips, 1995; Pitkin, 1967).

Por outro lado, dos limites revelados pela análise comparativa das fontes, destacam-se as reduzidas abordagens por interseccionalidade, ou a não tematização direta de gênero. Também são identificadas lacunas temporais amplas entre as análises, além de dificuldades em monitorar o dinamismo da representação em se tratando de temas como participação e governança (Phillips, 1995; Pitkin, 1967). Por fim, destacam-se as descontinuidades das pesquisas acadêmicas por motivos como

retrocessos ideológicos, ausência de financiamento e desinteresse, o que implica na dificuldade para o estabelecimento de uma base sólida sobre o tema, além do prejuízo à credibilidade institucional e ao desenvolvimento de soluções.

Analisados dados de Conselhos de Recursos Hídricos das 27 unidades da Federação brasileiras – UF (ANA, 2025a), apresentados no Quadro 1, verificou-se grande diversidade entre as variáveis de interesse. Em relação à organização dos trabalhos em Câmaras Técnicas – CT, os CRHED se subdividiam entre 1 e 15 Câmaras Técnicas, com uma média de 4 CT. Quanto ao número de membros, conforme previsto em regimento interno, os CRHED são compostos de 10 a 39 membros, com média de 27 membros, exercendo mandatos de 2 a 4 anos de duração.

Essa informação foi desagregada por gênero e indicou média de 72% de homens e 28% de mulheres na composição dos CRHED. Também essa variável apresentou grandes disparidades entre as UF, que podem ser mais bem observadas na Figura 1. Enquanto na Paraíba e no Piauí apenas 7% das vagas dos Conselhos Estaduais são ocupadas por mulheres, em Mato Grosso e Mato Grosso do Sul esse percentual chega a 50% e 53% respectivamente. Regionalmente, observa-se que Centro-Oeste e Norte apresentam maior participação feminina (42% e 32% respectivamente), enquanto Sudeste e Sul igualam a média (28%) e Nordeste se localiza abaixo da média com 22%.

A inclusão de gênero é um requisito, uma condição necessária para efetividade do SINGREH no sentido amplo da democratização do acesso e participação na tomada de decisão, segundo Nogueira (2023), pois a desigualdade de gênero compromete a efetividade, limitando perspectivas, soluções e a justiça, pelo simples fato de haver mais mulheres do que homens no Brasil (IBGE, 2023): 104,5 milhões de mulheres (51,5%) contra 98,5 milhões de homens (48,5%). Dessa forma, deveria-se reforçar o papel do SINGREH como instrumento não apenas técnico, mas de justiça social (Phillips, 1995)

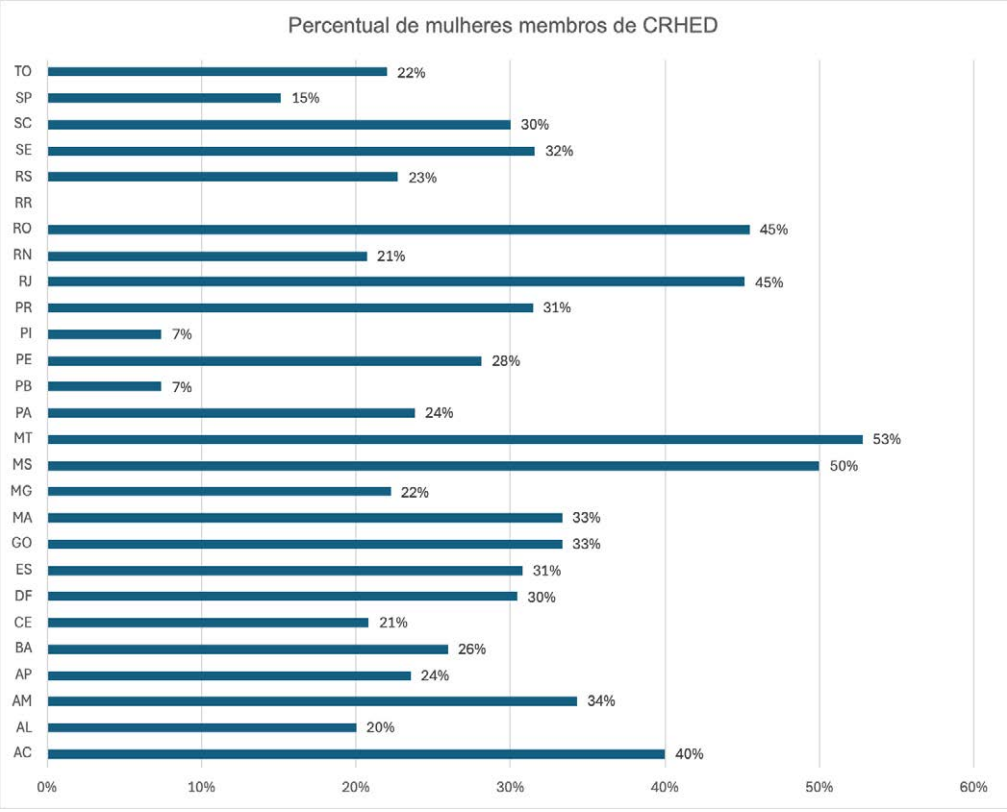

Figura 1 – Percentual de mulheres membros titulares de CRHED
Fonte: Elaborado pelos autores.

Em análise à representação dos segmentos da sociedade nos CRHED, sabidamente, poder público, usuários e sociedade civil, verificou-se média de 45% de vagas ocupadas pelo poder público (estadual e municipal), com 21% pelos usuários de recursos hídricos e 27% pela sociedade civil. Interessantemente, outros 9% das vagas não puderam ser enquadradas nos três segmentos anteriores (Figura 2).

Confrontar esses números com o previsto pela Resolução CNRH nº 05 de 2000 (Brasil, 2000), que estabelece diretrizes para a formação e o funcionamento dos Comitês de Bacia Hidrográfica, embora se trate de nível inferior no SINGREH, é interessante quanto ao significado inerente. A referida resolução define que no máximo 40% dos membros de CBH sejam representantes do setor público, que no mínimo 20% das vagas sejam destinadas para organizações da sociedade civil e exatos 40% para instituições representantes de usuários de recursos hídricos. Esses percentuais, fixados pelo órgão máximo do SINGREH, trazem consigo a preocupação de garantir participação do setor usuário, que depende diretamente da disponibilidade hídrica para suas atividades, e um balanceamento entre poder público e sociedade civil, com teto inferior ao quantitativo dos outros dois setores para o poder público de maneira a evitar a dominância total dos órgãos de governo sobre as decisões dos Comitês.

Em relação aos CRHED, contudo, observa-se que as políticas estaduais não trouxeram ou não obedecem a essa mesma preocupação. Os dados analisados na Figura 2 mostram que 16 das 27 UF apresentam mais de 40% de seus membros enquanto representantes do setor público. Cumpre destacar que constam do grupo "outros" também representantes do poder público federal, o que pode elevar ainda mais esse percentual. O poder público municipal não está presente nos CRHED de MS, MT, RN, RO, RS e SC (6 de 26 UF), além do próprio DF.

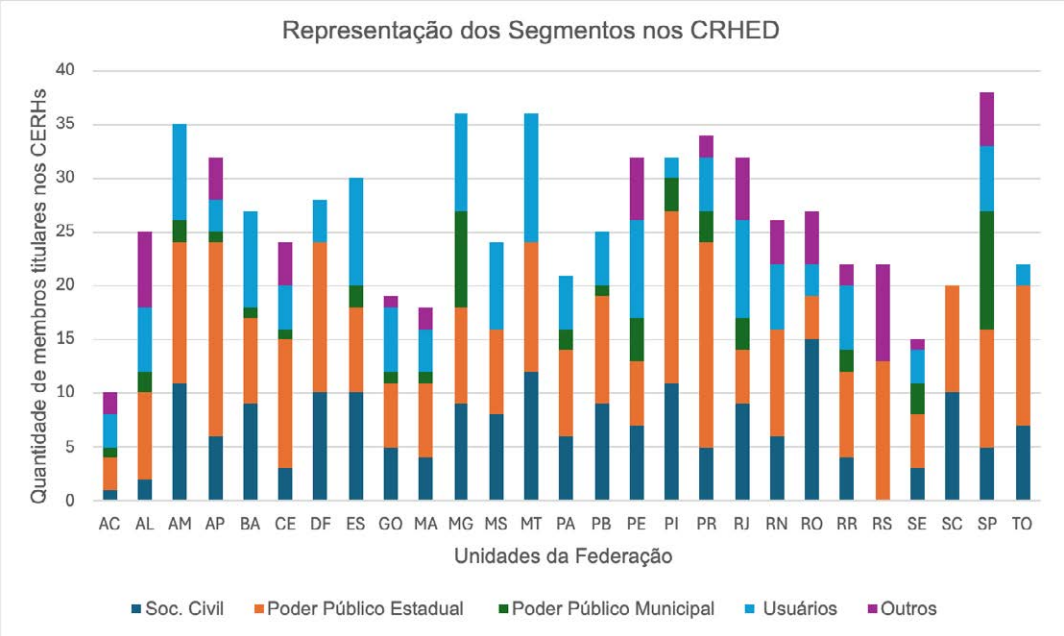

Figura 2 – Participação dos segmentos da sociedade nos CRHED por unidade da Federação

Fonte: Elaborado pelos autores.

Como apontam Cesar, Luna e Perkins (2020), a transição exitosa da tragédia à solução na gestão dos bens comuns no Brasil pressupõe a consolidação de arenas descentralizadas em que o Estado atue como facilitador, e não como ator hegemônico. A assimetria observada nos dados de 2024 restringe o potencial de auto-organização dos usuários e da sociedade civil, eixos que os autores consideram fundamentais para a sustentabilidade de políticas ambientais no país. Registra-se, ainda, que a

composição atual do próprio CNRH é extremamente desigual, com 70% dos membros representando o poder público, 16% os usuários de recursos hídricos e 14% as organizações da sociedade civil (Brasil, 2024).

Em relação à representação da sociedade civil, oito das 27 UF não atingem o mínimo de 20% de seus membros titulares nesse segmento, surpreendentemente com 0% no CRHED/RS. Embora possa se argumentar que 7 das 20 vagas no Rio Grande do Sul são destinadas a Comitês de Bacias Estaduais, a presidência dessas instâncias não necessariamente representa a sociedade civil no estado, podendo também estar ocupada por representantes do poder público e de usuários de recursos hídricos.

Finalmente, observado o segmento usuários de recursos hídricos, em média apenas 21% das vagas dos CRHED estão destinadas a esse grupo, e em nenhuma das UF ultrapassa 33% das instituições representadas. Destaca-se ainda que os usuários não estão diretamente representados no RS e em SC, e são menos de 10% no AP, PI e TO.

As assimetrias regionais e a forte concentração de vagas no poder público identificadas nos Conselhos de Recursos Hídricos brasileiros encontram eco no debate internacional sobre a eficácia de arranjos institucionais. De acordo com os Princípios de Governança da Água da OCDE (2015), a fragmentação de competências e a falta de simetria entre os atores geram lacunas de capacidade que comprometem a implementação de políticas hídricas integradas. Sob a ótica da governança policêntrica de Ostrom (1990), a sustentabilidade na gestão de recursos comuns exige que os colegiados operem com real equilíbrio de poder e autonomia de seus segmentos. Quando o setor governamental domina a arena deliberativa, fragiliza-se a confiança mútua e a capacidade de resolução de conflitos locais.

Foram analisados também dados que pudessem indicar o funcionamento desses Conselhos, notadamente a realização de reuniões, tanto ordinárias quanto extraordinárias, e a quantidade de deliberações publicadas pelo CRHED (Tabela 1). Embora a média de reuniões realizadas esteja próxima de trimestral (3,9), em alguns casos verificou-se reduzida atividade, com apenas uma (AC) ou duas reuniões (AP, DF, MS, PR e SE) realizadas no ano. Em um recorte regional, observa-se que os CRHED das regiões Nordeste, Norte e Sudeste conseguiram, em média, realizar o quantitativo planejado de reuniões, enquanto as regiões Centro-Oeste e Sul ficaram um pouco aquém.

Grande dispersão foi observada também quanto à produção de deliberações, com destaque para MG (25) e RS (32), enquanto o AC publicou apenas 1 resolução, referente à aprovação dos dados Progestão para envio à própria ANA. De maneira geral, os CRHED das regiões Norte e Nordeste produziram 1 deliberação por reunião, no Centro-Oeste, 2 deliberações por reunião, enquanto os do Sudeste quase 3, e no Sul próximo de 5 deliberações por reunião. A despeito da quantidade de deliberações publicadas, cumpre analisar também o teor destas, em específico quanto à relevância para o efetivo gerenciamento de recursos hídricos de domínio estadual. Esse nível de análise, contudo, não foi contemplado pelo presente trabalho.

A análise revelou diferenças marcantes entre regiões brasileiras. As assimetrias regionais demonstram que cada estado opera com capacidades institucionais, composição social e dinâmica deliberativa distintas. No Centro-Oeste há maior inclusão de gênero com índices relativamente altos (DF ~30%, MS ~50%, MT ~53%) contudo, com predominância do poder público, sendo que a sociedade civil e usuários possuem menos representatividade. Na Região Nordeste, observa-se baixíssima participação das mulheres, com média regional em torno de 22%, com extremos de apenas 7% na Paraíba e no Piauí. Há baixa diversidade social e irregularidade institucional como em alguns estados que cumprem seu calendário (BA e PE), enquanto outros apresentam baixa produção em termos de deliberações aprovadas (PB, PI e SE), revelando desigualdade de capacidade administrativa. No Norte, a participação feminina variou de 22% (TO) a 45% (RO), sendo que se demonstrou heterogeneidade em relação aos aspectos de conselhos ativos que convivem com conselhos com reduzido grau de atividade (AP e TO) e estrutura formal ampla como em RR com 18 câmaras técnicas, mas baixa inclusão social.

Já a Região Sudeste, com estruturas robustas, atividades deliberativas com produções relevantes, tem na participação feminina a média de 28%, com destaque para RJ (45%) e a baixa inclusão em SP (15%) demonstrando a assimetria no equilíbrio de gênero. No Sul, por sua vez, a participação feminina está próxima de 30%, e assimetrias importantes na produção de deliberações com baixos índices de realizações de reuniões, sendo que o RS concentra 32 deliberações em apenas três reuniões. Esse cenário sinaliza, do ponto de vista operacional, uma densa pauta por sessão, o que levanta a hipótese de uma dinâmica deliberativa concentrada, cuja profundidade qualitativa dos debates merece ser investigada em estudos futuros; SC apresenta baixa produção normativa (2); e PR tem poucas reuniões (2), mas muitas deliberações (11).

Os casos como o RS com apenas três reuniões, mas 32 deliberações, sugerem concentrações de decisões em poucos encontros e debates descontinuados. Em contraste, casos como o do AM, em que se realizam muitas reuniões com poucas deliberações, indicam baixa efetividade decisória. Os dados analisados corroboram afirmações já apresentadas que indicam elevada variabilidade de capacidades institucionais e a irregularidade nas reuniões e deliberações (Vitória, 2023); desigualdades regionais em termos de participação da sociedade civil (Marcondes; Moreira, 2021), em especial quanto à representatividade de gênero com a sub-representação das mulheres em média de 30% (ANA, 2022) e a predominância do poder público no contexto da representatividade (Marcondes; Moreira, 2021).

Complementarmente, tendo a capacidade administrativa dos CRHED como um dos pilares para sua efetividade, os dados demonstram que muitos conselhos parecem enfrentar limitações estruturais, operacionais e de pessoal que comprometem sua atuação como instância colegiada de gestão da água. Outro aspecto que permite esse entendimento é o número de câmaras técnicas reduzido em diversos estados (AC, DF e GO), o que pode indicar baixa capacidade de análise especializada. Ora, sem câmaras técnicas, os conselhos dependem exclusivamente da plenária para tratar de temas complexos como outorga, enquadramento e cobrança, o que sobrecarrega os membros e reduz a profundidade técnica das decisões.

Os achados deste estudo relativos à baixa frequência de reuniões plenárias e à disparidade regional na produção de deliberações corroboram as análises de Cesar, Luna e Perkins (2019) sobre a atualidade empírica dos recursos comuns no Brasil. Os autores advertem que a existência formal de comitês ou conselhos não garante, por si só, uma gestão democrática; se as regras operacionais mimetizarem velhas hierarquias ou centralizarem as decisões no aparato estatal, compromete-se a eficácia regulatória. Assim, os limites operacionais diagnosticados nos CRHED demonstram que o arranjo institucional brasileiro ainda enfrenta gargalos severos para converter os direitos de participação em influência deliberativa real.

4 CONSIDERAÇÕES FINAIS

Foi possível constatar que, nos últimos anos, houve aumento de publicações científicas tratando de temas específicos como os CRHED, equidade de gênero na política de águas e mesmo mudanças substanciais na regulação da governança na esfera nacional. Contudo, no caso da equidade de gênero, constata-se uma sensível lacuna no debate e no aprofundamento do tema no âmbito das publicações analisadas entre os limites da revisão, seja por CRHED ou ampliada ao SINGREH, mostrando a pertinência e a urgência da discussão do tema enquanto elemento fundamental da participação e governança.

Quanto ao retrato de governança dos CRHED propriamente dito, constatou-se a predominância do poder público em quase todos os conselhos, com relativa baixa participação da sociedade e dos usuários. Essa forte assimetria a favor do poder público pode limitar a pluralidade do colegiado, criando cenários propícios ao predomínio das agendas do Estado em detrimento de pactos sociais equilibrados. Tais desequilíbrios na representação e na regularidade das atividades podem fragilizar o dinamismo da governança participativa, distanciando os conselhos do modelo descentralizado preconizado pela

legislação. Uma possível consequência desse tipo de distorção das dinâmicas de representação, da falta de padrões nacionais e de suporte científico para avaliação e aprimoramento, é o comprometimento tanto da legitimidade quanto da efetividade das políticas públicas de recursos hídricos, não cumprindo sua função de instância colegiada de gestão participativa.

A sub-representação das mulheres nos CRHED reforça a exclusão de grupos sociais relevantes, enfraquecendo as decisões dos Conselhos, os quais não conseguem representar de forma equilibrada os diferentes atores do SINGREH. É preciso reconhecer a condição estruturante da inclusão de gênero como realização da missão democrática da Política Nacional de Recursos Hídricos, sob o risco de se reproduzir também nos Conselhos de Recursos Hídricos as desigualdades sociais presentes na sociedade brasileira de modo geral.

O comprometimento da participação e da representatividade, por sua vez, contribui para tornar a governança menos efetiva, manifestando-se sob a forma de conselhos que, embora formalmente constituídos e regularmente reunidos, não cumprem suas competências normativas e deliberativas. A produção deliberativa desbalanceada expõe duas fragilidades operacionais distintas: por um lado, a ineficiência gerada por reuniões frequentes sem resultados práticos e, por outro, o risco de sobrecarga decisória com debates superficiais devido ao acúmulo de pautas.

Reitera-se, assim, a importância da produção e disponibilização de dados consistentes e em periodicidade regular para permitir o monitoramento de variáveis de interesse quanto ao efetivo funcionamento dos CRHED em relação às competências a eles atribuídas por lei e à aderência aos princípios e fundamentos da política das águas. Das desigualdades regionais, registra-se ainda a ausência de padrão nacional de governança preconizado pela legislação, dificultando a integração e coordenação do SINGREH.

Considerando que a formulação, aprovação e implementação de políticas públicas envolvem escolhas deliberadas por atores políticos, traduzindo e reproduzindo ideologias, prioridades, pressões de grupos de interesse e a percepção das necessidades da sociedade, é importante que colegiados como os CRHED incorporem com mais agilidade tais avanços e perspectivas, ao passo que se promova a ampliação da produção acadêmica de forma a compensar ou evitar retrocessos, como o ocorrido com o tema de gênero no relatório pleno Conjuntura dos Recursos Hídricos 2025. Os CRHED são arenas relevantes de disputa e construção de governança; neles a participação existe, mas é desigual e assimétrica. Faz-se necessário, portanto, que os CRHED ampliem a visibilidade da Política de Recursos Hídricos, criem e ampliem os canais de controle social e abram portas para novos atores, ainda que de forma imperfeita, para que a Política Nacional de Recursos Hídricos se torne de fato descentralizada e participativa.

NOTAS

1 | https://www.researchgate.net/

2 | https://scholar.google.com/?hl=pt-BR

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Science and knowledge brokering in institutional arenas: the Brazilian climate agenda between 1999 and 2009

Ciência e intermediação em arenas institucionais: a agenda climática brasileira entre 1999 e 2009

Andréa Nascimento de Araújo [1]

Karen de Oliveira Silverwood-Cope [2]

Evandro Albiach Branco [3]

Jean Pierre Henry Balbaud Ometto [4]

[1] PhD in Earth System Science, Science and Technology Analyst,
Ministry of Science, Technology and Innovation,
Brasília, DF, Brazil
E-mail: anaraujo.andrea@gmail.com

[2] PhD in Political Science, Director of Climate, Economics and Finance,
World Resources Institute Brazil,
Brasília, DF, Brazil
E-mail: karencope@gmail.com

[3] PhD in Environmental Sciences, Researcher,
National Institute for Space Research (Inpe),
São José dos Campos, SP, Brazil
E-mail: *evandro.albiach@inpe.br*

[4] *PhD in Environmental Sciences, Researcher,*
National Institute for Space Research (Inpe), São José dos Campos, SP, Brazil
E-mail: jean.ometto@inpe.br

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ABSTRACT

This article investigates how science and scientific and technical brokers shaped the formation of Brazil's climate agenda between 1999 and 2009. Drawing on Kingdon's Multiple Streams Framework, it analyses how science was mobilised across the problem, policy, and politics streams. The study adopts a mixed-methods approach based on the coding of minutes and reports from the Interministerial Commission on Global Climate Change (CIMGC), within the executive branch, and the Joint Committee on Climate Change (CMMC), within the legislature. Findings show that the CIMGC operated in a fragmented manner, centred on executive-branch specialists, with predominantly conceptual and symbolic uses

of science and moderate scientific influence. By contrast, the CMMC functioned as a more pluralistic arena, mobilising mixed uses of science and strengthening its influence by linking technical diagnoses to politically recognised problems and viable policy alternatives. Institutional arrangements shaped both the legitimacy of science and its circulation across decision streams.

Keywords: Climate Change. Multiple Streams Framework. Knowledge Brokerage. Policy Agenda. Brazil.

RESUMO

Este artigo examina como a ciência e os intermediadores científico-técnicos atuaram na formação da agenda climática brasileira entre 1999 e 2009. À luz do Modelo dos Fluxos Múltiplos, analisa como a ciência foi mobilizada nos fluxos de problemas, alternativas e político. A pesquisa adota uma abordagem qualiquantitativa baseada na codificação de atas e relatórios da Comissão Interministerial de Mudança Global do Clima (CIMGC), no Executivo, e da Comissão Mista sobre Mudanças Climáticas (CMMC), no Legislativo. Os resultados mostram que a CIMGC operou de forma fragmentada, centrada em especialistas do Executivo, com usos da ciência predominantemente conceituais e simbólicos, e influência científica moderada. Em contraste, a CMMC constituiu uma arena mais plural, mobilizando usos mistos da ciência e ampliando sua influência ao conectar diagnósticos técnicos a problemas politicamente reconhecidos e alternativas viáveis. Os arranjos institucionais moldaram tanto a legitimidade da ciência quanto sua circulação entre os fluxos decisórios.

Palavras-chave: *Mudança do Clima. Modelo dos Fluxos Múltiplos. Intermediação do Conhecimento. Agenda de Políticas Públicas. Brasil.*

1 INTRODUCTION

Science plays a central role in climate policymaking by providing evidence-based assessments of the causes, impacts and possible responses to climate change. However, the availability of scientific knowledge does not guarantee that such knowledge will be translated into politically recognised problems or public policy decisions. The literature has shown that the influence of science depends on institutional processes, power relations and specific forms of mediation at the science–policy interface (Cairney, 2016; Capano; Malandrino, 2022).

In Brazil, the development of a national climate policy occurred relatively late despite significant advances in climate science and the country's growing engagement in international climate governance. This mismatch makes it analytically relevant to examine the institutional conditions under which science does – or does not – translate into influence on the domestic climate agenda. Accordingly, this study asks: how did science and technical-scientific brokers operate within the problem, policy and politics streams during the formation of the Brazilian climate agenda between 1999 and 2009? To address this question, the study draws upon the Multiple Streams Framework (MSF) and compares the role of two key institutional arenas in the Brazilian climate agenda: the Interministerial Commission on Global Climate Change (*Comissão Interministerial de Mudança Global do Clima* – CIMGC), a body within the federal Executive Branch, and the Joint Committee on Climate Change (*Comissão Mista sobre Mudanças Climáticas* – CMMC), established within the Brazilian National Congress.

1.1 HISTORICAL CONTEXT OF THE BRAZILIAN CLIMATE AGENDA (1990-2009)

Brazil's climate agenda began to take shape in the late 1980s, alongside the consolidation of the international climate regime. The establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988 and the adoption of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 brought Brazil into multilateral arenas grounded in global scientific consensus. The

Kyoto Protocol, adopted in 1997, reinforced this process by creating differentiated mechanisms for international cooperation, such as the Clean Development Mechanism (CDM).

During this initial period, climate-related issues were primarily managed by Brazil's Ministry of Foreign Affairs (MRE) and Ministry of Science and Technology (MCT). The creation of the Interministerial Commission on Global Climate Change (*Comissão Interministerial de Mudança Global do Clima* – CIMGC) in 1999 expanded the coordination of the national climate agenda. The commission brought together eight sectoral ministries and two advisory bodies linked to the Presidency of the Republic in order to coordinate Brazil's position in international climate negotiations and approve projects under the CDM (Brasil, 1999). Although this initiative represented an important institutional advance, it remained strongly oriented towards the domestic implementation of international commitments and the reproduction of the internationalist logic that characterised Brazilian climate policy at the time (Kiessling, 2018; Lahsen, 2009).

From 2003 onwards, changes in the domestic political context contributed to the expansion and diversification of the institutional arenas involved in climate policymaking. The Ministry of the Environment (MMA) assumed a more prominent role, leading interministerial initiatives such as the Action Plan for the Prevention and Control of Deforestation in the Brazilian Legal Amazon (PPCDAm) and promoting greater integration between scientific knowledge and public policy. This shift was accompanied by the creation of new institutional bodies, including the Brazilian Climate Change Forum (FBMC) and the Interministerial Committee on Climate Change (CIM), as well as increased investment in the national scientific community. Together, these developments signalled the progressive internalisation of climate change as a domestic policy issue and the diversification of decision-making arenas. At the same time, institutional disputes intensified among ministries holding different views on Brazil's role within the global climate regime (Andrade; Escada, 2023; Franchini; Viola, 2019; Hochstetler, 2021; Rodrigues, 2022).

Within this increasingly politicised context, the Legislative Branch assumed a more active role, particularly following the establishment of the Joint Special Committee on Climate Change (*Comissão Mista Especial sobre Mudanças Climáticas* – CMEMC) in 2007 and the Joint Permanent Committee on Climate Change (*Comissão Mista Permanente sobre Mudanças Climáticas* – CMMC) in 2009. Through public hearings and official reports, these committees expanded opportunities for dialogue among legislators, executive officials and climate-change specialists (CMEMC, 2008; CMMC, 2009).

Between 1990 and 2009, the Brazilian climate agenda evolved from a political-diplomatic arrangement centred on the federal Executive Branch into a more plural and politically contested system.

1.2 THEORETICAL FRAMEWORK

The Multiple Streams Framework (MSF), developed by Kingdon (2011), provides the analytical foundation for this study. The framework conceptualises agenda formation as the outcome of the interaction among three relatively independent streams: the problem stream, the policy stream, and the politics stream. The problem stream refers to the process through which conditions come to be recognised as public problems, whether through indicators, focusing events, or feedback from existing policies. The policy stream concerns the development and circulation of solutions within specialised communities, whose viability depends both on technical criteria and on their compatibility with prevailing values. The politics stream encompasses changes in government, institutional disputes, public opinion pressures and power dynamics that shape the receptiveness of political systems to policy proposals. In the Brazilian context, the politics stream reflects the institutional arenas, values and power relations that influence decision-making, helping to explain why technical assessments may circulate without becoming political priorities.

A key concept within the MSF is coupling, understood as the temporary convergence of the three streams, a necessary condition for the opening of policy windows and for change to occur on the policy agenda. Coupling is neither automatic nor cumulative; rather, it depends on framing processes, forms of mediation and political disputes that render problems politically recognisable and connect them to available policy alternatives within specific political contexts. Furthermore, coupling may be preceded by what Blum (2018) describes as argumentative pre-coupling, a process through which problems and policy alternatives are technically refined and become politically viable. This perspective helps explain why policy windows sometimes remain closed despite the availability of scientific evidence.

In the Brazilian context, the MSF has been applied to the study of climate policy, highlighting the role of institutions, decision-making arrangements and international influence in shaping and stabilising government agendas, as illustrated by the case of the Brazilian National Climate Change Policy (Silverwood-Cope, 2024).

Revisiting the MSF, Knaggård (2016) highlights a problem-brokering role within the problem stream, actors frame conditions and diagnoses as politically relevant problems and influence their entry onto the policy agenda. Unlike policy entrepreneurs, whose primary role involves promoting solutions, problem brokers are principally engaged in the political work of defining public problems.

Knaggård's contribution resonates with the classical literature on the use of science, which demonstrates that knowledge may influence public policy in different ways. Weiss (1979) identified instrumental, conceptual and symbolic uses of research, challenging linear assumptions according to which scientific knowledge automatically translates into better policy decisions. Subsequent studies have shown that knowledge is used selectively and competes with other inputs, including economic interests, political values and institutional constraints (Capano; Malandrino, 2022; Tangney, 2020). In contexts characterised by high levels of uncertainty, such as climate change, the influence of science depends not only on the robustness of evidence but also on its political relevance and institutional legitimacy (Parkhurst, 2017).

In this regard, the notion of the problem broker is closely related to the broader literature on knowledge brokerage, which examines different repertoires of action at the science-policy interface (Bandola-Gill, 2023; Turnhout *et al.*, 2013)academics are increasingly expected to not only produce research but also engage in brokering knowledge beyond academia. And yet little is known about the ways in which academics shape their practices in order to respond to these new forms of institutionalised expectations and make sense of knowledge brokering as a form of academic practice. Drawing on 51 qualitative interviews with researchers and research users involved in two large knowledge brokering initiatives in the UK, this study identifies four repertoires of co-production practices: (i. These studies operate at a different analytical level from the MSF and help explain how knowledge circulates – or is constrained – during processes of problem framing. Turnhout *et al.* (2013) distinguish between repertoires that maintain boundaries between knowledge production and knowledge use (technical provision) and those that seek to bridge these domains (mediation and facilitation), emphasising that, in practice, even so-called "new roles" may continue to reproduce traditional and linear assumptions.

Knaggård (2016) further argues that the actions of problem brokers are inherently political and may assume a selective character, generating forms of gatekeeping in problem definition by privileging certain framings while excluding others. Although gatekeeping may operate across different streams, it occupies a particularly central role within the problem stream because it directly affects the conditions under which the streams may be coupled.

In this article, these concepts are employed as analytical tools to interpret how science and different forms of brokerage contributed to the activation, blockage or convergence of streams within institutional arenas of the Brazilian climate agenda between 1999 and 2009.

2 METHODOLOGY

This study adopts a mixed-methods, exploratory and interpretive approach based on documentary analysis.

2.1 UNITS OF ANALYSIS AND DOCUMENTARY CORPUS

The study examined two key institutional arenas using the following official sources:

(i) Executive Branch: Interministerial Commission on Global Climate Change (Comissão Interministerial de Mudança Global do Clima – CIMGC).

Corpus: 60 official minutes of CIMGC meetings, including 38 meetings held between 1999 and 2006 and 22 meetings held between 2007 and 2009. The analysis focused on textual content, recorded decisions and institutional follow-up actions.

(ii) Legislative Branch: Joint Committee on Climate Change (Comissão Mista sobre Mudanças Climáticas – CMMC), including its earlier phase as the Joint Special Committee on Climate Change (Comissão Mista Especial sobre Mudanças Climáticas – CMEMC), between 2007 and 2009.

Corpus: the CMEMC Final Report (CMEMC, 2008), the 2009 CMMC Final Report (CMMC, 2009), as well as minutes, verbatim transcripts and standardised summaries relating to 55 deliberative meetings and public hearings, excluding meetings devoted exclusively to administrative matters.

The empirical corpus comprised 115 official meetings or public hearings, complemented by two final committee reports, resulting in a total of 117 documents analysed.

2.2 DATA EXTRACTION PROCEDURES AND CATEGORISATION

Data were extracted through manual content analysis supported by electronic spreadsheets. Three main dimensions were examined:

(i) Participation of effective brokers (recognised scientists or executive-branch specialists occupying decision-making positions);

(ii) Forms of scientific knowledge use (instrumental, conceptual, symbolic or mixed), as well as situations involving blockage or absence of scientific mobilisation; and

(iii) Activation or blockage of streams based on the mobilisation of evidence and institutional articulation.

Routine bureaucratic activities, such as compliance reviews of CDM projects, were not classified as instances of scientific knowledge use.

2.3 ASSESSING THE USE AND DEGREE OF SCIENTIFIC INFLUENCE

The use of science was classified into four categories, drawing on the literature on research utilisation in public policy (Nutley; Walter; Davies, 2007; Weiss, 1979):

- Instrumental: scientific evidence directly informed decisions or policy proposals;
- Conceptual: scientific evidence contributed to problem diagnosis without directly informing policy proposals;
- Symbolic: scientific evidence was used to legitimise pre-existing positions;
- Mixed: more than one type of use occurred simultaneously.

To assess scientific influence within each stream and institutional arena, a qualitative approach combined with categorical quantification was adopted. Each meeting was classified according to four levels of influence: absent (0), low (1), moderate (2), or high (3), depending on the extent to which the scientific knowledge mobilised resulted in concrete decisions, recommendations or institutional actions.

To synthesise these findings, a weighted average was calculated by multiplying the number of meetings in each category by its respective score and dividing the result by the total number of meetings in which the stream was activated.

2.4 IDENTIFICATION OF KINGDON'S STREAMS

The identification of streams took into account both the substance of discussions and the role played by participating actors.

- Problem stream: activated when diagnoses, indicators or focusing events were presented on the basis of scientific evidence, particularly by specialists.
- Policy stream: activated when technically feasible solutions or policy proposals grounded in scientific and technical knowledge were formulated and discussed, in some cases accompanied by institutional articulation.
- Politics stream: activated when legislative or executive deliberation occurred or when executive-branch specialists possessing decision-making authority engaged in significant processes of institutional coordination, negotiation or science-based decision-making.

To capture obstacles to scientific influence, instances of stream blockage were recorded whenever scientific evidence was deliberately rejected, explicitly prevented from influencing deliberations, or when institutional articulation based on scientific and technical knowledge was obstructed. Within the problem stream, blockage was identified when technical diagnoses were not mobilised to define a public problem or were dismissed or disregarded. Within the policy stream, blockage was identified when technically grounded proposals or policy instruments were removed from consideration or rejected without technical

assessment. Within the politics stream, blockage occurred when the committee refused to deliberate on or institutionally advance issues supported by scientific and technical evidence, or when science was confined to a merely symbolic or tactical role without any meaningful deliberative consequences.

2.5 RELATIVE FREQUENCIES

The activation of each stream was calculated in relation to the total number of meetings analysed within each arena and period. In contrast, the relative frequencies of internal indicators within each stream – such as knowledge brokerage, use of science and predominant form of knowledge use – were calculated in relation to the number of meetings in which that stream was activated.

For interpretive purposes, the results were organised into equal percentage ranges: None: 0%; Isolated: 1–10%; Low: 11–25%; Occasional: 26–50%; Recurring: 51–75%; Systematic: 76–100%

2.6 RELIABILITY AND LIMITATIONS

The study is subject to limitations associated with its reliance on official records, which may not fully capture behind-the-scenes deliberative processes, as well as the absence of interviews. The robustness of the analysis was strengthened through a three-tier triangulation strategy: Micro level: detailed examination of meeting minutes and documentary records; Meso level: cross-arena comparative analysis; and Macro level: contextualisation within the international climate regime and the historical development of the Brazilian climate agenda.

3 RESULTS

This section presents the results of the analysis of meetings held by the Interministerial Commission on Global Climate Change (CIMGC) between 1999 and 2009 and the Joint Committee on Climate Change (CMMC) between 2007 and 2009. The findings are organised according to the activation of the problem, policy and politics streams. To enhance the comparison, the trajectory of the CIMGC was divided into two periods (1999–2006 and 2007–2009), allowing potential shifts associated with institutional reconfigurations and the concurrent operation of the CMMC to be identified.

3.1 PROBLEM STREAM

Within the CIMGC, the problem stream was activated on an occasional basis, occurring in 37% of meetings between 1999 and 2006 and in 27% of meetings held between 2007 and 2009. Table 1 summarises the main patterns observed.

Table 1 – Main patterns of problem stream activation, by committee and period

Analytical dimension	*Indicator*	*CIMGC (1999–2006)*	*CIMGC (2007–2009)*	*CMMC (2007–2009)*
Knowledge brokerage	Executive-branch specialists	14 (100%) Systematic	6 (100%) Systematic	26 (59%) Recurring
	Recognised scientists	7 (50%) Recurring	0 None	24 (55%) Recurring
Use of science	Occurrence	13 (93%) Systematic	6 (100%) Systematic	44 (100%) Systematic

Analytical dimension	*Indicator*	*CIMGC (1999–2006)*	*CIMGC (2007–2009)*	*CMMC (2007–2009)*
Type of scientific use	Predominant	Conceptual 8 (57%) Recurring	Mixed 3 (50%) Occasional	Mixed 26 (59%) Recurring
Scientific influence	Mean score (0–3 scale)	1.9 Moderate	2.0 Moderate	2.7 High
Number of meetings	With stream activated	14	6	44
	Analysed	38	22	55

Note: Absolute values indicate meetings in which the stream was activated; percentages refer to the proportion of that total. Frequency and knowledge brokerage categories follow the criteria detailed in the Methodology section.

Source: Authors' own elaboration based on CIMGC minutes (1999–2009) and CMEMC/CMMC records (2007–2009).

Whenever the problem stream was activated during the first period, effective brokerage was systematically performed by executive-branch specialists holding decision-making positions, suggesting the central role of these actors in the mobilisation of policy-relevant diagnoses. In addition, scientists who had assumed positions within the Ministry of Science and Technology (MCT) acted as brokers in 50% of these meetings. The use of science was systematic and predominantly conceptual, relying on references to international scientific reports but without generating practical developments in the form of alternatives to national policy. Scientific influence was classified as moderate, indicating a role that was primarily informative rather than decisional in the construction of public problems.

The 8th meeting (2002) illustrates this pattern. References to IPCC reports were invoked as evidence, but the discussion did not lead to any decisions or follow-up actions. On other occasions, such as the 10th meeting (2003), the commission merely acknowledged decisions formulated elsewhere, without producing additional diagnoses of its own. Even more illustrative is the 17th meeting (2004), which marked an institutional turning point: the CIMGC declared that it lacked the mandate to discuss mitigation, vulnerability or legislative proposals. This stance reinforced a procedural logic, created a blockage in the policy stream and indirectly weakened the role of the problem stream, thereby reducing the conditions for stream coupling.

During the second phase (2007–2009), knowledge brokerage was restricted to executive-branch specialists. The predominant pattern of scientific use was mixed, suggesting a greater potential for linking diagnoses to subsequent actions. Nevertheless, scientific influence remained at a moderate level, since the scientific evidence discussed did not translate into substantive policy proposals. The 32nd meeting (2007) exemplifies this pattern: scientific evidence was mobilised, and technical alternatives were discussed, but the debate remained limited to procedural adjustments.

By contrast, within the Joint Committee on Climate Change (CMMC), the problem stream was activated systematically. Effective brokerage was recurring and more pluralistic, with recognised scientists and executive-branch specialists participating jointly in nearly 25% of meetings. The use of science was systematic and predominantly mixed, combining technical diagnoses with the symbolic legitimisation of climate change as a public problem and with normative proposals. This arrangement resulted in a high level of scientific influence.

The public hearing of 22 September 2009 on deforestation exemplifies this pattern. Monitoring data, climate projections and economic analyses were mobilised and subsequently translated into recommendations concerning Reducing Emissions from Deforestation and Forest Degradation (REDD) initiatives, which were incorporated into the committee's final report (CMMC, 2009, p. 152). Analytically, this suggests a greater capacity to translate scientific diagnoses into politically recognised public problems.

3.2 POLICY STREAM

Table 2 summarises the main patterns of policy stream activation across institutional arenas and periods. Within the Interministerial Commission on Global Climate Change (CIMGC), the policy stream was activated on an occasional basis throughout both periods analysed.

Between 1999 and 2009, although executive-branch specialists were present in nearly two-thirds of all meetings, they acted as effective brokers only sporadically. The use of science was predominantly conceptual, relying on international references and technical criteria without giving rise to substantive policy alternatives. In three meetings (27%), the commission approved regulations related to the CDM without explicitly drawing on scientific evidence, suggesting that the selection of policy alternatives was often driven by administrative routines.

The 11th meeting (2003) is representative of this pattern. Executive-branch specialists discussed sustainability criteria on a technical basis and approved the CIMGC's first resolution governing the operation of Brazil's Designated National Authority for the CDM, including monitoring procedures. Although technical content was present, the discussion remained centred on administrative routines and displayed limited articulation with the other streams.

Table 2 – Main patterns of policy stream activation, by committee and period

Analytical dimension	*Indicator*	*CIMGC (1999–2006)*	*(2007–2009)*	*CMMC (2007–2009)*
Knowledge brokerage	Executive-branch specialists	1 (9%) Isolated	4 (83%) Systematic	21 (40%) Occasional
	Recognised scientists	0 None	0 None	23 (44%) Occasional
Use of science	Occurrence	7 (64%) Recurring	6 (100%) Systematic	52 (100%) Systematic
Type of scientific use	Predominant	Conceptual 4 (36%) Occasional	Instrumental, conceptual and mixed 2 (33% each) Occasional	Mixed 29 (55%) Recurring
Scientific influence	Mean score (0–3 scale)	1.4 Moderate	2.2 High	2.4 High
Number of meetings	With stream activated	11	6	52
	Analysed	38	22	55

Note: Absolute values indicate meetings in which the stream was activated; percentages refer to the proportion of that total. Frequency and knowledge brokerage categories follow the criteria detailed in the Methodology section.

Source: Authors' own elaboration based on CIMGC minutes (1999–2009) and CMEMC/CMMC records (2007–2009).

During the second phase of the CIMGC (2007–2009), both the effective brokerage of executive-branch specialists and the use of science were systematic. A balanced distribution among instrumental, conceptual and mixed uses of science was observed, suggesting a greater potential for connecting diagnoses with policy alternatives. Scientific influence was classified as high, reflecting decisions grounded in technical assessments, coordination with the National System Operator (ONS) and the Ministry of Mines and Energy (MME), as well as the formalisation of regulations. Nevertheless, the circulation of scientific knowledge remained largely confined to procedural matters and did not extend to broader strategic debates.

Within the Joint Committee on Climate Change (CMMC), the policy stream was activated systematically, occurring in 95% of meetings. Scientific knowledge was predominantly used in a mixed manner and exerted a high level of influence. The public hearing held on 11 September 2007 illustrates the translation of technical inputs into policy proposals: scientists and executive-branch specialists supported specific recommendations and proposed monitoring instruments related to the conservation of the Cerrado biome, which were subsequently incorporated into the committee's final report (CMEMC, 2008, p. 73–75).

Analytically, this pattern suggests a greater capacity for the maturation and circulation of policy alternatives within a deliberative setting.

3.3 POLITICS STREAM

Table 3 summarises the main patterns of politics stream activation by committee and period. Within the Interministerial Commission on Global Climate Change (CIMGC), the politics stream was activated in 45% of meetings held between 1999 and 2006 and in 55% of meetings between 2007 and 2009, displaying broadly similar patterns across both periods. In each phase, brokerage was concentrated among executive-branch specialists holding decision-making authority, albeit in a limited manner and without full articulation with the problem and policy streams. The use of science was recurring and fragmented across conceptual, mixed and, in some cases, absent forms of use, indicating that political-administrative deliberation was not always connected to structured evidence or novel policy proposals.

In meetings focused on verifying the compliance of CDM projects, no scientific evidence was mobilised. In these cases, activation of the politics stream resulted primarily from political-administrative coordination, sometimes accompanied by symbolic uses of science intended to legitimise decisions that had already been made. The 50th meeting in 2009 exemplifies this pattern. A proposal for a normative instruction with potential legal, economic and environmental implications was discussed. Technical arguments were presented, and interministerial working groups were established, yet no systematic use of scientific evidence occurred. Resistance was also observed towards creating a permanent role for external epistemic actors, such as the Brazilian Climate Change Forum (FBMC), thereby limiting the institutionalisation of scientific input into decision-making.

Table 3 – Main patterns observed in the activation of the politics stream, by committee and period

Analytical dimension	*Indicator*	*CIMGC (1999–2006)*	*(2007–2009)*	*CMMC (2007–2009)*
Knowledge brokerage	Executive-branch specialists	9 (53%) Recurring	6 (50%) Occasional	0 None
	Recognised scientists	0 None	0 None	23 (43%) Occasional
Use of science	Occurrence	11 (65%) Recurring	9 (75%) Recurring	53 (100%) Systematic
Type of scientific use	Predominant	Conceptual, mixed and absent 4 (24% each) Occasional	Conceptual, mixed and absent 3 (25% each) Occasional	Mixed 29 (55%) Recurring
Scientific influence	Mean score (0–3 scale)	1.4 Moderate	1.4 Moderate	2.4 High

Analytical dimension	Indicator	CIMGC (1999–2006)	(2007–2009)	CMMC (2007–2009)
Number of meetings	With stream activated	17	12	53
	Analysed	38	22	55

Note: Absolute values indicate meetings in which the stream was activated; percentages refer to the proportion of that total. Frequency and knowledge brokerage categories follow the criteria detailed in the Methodology section.

Source: Authors' own elaboration based on CIMGC minutes (1999–2009) and CMEMC/CMMC records (2007–2009).

Within the Joint Committee on Climate Change (CMMC), the politics stream was activated systematically, occurring in 96% of the meetings analysed. Scientific evidence was systematically mobilised in combination with institutional coordination and the formulation of viable policy alternatives, with mixed use of science predominating and scientific influence classified as high. The public hearing held in September 2009 on the Brazilian National Climate Change Policy illustrates this pattern of integration. The hearing informed recommendations concerning emissions-reduction targets and activated the three streams of Kingdon's framework simultaneously (CMMC, 2009, p. 158).

Analytically, this pattern suggests a greater capacity to transform scientific knowledge into a legitimate input for political deliberation within a parliamentary arena.

3.4 CROSS-STREAM ANALYSIS: BLOCKAGES, DISCONNECTION AND STREAM CONVERGENCE

A comparison between the executive arena, represented by the Interministerial Commission on Global Climate Change (CIMGC), and the Legislative arena, represented by the Joint Committee on Climate Change (CMMC), reveals how different institutional arrangements shaped the circulation of science, the ways in which it was used, and the integration of streams. Table 4 summarises the configurations of stream activation and convergence observed across each arena and period, as well as the blockages identified during the coding process, thereby providing context for the patterns described in the previous sections.

Table 4 – Configurations of stream activation, convergence and blockage in the problem, policy and politics streams by arena and period

Stream configuration	CIMGC (1999–2006)	CIMGC (2007–2009)	CMMC (2007–2009)
No stream activated	10 (26%)	10 (45%)	2 (4%)
Isolated activation (one stream)	14 (37%)	5 (23%)	0
Partial convergence (two streams)	14 (37%)	2 (9%)	10 (18%)
Expanded convergence (three streams)	0	5 (23%)	43 (78%)
Total meetings analysed	38	22	55
Identified blockages	5 (13%)	2 (9%)	0

Note: Absolute values indicate the number of meetings, whereas percentages refer to the proportion of the total number of meetings analysed within each arena and period. Stream-activation configurations are mutually exclusive and indicate the number of streams activated individually or simultaneously during each meeting. The category "expanded convergence" corresponds to the simultaneous activation of all three streams and indicates a greater potential for coupling, although it does not, by itself, constitute evidence of effective coupling. Blockages were identified at the stream level during the coding process and are presented in aggregated form by arena and period. As a transversal condition, they are not additive to the activation configurations and may occur alongside them.

Source: Authors' own elaboration based on CIMGC minutes (1999–2009) and CMEMC/CMMC records (2007–2009).

Within the CIMGC, stream activation was irregular and fragmented, with a strong emphasis on administrative routines and compliance assessments associated with the CDM. This pattern is reflected in the predominance of isolated stream activation and partial convergence between streams, as well as in the occurrence of blockages identified exclusively within this arena during the coding process. Between 1999 and 2009, the commission assessed 237 projects submitted under the CDM framework (Brasil, 2009, p. 9), and the meeting records indicate that it avoided deliberating on technical proposals related to the Brazilian National Climate Change Policy, curtailed emerging debates on Reducing Emissions from Deforestation and Forest Degradation (REDD) initiatives, and refused to discuss climate-related legislative proposals amid interministerial disputes. These explicit and implicit blockages were associated with weaker integration between diagnosis, policy alternatives and political deliberation, fostering a pattern of stream disconnection and reducing the conditions favourable to coupling.

Although isolated episodes demonstrated greater scientific influence, such as regulatory decisions concerning methodologies for calculating the emissions factor of Brazil's National Interconnected Electricity System (SIN), these advances remained confined to technical issues and did not result in sustained articulation with the other streams. Consequently, the predominant pattern within the CIMGC was one of stream disconnection, characterised by fragmented action and the failure to capitalise on legitimate opportunities for integration.

By contrast, the CMMC exhibited a more open and pluralistic decision-making pattern, characterised by the systematic occurrence of expanded convergence and the absence of identified blockages. Recognised scientists and executive-branch specialists acted in a coordinated manner through public hearings and committee reports, mobilising evidence to structure policy proposals and foster institutional articulation, as exemplified by the September 2009 public hearing on the Brazilian National Climate Change Policy.

The cross-stream analysis reveals two predominant patterns of stream activation. The first is disconnection, characterised by isolated or only partially integrated activation of streams. The second is expanded convergence, which predominated within the CMMC, where all three streams were activated simultaneously in 78% of the meetings analysed – a proportion classified as systematic according to the interpretive categories outlined in the Methodology section. Alongside these patterns, both implicit and explicit blockages identified during the coding process occurred exclusively within the CIMGC and were associated with the restriction or non-incorporation of scientific evidence, policy proposals and science-based institutional articulation. Although the simultaneous activation of all three streams does not constitute evidence of effective coupling, it indicates a greater potential for integration between diagnoses, policy alternatives and political deliberation. Taken together, these findings reinforce the argument that institutional arrangements shape not only the presence of science in policymaking but also its capacity to circulate across streams and acquire political legitimacy.

4 DISCUSSION

The fundamental difference between the institutional arenas examined in this study was institutional in nature. The Interministerial Commission on Global Climate Change (CIMGC) operated within a more closed and procedural executive arrangement, whereas the Joint Committee on Climate Change (CMMC) functioned as a more pluralistic and deliberative legislative arena.

Within the CIMGC, technical diagnoses were present but displayed limited capacity to reshape political debate. Conceptual uses of science predominated, and, at critical moments, symbolic uses were employed to legitimise routines and decisions that had already been established, without leading to substantive policy alternatives. As a result, science circulated within a decision-making environment in which it had only a limited capacity to become a politically recognised problem or to create more favourable conditions for stream coupling. The absence of permanent spaces for external scientists

and the restriction of debate to executive-branch specialists reinforced the technocratic character of the arrangement and its low permeability to substantive domestic policy disputes. The persistence of a political-diplomatic logic within the CIMGC, closely associated with the routines of the CDM and with the international climate agenda, constrained the circulation of science within broader domestic debates on mitigation and climate policymaking, favouring more selective and procedural uses of scientific knowledge (Lahsen, 2009). In this context, the delimitation of the scope of debate also functioned as a mechanism for stabilising Brazil's position within the international climate regime.

This pattern is consistent with the dynamics described by Knaggård (2016), whereby diagnoses fail to become politically recognised public problems when framing mechanisms are restricted or subordinated to institutional filters. The findings suggest selective dynamics compatible with forms of institutional gatekeeping, operating not only through explicit exclusion but also through the repeated narrowing of what was considered an acceptable policy agenda. The filtering of issues such as mitigation and emerging instruments – including debates surrounding Reducing Emissions from Deforestation and Forest Degradation (REDD) initiatives – reflects a form of selectivity that reduced opportunities for knowledge to circulate across streams and preserved an agenda more compatible with established diplomatic commitments and administrative routines.

By contrast, scientific and technical evidence circulated within the CMMC in a more pluralistic institutional environment, characterised by stronger interaction among science, bureaucracy and parliamentary deliberation. The coordinated involvement of recognised scientists, executive-branch specialists and legislators enhanced the capacity to transform diagnoses into politically recognised problems and to connect them to viable policy alternatives. In this setting, science simultaneously served as a resource for diagnosis, policy formulation and political legitimation, fostering recurring patterns of expanded convergence among the streams and creating more favourable conditions for stream coupling. Although disputes and asymmetries were also present, the committee's institutional openness broadened opportunities for knowledge to circulate across actors and decision-making arenas. In line with Knaggård's (2016) argument, knowledge brokerage occurred in a more comprehensive manner, bringing scientific evidence closer to the deliberative dynamics of the Legislative Branch.

The variation in the use of science across streams and institutional arenas highlights a fundamental distinction: the issue is not one of "more science" versus "less science", but rather which forms of expertise are legitimised, which actors are able to move across institutional arenas, and which diagnoses are capable of acquiring political relevance. When brokerage is limited to the provision of knowledge, with rigid boundaries separating knowledge production from knowledge use, a linear logic tends to prevail, favouring symbolic uses of science and reducing the responsiveness of decision-making processes to expertise (Turnhout *et al.*, 2013). Tangney (2022) goes further by arguing that the persistence of such patterns reflects deliberate institutional and political choices rather than a lack of evidence or failures of translation. From this perspective, the marginalisation of science may serve to preserve established power balances, economic priorities and institutionalised forms of political coordination.

Overcoming the symbolic use of science, therefore, is not a technocratic prescription; rather, it is a necessary condition for diagnoses to effectively influence problem definition and the selection of policy alternatives. The findings highlight the importance of deliberative arenas capable of sustaining repertoires of mediation and facilitation, thereby reducing dependence on institutional filters that obstruct the circulation of knowledge. Bandola-Gill (2023) similarly emphasises that brokerage is not a neutral activity: it involves selecting evidence, defining access and determining which forms of expertise acquire political legitimacy.

The dependence on particular institutional arrangements for scientific diagnoses to gain political traction was already evident during the period examined here and reappeared later as a defining element in the formation, transformation and subsequent retrenchment of the Brazilian National

Climate Change Policy, as demonstrated by Silverwood-Cope's (2024) longitudinal analysis of the policy process. This continuity suggests that the blockages and openings identified in this study were not isolated events, but rather part of a broader institutional trajectory that has shaped the development of Brazilian climate policy.

5 CONCLUSIONS

The findings suggest that the formation of the Brazilian climate agenda was more closely associated with the institutional configuration of decision-making arenas than with the mere availability of scientific evidence. Within the Interministerial Commission on Global Climate Change (CIMGC), science remained largely associated with procedural routines and conceptual or symbolic uses, displaying limited capacity to transform diagnoses into politically recognised problems or substantive policy alternatives. In contrast, within the Joint Committee on Climate Change (CMMC), the plurality of actors involved and the openness of deliberative processes promoted greater integration between diagnoses, policy proposals and decision-making. This enhanced the influence of science and created more favourable conditions for stream convergence and potential coupling.

From a theoretical perspective, the comparison contributes to debates surrounding the Multiple Streams Framework (MSF) by demonstrating that the type of brokerage relevant for agenda change depends on the ability to frame diagnoses as public problems and connect them to viable policy alternatives under specific political conditions. The analysis also reinforces the importance of understanding knowledge brokerage beyond linear models of knowledge transfer. Brokerage processes are shaped by choices, filters and political disputes that determine which forms of evidence circulate, which actors acquire legitimacy and which issues ultimately reach the policy agenda.

The findings also have implications for the design of institutions dedicated to climate governance. They suggest that more pluralistic and stable arenas – capable of sustaining diverse brokerage repertoires and facilitating the maturation of ideas within public debate – are likely to reduce the occurrence of blockages such as those identified within the CIMGC. At the domestic level, this evidence is relevant for strengthening the Brazilian National Climate Change Policy and its planning instruments. More broadly, it may also inform the formulation and revision of Nationally Determined Contributions (NDCs), which require institutional arrangements capable of effectively integrating scientific knowledge and political decision-making while balancing domestic legitimacy with international credibility.

Two avenues for future research appear particularly promising. First, further studies could investigate the role of non-state actors, sectoral coalitions, civil society organisations and epistemic communities in problem definition and policy alternative generation during periods of institutional retrenchment. Second, comparative analyses involving other countries in the Global South could deepen understanding of how brokers navigate tensions between global climate science, developmental imperatives and domestic struggles over legitimacy and sovereignty.

NOTES

1 | Available at: https://www.gov.br/mcti/pt-br/acompanhe-o-mcti/cgcl/paginas/copy_of_autoridade-nacional-designada-para-o-mdl.

2 | Available at: https://legis.senado.leg.br/atividade/comissoes/comissao/1450/

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Ciência e intermediação em arenas institucionais: a agenda climática brasileira entre 1999 e 2009

Science and knowledge brokering in institutional arenas: the Brazilian climate agenda between 1999 and 2009

Andréa Nascimento de Araújo [1]

Karen de Oliveira Silverwood-Cope [2]

Evandro Albiach Branco [3]

Jean Pierre Henry Balbaud Ometto [4]

[1] *Doutorado em Ciência do Sistema Terrestre, Analista em C&T, Ministério da Ciência, Tecnologia e Inovação (MCTI), Brasília, DF, Brasil*
E-mail: anaraujo.andrea@gmail.com

[2] *Doutorado em Ciência Política, Diretora de Clima, Economia e Finanças, WRI Brasil, Brasília, DF, Brasil*
E-mail: karencope@gmail.com

[3] *Doutorado em Ciências Ambientais, Pesquisador, Instituto Nacional de Pesquisas Espaciais (Inpe), São José dos Campos, SP, Brasil*
E-mail: evandro.albiach@inpe.br

[4] *Doutorado em Ciências Ambientais, Pesquisador, Instituto Nacional de Pesquisas Espaciais (Inpe), São José dos Campos, SP, Brasil*
E-mail: jean.ometto@inpe.br

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ARTICLE- VARIA

RESUMO

Este artigo examina como a ciência e os intermediadores científico-técnicos atuaram na formação da agenda climática brasileira entre 1999 e 2009. À luz do Modelo dos Fluxos Múltiplos, analisa como a ciência foi mobilizada nos fluxos de problemas, alternativas e político. A pesquisa adota uma abordagem qualiquantitativa baseada na codificação de atas e relatórios da Comissão Interministerial de Mudança Global do Clima (CIMGC), no Executivo, e da Comissão Mista sobre Mudanças Climáticas (CMMC), no Legislativo. Os resultados mostram que a CIMGC operou de forma fragmentada, centrada em especialistas do Executivo, com usos da ciência predominantemente conceituais e simbólicos, e influência científica moderada. Em contraste, a CMMC constituiu uma arena mais plural, mobilizando

usos mistos da ciência e ampliando sua influência ao conectar diagnósticos técnicos a problemas politicamente reconhecidos e alternativas viáveis. Os arranjos institucionais moldaram tanto a legitimidade da ciência quanto sua circulação entre os fluxos decisórios.

Palavras-chave: Mudança do Clima. Modelo dos Fluxos Múltiplos. Intermediação do Conhecimento. Agenda de Políticas Públicas. Brasil.

ABSTRACT

This article investigates how science and scientific and technical brokers shaped the formation of Brazil's climate agenda between 1999 and 2009. Drawing on Kingdon's Multiple Streams Framework, it analyses how science was mobilised across the problem, policy, and politics streams. The study adopts a mixed-methods approach based on the coding of minutes and reports from the Interministerial Commission on Global Climate Change (CIMGC), within the executive branch, and the Joint Committee on Climate Change (CMMC), within the legislature. Findings show that the CIMGC operated in a fragmented manner, centred on executive-branch specialists, with predominantly conceptual and symbolic uses of science and moderate scientific influence. By contrast, the CMMC functioned as a more pluralistic arena, mobilising mixed uses of science and strengthening its influence by linking technical diagnoses to politically recognised problems and viable policy alternatives. Institutional arrangements shaped both the legitimacy of science and its circulation across decision streams.

Keywords: *Climate Change. Multiple Streams Framework. Knowledge Brokerage. Policy Agenda. Brazil.*

1 INTRODUÇÃO

A ciência desempenha papel central na formulação de políticas climáticas ao fornecer diagnósticos sobre causas, impactos e alternativas de respostas à mudança do clima. Contudo, a disponibilidade do conhecimento científico não garante por si só sua tradução em problemas politicamente reconhecidos ou em decisões públicas. A literatura tem demonstrado que a influência da ciência depende de processos institucionais, disputas de poder e formas específicas de mediação na interface entre ciência e política (Cairney, 2016; Capano; Malandrino, 2022).

No Brasil a formulação de uma política climática nacional foi tardia, apesar do fortalecimento científico e da inserção internacional. Esse descompasso torna analiticamente relevante examinar as condições institucionais sob as quais a ciência se traduz, ou não, em influência na agenda climática doméstica. Assim, este estudo pergunta: como a ciência e os intermediadores técnico-científicos atuaram nos fluxos de problemas, alternativas e político na formação da agenda climática brasileira entre 1999 e 2009? Para responder a essa questão, utiliza-se o Modelo dos Fluxos Múltiplos (MFM) e compara-se a atuação de duas arenas centrais da agenda climática: a Comissão Interministerial de Mudança Global do Clima (CIMGC), vinculada ao poder Executivo, e a Comissão Mista sobre Mudanças Climáticas (CMMC), instituída no Legislativo.

1.1 CONTEXTO HISTÓRICO DA AGENDA CLIMÁTICA BRASILEIRA (1990-2009)

A agenda climática brasileira começou a se estruturar no final da década de 1980, em paralelo à consolidação do regime internacional do clima. A criação do Painel Intergovernamental sobre Mudança do Clima (IPCC), em 1988, e a assinatura da Convenção-Quadro das Nações Unidas sobre Mudança do Clima (CQNUMC), em 1992, inseriram o país em arenas multilaterais ancoradas em consensos científicos globais. O Protocolo de Quioto, firmado em 1997, reforçou essa dinâmica ao estabelecer mecanismos diferenciados de cooperação, como o Mecanismo de Desenvolvimento Limpo (MDL).

Nesse período inicial, a condução da questão climática esteve concentrada no Ministério das Relações Exteriores (MRE) e no Ministério da Ciência e Tecnologia (MCT). A criação, em 1999, da Comissão Interministerial de Mudança Global do Clima (CIMGC) ampliou a coordenação da agenda climática, reunindo oito ministérios setoriais e dois órgãos assessores da Presidência da República para articular a posição nacional nas negociações internacionais e credenciar projetos no âmbito do MDL (Brasil, 1999). Embora a iniciativa tenha representado um avanço institucional, ela estava fortemente voltada à internalização dos compromissos internacionais e reprodução da lógica internacionalista da política climática (Kiessling, 2018; Lahsen, 2009).

A partir de 2003, mudanças no contexto político interno favoreceram a ampliação e a diversificação das arenas decisórias da agenda climática. O Ministério do Meio Ambiente (MMA) passou a exercer maior protagonismo, liderando políticas interministeriais como o Plano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal (PPCDAm) e articulando iniciativas de integração entre ciência e políticas públicas. Esse movimento foi acompanhado pela criação de novas instâncias, como o Fórum Brasileiro de Mudança do Clima (FBMC), o Comitê Interministerial sobre Mudança do Clima (CIM), e de investimentos na base científica nacional, indicando uma progressiva internalização do tema climático no debate doméstico e a diversificação dos espaços de decisão. Ao mesmo tempo, intensificaram-se disputas institucionais entre ministérios com diferentes visões sobre o papel do Brasil no regime climático global (Andrade; Escada, 2023; Franchini; Viola, 2019; Hochstetler, 2021; Rodrigues, 2022).

Nesse contexto de maior politização, o Poder Legislativo passou a desempenhar papel mais ativo, especialmente a partir da criação da Comissão Mista Especial sobre Mudanças Climáticas (CMEMC), em 2007, e da Comissão Mista Permanente sobre Mudanças Climáticas (CMMC), em 2009. As audiências públicas e relatórios ampliaram o espaço para o debate entre parlamentares, representantes do Executivo e especialistas em mudança do clima (CMEMC, 2008; CMMC, 2009).

Entre 1990 e 2009, a agenda climática brasileira transitou de um arranjo político-diplomático, centrado no Executivo federal, para um sistema mais plural e politizado.

1.2 REFERENCIAL TEÓRICO

O Modelo dos Fluxos Múltiplos (MFM), proposto por Kingdon (2011), constitui o eixo analítico deste artigo. O modelo concebe a formação de agendas como resultado da interação de três fluxos relativamente autônomos: problemas, alternativas (*policy*) e político (*politics*). O fluxo de problemas refere-se ao processo pelo qual determinadas questões passam a ser reconhecidas como problemas públicos, seja por meio de indicadores, eventos críticos ou *feedbacks* de políticas existentes. O fluxo de alternativas corresponde ao desenvolvimento e à circulação de soluções em comunidades especializadas, cuja viabilidade depende tanto de critérios técnicos quanto de sua compatibilidade com valores predominantes. Já o fluxo político envolve mudanças no governo, disputas institucionais, pressões da opinião pública e dinâmicas de poder que acomodam a receptividade às propostas. No Brasil, o fluxo político envolve arenas, valores e relações de poder que moldam decisões, explicando por que diagnósticos técnicos podem circular sem se tornarem prioritários.

Um conceito-chave do MFM é o de acoplamento, entendido como a convergência temporária dos três fluxos, condição necessária para a abertura de janelas de oportunidade e para mudanças na agenda. O acoplamento não ocorre de forma automática nem cumulativa: ele depende de enquadramentos, mediações e disputas que tornam determinados problemas politicamente reconhecíveis e conectáveis a alternativas disponíveis em contextos políticos específicos. Ademais, o acoplamento pode ser antecedido por um pré-acoplamento argumentativo, no qual problemas e alternativas são tecnicamente amadurecidos e se tornam politicamente viáveis. Esse processo ajuda a explicar por que certas janelas permanecem fechadas mesmo diante de diagnósticos científicos disponíveis (Blum, 2018).

No contexto brasileiro, o MFM tem sido aplicado à análise da política climática, evidenciando o papel das instituições, dos arranjos decisórios e da influência internacional na formação e na estabilidade da agenda governamental, como no caso da Política Nacional sobre Mudança do Clima (Silverwood-Cope, 2024).

Ao revisitar o MFM, Knaggård (2016) apresenta os intermediadores do problema, atores que atuam prioritariamente no fluxo de problemas, enquadrando condições e diagnósticos como problemas politicamente relevantes e influenciando sua entrada na agenda. Diferentemente dos empreendedores de políticas, esses intermediadores não têm como função central a proposição de soluções, mas o trabalho político de definição do problema público.

A contribuição de Knaggård dialoga com a literatura clássica sobre uso da ciência, que demonstra que o conhecimento pode influenciar políticas de formas distintas. Weiss (1979) identificou usos instrumentais, conceituais e simbólicos da pesquisa, rompendo com concepções lineares segundo as quais a ciência se traduziria automaticamente em melhores decisões. Estudos posteriores reforçam que o conhecimento é usado seletivamente e compete com outros insumos, como interesses econômicos, valores políticos e constrangimentos institucionais (Capano; Malandrino, 2022; Tangney, 2020). Em contextos de alta incerteza, como a mudança do clima, a influência da ciência depende não apenas da robustez dos dados, mas também de sua relevância política e de sua legitimidade institucional (Parkhurst, 2017).

Nesse sentido, a noção de intermediador do problema dialoga com a literatura mais ampla sobre intermediação do conhecimento, que descreve repertórios de atuação na interface ciência–política (Bandola-Gill, 2023; Turnhout *et al.*, 2013). Esses estudos operam em um plano analítico distinto do MFM e ajudam a qualificar como o conhecimento circula, ou é restringido, durante o processo de enquadramento de problemas. Turnhout *et al.* (2013) distinguem repertórios que mantêm fronteiras entre produção e uso do conhecimento (fornecimento técnico) e repertórios que buscam aproximá-los (mediação/facilitação), ressaltando que, na prática, mesmo "novos papéis" podem reforçar pressupostos tradicionais e lineares.

Knaggård (2016) também destaca que a atuação dos intermediadores do problema é inerentemente política e pode assumir um caráter seletivo, produzindo dinâmicas de gatekeeping na definição de problemas ao favorecer certos enquadramentos e excluir outros. Embora o gatekeeping possa operar em diferentes fluxos, é no fluxo de problemas que ele assume centralidade analítica, ao afetar diretamente as condições para o acoplamento dos fluxos.

Neste artigo, esses conceitos são utilizados como ferramentas analíticas para interpretar como a ciência e diferentes formas de intermediação atuaram na ativação, no bloqueio ou na convergência dos fluxos em arenas institucionais da agenda climática brasileira entre 1999 e 2009.

2 METODOLOGIA

Este estudo adota uma abordagem qualiquantitativa, exploratória e interpretativa, baseada na análise documental.

2.1 UNIDADES DE ANÁLISE E *CORPUS DOCUMENTAL*

A pesquisa investigou duas arenas institucionais centrais, utilizando os seguintes materiais oficiais:

(i) Executivo: Comissão Interministerial de Mudança Global do Clima (CIMGC).

Corpus: 60 atas oficiais de reuniões da CIMGC1, sendo 38 referentes ao período de 1999 a 2006 e 22 ao período de 2007 a 2009, analisadas quanto ao conteúdo textual, às decisões registradas e aos encaminhamentos institucionais.

(ii) Legislativo: Comissão Mista sobre Mudanças Climáticas (CMMC), incluindo sua fase como Comissão Mista Especial (CMEMC), 2007-2009.

Corpus: Relatório Final da CMEMC (CMEMC, 2008), Relatório Final da CMMC de 2009 (CMMC, 2009), além de atas, notas taquigráficas e resumos padronizados relativos a 55 reuniões deliberativas e audiências públicas2, excluídas as reuniões estritamente administrativas.

O *corpus* empírico abrangeu 115 reuniões ou audiências oficiais, complementadas por dois relatórios finais das comissões legislativas, totalizando 117 materiais analisados.

2.2 PROCEDIMENTOS DE EXTRAÇÃO DE DADOS E CATEGORIZAÇÃO

A extração de dados foi realizada por análise de conteúdo manual, com apoio de planilhas eletrônicas. Foram analisadas três dimensões principais:

(i) participação de intermediadores efetivos (cientistas reconhecidos ou especialistas do Executivo com papel decisório);

(ii) formas de uso da ciência (instrumental, conceitual, simbólico ou misto), bem como situações de bloqueio ou ausência de mobilização científica; e

(iii) ativação ou bloqueio dos fluxos a partir da mobilização de evidências e articulações institucionais.

O *corpus* empírico abrangeu 115 reuniões ou audiências oficiais, complementadas por dois relatórios finais das comissões legislativas, totalizando 117 materiais analisados.

2.3 AVALIAÇÃO DO USO E GRAU DE INFLUÊNCIA DA CIÊNCIA

O uso da ciência foi classificado em quatro tipos, amparados na literatura sobre a utilização do conhecimento nas políticas públicas (Nutley; Walter; Davies, 2007; Weiss, 1979):

- Instrumental: quando evidências científicas fundamentaram decisões ou proposições de políticas;
- Conceitual: quando contribuiu para a construção de diagnósticos sem proposição direta;
- Simbólico: quando legitimou posições já estabelecidas;
- Misto: quando mais de um tipo ocorreu simultaneamente.

Para avaliar a influência da ciência em cada fluxo e comissão, adotou-se uma abordagem qualitativa com quantificação por categorias. Cada reunião foi classificada em quatro níveis de influência: ausente

(0), baixa (1), média (2) ou alta (3), conforme a extensão na qual o conhecimento científico mobilizado resultou em deliberações, recomendações ou encaminhamentos concretos. Para sintetizar esses resultados, calculou-se uma média ponderada, multiplicando-se o número de reuniões em cada nível pelo respectivo peso e dividindo-se pelo total de reuniões com o fluxo ativado.

2.4 IDENTIFICAÇÃO DOS FLUXOS DE KINGDON

A identificação dos fluxos considerou tanto o conteúdo das discussões quanto o papel dos atores envolvidos:

- Fluxo de problemas: ativado quando diagnósticos, indicadores ou eventos críticos foram apresentados com base em evidências científicas, especialmente por especialistas.
- Fluxo de alternativas: ativado mediante formulação e discussão de soluções ou propostas técnicas viáveis fundamentadas em conhecimento técnico-científico e, em alguns casos, articuladas institucionalmente.
- Fluxo político: ativado mediante deliberação legislativa ou executiva, ou quando especialistas do Executivo com poder decisório atuaram em processos de articulação institucional relevante, negociação e tomada de decisão com base científica.

Para capturar obstáculos à influência da ciência, registraram-se situações de bloqueio dos fluxos, identificadas quando houve rejeição deliberada de evidências científicas, impedimento explícito de sua incorporação nas deliberações ou bloqueio de articulações institucionais com base técnico-científica. No fluxo de problemas, o bloqueio foi registrado quando diagnósticos técnicos não foram acionados para estruturar o problema público ou foram esvaziados/rejeitados. No fluxo de alternativas, o bloqueio foi registrado quando propostas ou instrumentos tecnicamente fundamentados foram retirados de pauta ou recusados sem exame técnico. No fluxo político, quando a comissão recusou deliberar ou articular institucionalmente pautas com base técnico-científica, ou quando restringiu a ciência a um uso meramente simbólico/tático sem desdobramentos deliberativos.

2.5 FREQUÊNCIAS RELATIVAS

A ativação de cada fluxo foi calculada em relação ao total de reuniões analisadas em cada arena e período. Já as frequências relativas dos indicadores internos de cada fluxo, como intermediação, uso da ciência e tipo predominante de uso, foram calculadas em relação ao número de reuniões em que aquele fluxo foi ativado. Para fins interpretativos, os resultados foram organizados em faixas percentuais iguais: nula (0%), pontual (1-10%), baixa (11-25%), ocasional (26-50%), recorrente (51-75%) e sistemática (76-100%).

2.6 CONFIABILIDADE E LIMITAÇÕES

As limitações incluem dependência de registros oficiais, que podem não refletir integralmente os bastidores do processo deliberativo, e a ausência de entrevistas. A robustez da análise foi fortalecida por triangulação em três camadas: micro (exame minucioso de atas), meso (análise transversal entre arenas) e macro (contextualização com a política internacional e histórico da agenda climática brasileira).

3 RESULTADOS

Esta seção apresenta os resultados das análises das reuniões da CIMGC (1999-2009) e da CMMC (2007-2009), organizados pela ativação dos fluxos de problemas, alternativas e político. Para qualificar a comparação, a trajetória da CIMGC foi segmentada em dois períodos (1999-2006 e 2007-2009), permitindo situar possíveis inflexões no contexto de reconfigurações institucionais e do funcionamento concomitante da CMMC.

3.1 FLUXO DE PROBLEMAS

Na Comissão Interministerial de Mudança Global do Clima (CIMGC), o fluxo de problemas foi ativado de forma ocasional, em 37% das reuniões entre 1999-2006 e em 27% das realizadas entre 2007-2009. A Tabela 1 resume os principais padrões.

Tabela 1 – Principais padrões de ativação do fluxo de problemas, por comissão e período

Dimensão analítica	*Indicador*	*CIMGC (1999-2006)*	*CIMGC (2007-2009)*	*CMMC (2007-2009)*
Intermediação	Especialistas do Executivo	14 (100%) Sistemática	6 (100%) Sistemática	26 (59%) Recorrente
	Cientistas reconhecidos	7 (50%) Recorrente	0 Nula	24 (55%) Recorrente
Uso da ciência	Ocorrência	13 (93%) Sistemático	6 (100%) Sistemático	44 (100%) Sistemático
Tipo de uso da ciência	Predominante	Conceitual 8 (57%) Recorrente	Misto 3 (50%) Ocasional	Misto 26 (59%) Recorrente
Influência da ciência	Média (escala 0-3)	1,9 Média	2,0 Média	2,7 Alta
Nº de reuniões	Com o fluxo ativado	14	6	44
	Analisadas	38	22	55

Nota: Valores absolutos indicam as reuniões com o fluxo ativado; os percentuais referem-se à proporção desse total. As categorias de frequência e de intermediação seguem os critérios detalhados na Metodologia.

Fonte: Elaboração própria a partir das atas da CIMGC (1999-2009) e da CMEMC/CMMC (2007-2009).

Sempre que ativado no primeiro período, houve a intermediação efetiva sistemática por parte de especialistas do Executivo com poder decisório, o que sugere a centralidade desses atores na mobilização de diagnósticos. Além disso, cientistas que assumiram cargo no MCT atuaram como intermediadores em 50% dessas reuniões. O uso da ciência foi sistemático, com predominância conceitual, com referências a relatórios científicos internacionais, mas sem desdobramentos práticos em alternativas nacionais. A influência da ciência foi classificada como média, sugerindo um papel mais informativo do que deliberativo na construção do problema público.

A 8ª reunião (2002) exemplifica esse padrão. Referências aos relatórios do IPCC foram invocadas como evidência, mas o debate não resultou em deliberações ou encaminhamentos. Em outras ocasiões, como na 10ª reunião (2003), a comissão limitou-se a tomar conhecimento de decisões previamente formuladas, sem produzir diagnósticos adicionais. De forma ainda mais clara, a 17ª reunião (2004), que marcou uma inflexão institucional: a CIMGC declarou não ter atribuição para discutir mitigação,

vulnerabilidade ou proposições legislativas. Essa posição reforçou uma lógica procedimental, configurando bloqueio do fluxo de alternativas e enfraquecendo indiretamente o papel do fluxo de problemas, reduzindo as condições para o acoplamento dos fluxos.

Na segunda fase (2007-2009), a intermediação foi restrita a especialistas do Executivo. O padrão de uso da ciência foi o misto, sugerindo maior potencial de articulação entre diagnósticos e encaminhamentos. Ainda assim, a influência permaneceu em nível médio, uma vez que as evidências científicas mencionadas não se traduziram em proposições substantivas. A 32ª reunião (2007) ilustra esse padrão: houve mobilização de evidências científicas e discussões sobre alternativas técnicas, mas o debate se limitou a ajustes procedimentais.

Já na Comissão Mista sobre Mudanças Climáticas (CMMC), o fluxo de problemas foi ativado de forma sistemática. A intermediação efetiva foi recorrente e mais plural, com a participação combinada de cientistas e especialistas do Executivo em quase 25% das reuniões. O uso da ciência foi sistemático e majoritariamente misto, articulando diagnósticos técnicos com legitimação simbólica do problema climático e proposições normativas. Esse arranjo elevou a influência da ciência a grau alto. A audiência de 22/09/2009 sobre desmatamento exemplifica esse padrão ao acionar dados de monitoramento, projeções climáticas e análises econômicas com desdobramento em recomendações sobre projetos de Redução de Emissões por Desmatamento e Degradação Florestal (REDD) incorporadas ao relatório final (CMMC, 2009, p. 152). No plano analítico, isso indica maior capacidade de converter diagnósticos em problemas politicamente reconhecidos.

3.2 FLUXO DE ALTERNATIVAS

A Tabela 2 resume os principais padrões de ativação do fluxo de alternativas por arena e período. Na CIMGC, esse fluxo foi ativado de forma ocasional nos dois períodos analisados.

Entre 1999 e 2009, embora os especialistas do Executivo estivessem presentes em quase dois terços das reuniões ocorridas, eles atuaram como intermediadores efetivos apenas de forma pontual. O uso da ciência foi predominantemente conceitual, associado a referências internacionais e a critérios técnicos sem desdobramento em alternativas substantivas. Em três reuniões (27%), a comissão aprovou normativas relacionadas ao MDL sem uso explícito da ciência, sugerindo que a seleção de alternativas foi frequentemente conduzida por rotinas administrativas.

A 11ª reunião (2003) é representativa: especialistas do Executivo discutiram critérios de sustentabilidade com base técnica e aprovaram a primeira resolução da CIMGC para o funcionamento da Autoridade Nacional Designada do Brasil para o MDL, envolvendo regras de monitoramento. Ainda que existisse conteúdo técnico, a dinâmica permaneceu centrada em rotinas administrativas, com baixa articulação com os demais fluxos.

Tabela 2 – Principais padrões de ativação do fluxo de alternativas, por comissão e período

Dimensão analítica	*Indicador*	*CIMGC (1999-2006)*	*(2007-2009)*	*CMMC (2007-2009)*
Intermediação	Especialistas do Executivo	1 (9%) Pontual	4 (83%) Sistemática	21 (40%) Ocasional
	Cientistas reconhecidos	0 Nula	0 Nula	23 (44%) Ocasional
Uso da ciência	Ocorrência	7 (64%) Recorrente	6 (100%) Sistemático	52 (100%) Sistemático

Dimensão analítica	Indicador	CIMGC (1999-2006)	(2007-2009)	CMMC (2007-2009)
Tipo de uso da ciência	Predominante	Conceitual 4 (36%) Ocasional	Instrumental, conceitual e misto 2 (33% cada) Ocasional	Misto 29 (55%) Recorrente
Influência da ciência	Média (escala 0-3)	1,4 Média	2,2 Alta	2,4 Alta
Nº de reuniões	Com o fluxo ativado	11	6	52
	Analisadas	38	22	55

Nota: Valores absolutos indicam as reuniões com o fluxo ativado; os percentuais referem-se à proporção desse total. As categorias de frequência e de intermediação seguem os critérios detalhados na Metodologia.

Fonte: Elaboração própria a partir das atas da CIMGC (1999-2009) e da CMEMC/CMMC (2007-2009).

Na segunda fase da CIMGC (2007-2009), a intermediação efetiva de especialistas do Executivo e o uso da ciência tornaram-se sistemáticos. Observou-se uma distribuição equilibrada entre usos instrumental, conceitual e misto, sugerindo a existência de um potencial de articulação entre diagnósticos e alternativas. A influência da ciência foi classificada como alta, refletindo decisões ancoradas em pareceres técnicos, articulação com o Operador Nacional do Sistema Elétrico (ONS) e o Ministério de Minas e Energia (MME), e formalização normativa. Ainda assim, a circulação do conhecimento científico permaneceu restrita a pautas procedimentais, sem alcançar debates estratégicos mais amplos.

Na CMMC, o fluxo de alternativas foi ativado de forma sistemática (95% das reuniões), com uso da ciência majoritariamente misto e influência alta. A audiência pública de 11/09/2007 ilustra a transformação de insumos técnicos em proposições: cientistas e especialistas do Executivo fundamentaram propostas e sugeriram instrumentos de monitoramento vinculados à conservação do Cerrado, posteriormente incorporados ao relatório final (CMEMC, 2008, p. 73-75).

Em termos analíticos, isso indica maior capacidade de maturação e circulação de alternativas em ambiente deliberativo.

3.3 FLUXO POLÍTICO

A Tabela 3 sintetiza os principais padrões de ativação do fluxo político por comissão e período. Na CIMGC, esse fluxo foi ativado em 45% das reuniões realizadas entre 1999-2006 e em 55% entre 2007-2009, com padrões semelhantes. Em ambos os períodos, a intermediação concentrou-se nos especialistas do Executivo com poder decisório, mas de forma limitada e sem articulação plena com os fluxos de problemas e alternativas. O uso da ciência foi recorrente e fragmentado entre usos conceitual, misto e, em alguns casos, ausente, indicando que a deliberação político-administrativa nem sempre se conectou a evidências estruturadas ou a proposições novas.

Em reuniões centradas na verificação de conformidade de projetos do MDL, não houve mobilização de evidências científicas; nesses episódios, o acionamento do fluxo político decorreu sobretudo de articulações político-administrativas, por vezes acompanhadas de uso simbólico da ciência para legitimar decisões já encaminhadas. A 50ª reunião de 2009 ilustra esse padrão: discutiu-se uma proposta de Instrução Normativa com potenciais impactos legais, econômicos e ambientais. Foram acionados argumentos técnicos e criados grupos de trabalho interministeriais, mas sem uso estruturado de evidências científicas. Observou-se também resistência em abrir espaço permanente

para articuladores epistêmicos externos, como o Fórum Brasileiro de Mudança do Clima (FBMC), limitando a institucionalização da escuta científica.

Tabela 3 – Principais padrões observados na ativação do fluxo político, por comissão e período

Dimensão analítica	*Indicador*	*CIMGC (1999-2006)*	*(2007-2009)*	*CMMC (2007-2009)*
Intermediação	Especialistas do Executivo	9 (53%) Recorrente	6 (50%) Ocasional	0 Nula
	Cientistas reconhecidos	0 Nula	0 Nula	23 (43%) Ocasional
Uso da ciência	Ocorrência	11 (65%) Recorrente	9 (75%) Recorrente	53 (100%) Sistemático
Tipo de uso da ciência	Predominante	Conceitual, misto, ausente 4 (24% cada) Ocasional	Conceitual, misto, ausente 3 (25% cada) Ocasional	Misto 29 (55%) Recorrente
Influência da ciência	Média (escala 0-3)	1,4 Média	1,4 Média	2,4 Alta
Nº de reuniões	Com o fluxo ativado	17	12	53
	Analisadas	38	22	55

Nota: Valores absolutos indicam as reuniões com o fluxo ativado; os percentuais referem-se à proporção desse total. As categorias de frequência e de intermediação seguem os critérios detalhados na Metodologia.

Fonte: Elaboração própria a partir das atas da CIMGC (1999-2009) e da CMEMC/CMMC (2007-2009).

Na CMMC, o fluxo político foi ativado de forma sistemática em 96% das reuniões analisadas. Houve mobilização sistemática de evidências científicas combinada com articulação institucional e formulação de alternativas viáveis, com predominância de uso da ciência misto e influência alta. A audiência pública de setembro de 2009 sobre a Política Nacional de Mudança do Clima (PNMC) exemplifica essa integração ao fundamentar recomendações para metas de redução de emissões e ativar simultaneamente os três fluxos do modelo de Kingdon (CMMC, 2009, p. 158). Esse padrão sugere maior capacidade de converter ciência em insumo legítimo do debate político em arena deliberativa.

3.4 ANÁLISE TRANSVERSAL: BLOQUEIOS, DISTANCIAMENTO E CONVERGÊNCIA DOS FLUXOS

A comparação entre as arenas do Executivo, representada pela CIMGC, e do Legislativo, pela CMMC, permite observar como diferentes arranjos institucionais condicionaram a circulação da ciência, sua forma de uso e a integração entre fluxos. A Tabela 4 sintetiza as configurações de ativação e convergência dos fluxos de problemas, alternativas e político observadas em cada arena e período, além dos bloqueios identificados durante a codificação, permitindo contextualizar os padrões apresentados nas seções anteriores.

Tabela 4 – Configurações de ativação, convergência e bloqueio dos fluxos de problemas, alternativas e político por arena e período

Configuração dos fluxos	*CIMGC 1999-2006*	*CIMGC 2007-2009*	*CMMC 2007-2009*
Nenhum fluxo ativado	10 (26%)	10 (45%)	2 (4%)
Ativação isolada (um fluxo)	14 (37%)	5 (23%)	0
Convergência parcial (dois fluxos)	14 (37%)	2 (9%)	10 (18%)
Convergência ampliada (três fluxos)	0	5 (23%)	43 (78%)
Total de reuniões analisadas	38	22	55
Bloqueios identificados	5 (13%)	2 (9%)	0

Nota: Os valores absolutos indicam o número de reuniões; os percentuais referem-se à proporção em relação ao total de reuniões analisadas em cada arena e período. As configurações de ativação dos fluxos são mutuamente exclusivas e expressam o número de fluxos ativados isolada ou simultaneamente em cada reunião. A categoria "Convergência ampliada" corresponde à ativação simultânea dos três fluxos e indica maior potencial de acoplamento, mas não constitui, isoladamente, evidência de acoplamento efetivo. Os bloqueios foram identificados por fluxo durante a codificação e são apresentados de forma agregada por arena e período. Condição transversal, não somável às configurações anteriores, podendo ocorrer concomitantemente às demais configurações.

Fonte: Elaboração própria a partir das atas da CIMGC (1999-2009) e da CMEMC/CMMC (2007-2009).

Na CIMGC, a ativação foi irregular e fragmentada, com forte peso de rotinas administrativas e de análise de conformidade associadas ao MDL. Esse padrão se reflete na predominância de ativações isoladas ou convergências parciais entre fluxos, bem como na ocorrência de bloqueios identificados apenas nessa arena durante a codificação das reuniões. Entre 1999 e 2009, foram analisados 237 projetos submetidos ao MDL (Brasil, 2009, p. 9), e as atas indicam que a comissão evitou deliberar sobre propostas técnicas para o Plano Nacional de Mudança do Clima, esvaziou debates emergentes sobre REDD e recusou discutir projetos de lei sobre mudança do clima em meio a disputas interministeriais. Esses bloqueios explícitos e implícitos estiveram associados à menor integração entre diagnóstico, alternativas e deliberação, favorecendo um padrão de distanciamento entre fluxos e reduzindo as condições de acoplamento.

Ainda que episódios pontuais tenham mostrado maior influência da ciência, como nas decisões normativas sobre metodologias de cálculo do fator de emissão do SIN, esses avanços permaneceram restritos a questões técnicas e não resultaram em articulação duradoura com os demais fluxos. O padrão predominante na CIMGC foi, portanto, o distanciamento entre os fluxos, marcado pela atuação fragmentada e pela omissão diante de oportunidades legítimas de integração.

Na CMMC, por sua vez, predominou um padrão decisório mais aberto e plural, caracterizado por frequência sistemática de convergência ampliada entre os fluxos e ausência de bloqueios identificados. Cientistas reconhecidos e especialistas do Executivo atuaram de forma articulada em audiências e relatórios, mobilizando evidências para estruturar propostas normativas e fomentar articulações institucionais, como ocorreu na audiência pública de setembro de 2009 sobre a PNMC.

A leitura cruzada dos resultados identifica dois padrões predominantes de ativação de fluxos: (i) distanciamento, caracterizado pela ativação isolada ou parcialmente integrada dos fluxos; e (ii) convergência ampliada, predominante na CMMC, onde os três fluxos foram ativados simultaneamente em 78% das reuniões analisadas, percentual classificado como sistemático segundo as faixas interpretativas adotadas na Metodologia. Paralelamente, os bloqueios implícitos e explícitos identificados durante a codificação ocorreram exclusivamente na CIMGC, associados à restrição ou não incorporação de evidências, propostas e articulações técnico-científicas. Embora a ativação simultânea dos três fluxos não constitua, por si só, evidência de acoplamento efetivo, ela indica maior potencial de integração

entre diagnósticos, alternativas e deliberação política. Em conjunto, os resultados reforçam que os arranjos institucionais não apenas moldam a presença da ciência, mas condicionam sua capacidade de circular entre os fluxos e adquirir legitimidade política.

4 DISCUSSÃO

A diferença central entre as arenas analisadas foi institucional: a Comissão Interministerial de Mudança Global do Clima (CIMGC) operou sob um arranjo executivo mais fechado e procedimental, enquanto a Comissão Mista sobre Mudanças Climáticas (CMMC) funcionou como arena legislativa mais plural e deliberativa.

Na CIMGC, diagnósticos técnicos apareceram, mas permaneceram com baixa capacidade de reorganizar o debate político. Predominaram usos conceituais e, em momentos relevantes, usos simbólicos que legitimaram rotinas e decisões já encaminhadas, sem desdobramento em alternativas substantivas. O resultado foi a manutenção de um circuito decisório no qual a ciência circulou com baixa capacidade de se converter em problema politicamente reconhecido ou de criar condições mais favoráveis ao acoplamento dos fluxos. A ausência de espaços permanentes para cientistas externos e a restrição do debate a especialistas do Executivo reforçaram o caráter tecnocrático do arranjo e sua baixa permeabilidade a disputas domésticas substantivas. A permanência da CIMGC em uma lógica político-diplomática, fortemente associada às rotinas do MDL e à agenda internacional, restringiu a circulação da ciência em debates domésticos mais amplos sobre mitigação e formulação de políticas climáticas, favorecendo usos mais seletivos e procedimentais do conhecimento científico (Lahsen, 2009). Nesse contexto, a delimitação do escopo de debate funcionou também como mecanismo de estabilização institucional da posição brasileira no regime climático internacional.

Esse padrão dialoga com as dinâmicas descritas por Knaggård (2016) nas quais diagnósticos deixam de ser convertidos em problemas politicamente reconhecíveis quando mecanismos de enquadramento são restringidos ou subordinados a filtros institucionais. Os resultados sugerem dinâmicas seletivas compatíveis com formas de gatekeeping institucional, não apenas por exclusão explícita, mas como limitação reiterada do escopo admissível da agenda. A filtragem de temas como mitigação e instrumentos emergentes, por exemplo, debates sobre REDD, expressa uma seletividade que reduziu as possibilidades de circulação do conhecimento entre fluxos e preservou uma agenda mais compatível com compromissos diplomáticos e rotinas técnico-administrativas já consolidadas.

Na CMMC, por contraste, evidências técnico-científicas circularam em ambiente institucional mais plural, com interação mais intensa entre ciência, burocracia e deliberação parlamentar. A atuação articulada de cientistas reconhecidos, especialistas do Executivo e parlamentares ampliou a capacidade de transformar diagnósticos em problemas politicamente reconhecidos e de conectá-los a alternativas normativas viáveis. Nesse contexto, a ciência operou simultaneamente como recurso de diagnóstico, formulação e legitimação política, favorecendo padrões recorrentes de convergência ampliada entre os fluxos e criando condições mais consistentes para o acoplamento de fluxos.

Embora disputas e assimetrias também estivessem presentes, a abertura institucional da comissão ampliou as possibilidades de circulação do conhecimento entre diferentes atores e arenas decisórias. Em linha com Knaggård (2016), a intermediação do problema ocorreu de forma mais ampla, aproximando evidências técnico-científicas da dinâmica deliberativa do Legislativo.

A heterogeneidade do uso da ciência entre fluxos e arenas reforça uma distinção fundamental: não se trata de "mais ciência" versus "menos ciência", mas de quais formas de expertise são legitimadas, quais atores podem circular entre arenas e quais diagnósticos conseguem adquirir relevância política. Quando a intermediação se restringe ao fornecimento do conhecimento, com fronteiras rígidas entre produção e uso do conhecimento, tende a prevalecer uma lógica linear que favorece usos simbólicos

e reduz a sensibilidade do processo decisório à expertise (Turnhout *et al.*, 2013). Tangney (2022) vai além ao interpretar a persistência desse padrão como resultado de escolhas institucionais e políticas deliberadas, e não como déficit de evidência ou de tradução: a marginalização da ciência pode responder a preservação de certos equilíbrios de poder, prioridades econômicas e formas institucionalizadas de coordenação decisória.

A superação do uso simbólico da ciência, nesse contexto, não é uma prescrição tecnocrática; é uma condição para que diagnósticos influenciem de fato a definição de problemas e a seleção de alternativas. Esses resultados sugerem a importância de arenas deliberativas capazes de sustentar repertórios de mediação e facilitação, reduzindo a dependência de filtros institucionais que barram a circulação do conhecimento. A crítica de Bandola Gill (2023) reforça que a intermediação não é neutra: ela seleciona evidências, define acessos e hierarquiza quais formas de expertise podem adquirir legitimidade política.

A dependência de arranjos institucionais específicos para que diagnósticos científicos adquiram tração política já se manifesta nesses períodos anteriores, reaparecendo mais tarde como elemento estruturante da formação, da transformação e da retração da Política Nacional sobre Mudança do Clima, conforme evidenciado na análise longitudinal do processo decisório da PNMC (Silverwood-Cope, 2024). Esse encadeamento sugere que bloqueios e aberturas observados no período analisado não são episódicos, mas parte de uma trajetória institucional mais ampla da política climática brasileira.

5 CONSIDERAÇÕES FINAIS

Os resultados sugerem que a formação da agenda climática esteve mais associada à configuração institucional das arenas do que à disponibilidade de evidências científicas. Na CIMGC, a ciência permaneceu frequentemente associada a rotinas procedimentais e usos conceituais ou simbólicos, com baixa capacidade de converter diagnósticos em problemas politicamente reconhecidos ou em alternativas substantivas. Na CMMC, a pluralidade de atores e a abertura deliberativa favoreceram a integração entre diagnósticos, proposições e decisões, ampliando a influência da ciência e criando condições mais consistentes para a convergência dos fluxos e para seu potencial acoplamento.

Do ponto de vista teórico, a comparação contribui para o debate sobre o Modelo de Fluxos Múltiplos ao evidenciar que a intermediação relevante para mudança de agenda depende da capacidade de enquadrar diagnósticos como problemas públicos e de conectálos a alternativas viáveis sob condições políticas específicas. A análise reforça a importância de compreender a intermediação do conhecimento para além de modelos lineares de transferência: ela é atravessada por escolhas, filtros e disputas que definem quais evidências circulam, quais atores adquirem legitimidade e quais problemas conseguem entrar na agenda pública.

Os achados sugerem implicações para o desenho de instituições voltadas à governança climática. Em particular, indicam que arenas mais plurais e estáveis, capazes de sustentar diferentes repertórios de intermediação e de favorecer a maturação das ideias no debate público, tendem a reduzir a probabilidade de bloqueios como os observados na CIMGC. No plano doméstico, essa evidência é relevante para o fortalecimento da Política Nacional sobre Mudança do Clima (PNMC) e de seus instrumentos de planejamento. Em termos mais amplos, também pode informar a formulação e a atualização das Contribuições Nacionalmente Determinadas (NDCs), que demandam arranjos institucionais consistentes de integração entre ciência e decisão, combinando legitimidade interna e credibilidade externa.

Como agenda de pesquisa, duas direções se mostram particularmente promissoras: (i) investigar a atuação de atores não estatais, coalizões setoriais, organizações da sociedade civil e redes epistêmicas na definição de problemas e na produção de alternativas em momentos de retração institucional; (ii) ampliar comparações com outros países do Sul Global para compreender como intermediadores

navegam tensões entre ciência climática global, imperativos de desenvolvimento e disputas domésticas por legitimidade e soberania.

NOTAS

1 | Disponíveis em: https://www.gov.br/mcti/pt-br/acompanhe-o-mcti/cgcl/paginas/copy_of_autoridade-nacional designada-para-o-mdl.

2 | Disponíveis em: https://legis.senado.leg.br/atividade/comissoes/comissao/1450/

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DECLARAÇÃO SOBRE O USO DE INTELIGÊNCIA ARTIFICIAL

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Multitemporal analysis of soil quality in an irrigation scheme in the Brazilian semi-arid region

Análise multitemporal da qualidade do solo em perímetro irrigado do semiárido brasileiro

Elton Souza Oliveira [1]

Daniela Nogueira Soares [2]

Nelson Bernal Dávalos [3]

Juliana Dalboni Rocha [4]

Guadalupe Souza Sátiro [5]

Airon José da Silva [6]

[1] PhD in Applied Geosciences, Lecturer, Researcher, Centre of Humanities, Federal University of Western Bahia, Barreiras, BA, Brazil
E-mail: esoliveira@ufob.edu.br

[2] PhD in Sociology, Professor, Programme in Management and Regulation of Water Resources; Researcher, Center for Sustainable Development, University of Brasília, Brasília, DF, Brazil
E-mail: danielanogueiracds@gmail.com

[3] PhD in Sustainable Development, Researcher, Centre for Sustainable Development, University of Brasília, Brasília, DF, Brazil
E-mail: neleduberdav@gmail.com

[4] PhD in Sustainable Development, Visiting Professor, Engineering Course in Energy, Gama Campus/ FCTE/UnB, University of Brasília, Brasília, DF, Brazil
E-mail: dalboni.unb@gmail.com

[5] PhD in Sustainable Development, Researcher, Centre for Sustainable Development, University of Brasília, Brasília, DF, Brazil
E-mail: guadalupesatiro@gmail.com

[6] PhD in Agronomy, Lecturer, Department of Agronomic Engineering, Federal University of Sergipe, São Cristóvão, SE, Brazil
E-mail: aironjs@gmail.com

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ABSTRACT

The expansion of irrigation projects in the Brazilian semi-arid region, supported by water abstraction from the São Francisco River, has led to initiatives such as the Jacaré Curituba Settlement Project (PAJC) in Sergipe. Established on soils vulnerable to salinisation and sodification and developed without adequate technical support, the PAJC encountered significant challenges that compromised agricultural productivity. Although the signs of salinisation identified in 2014 had largely been mitigated by 2022, areas exhibiting salt and sodium imbalances remain. The most recent survey also revealed substantial changes in the concentration of soil nutrients, particularly available phosphorus, with increases of up to 587%, thereby highlighting persistent nutritional imbalances. The cation exchange capacity (CEC) was classified as moderate at several sampling locations. Consequently, there is an urgent need for public policies and technical assistance tailored to local conditions to ensure the long-term sustainability of agricultural production in irrigated areas of the Brazilian semi-arid region.

Keywords: Salinisation. Sodification. Irrigation. ESP. Nexus+. Socio-environmental.

RESUMO

A expansão dos projetos de irrigação no semiárido brasileiro, viabilizada pelo uso das águas do Rio São Francisco, impulsionou iniciativas como o Projeto de Assentamento Jacaré Curituba (PAJC), em Sergipe. Implantado em solos suscetíveis à salinização e sodificação, e sem assistência técnica adequada, o PAJC enfrentou sérios problemas, afetando sua produtividade agrícola. Embora os sinais de salinização identificados em 2014 tenham sido mitigados até 2022, ainda persistem áreas com desequilíbrio de sais e sódio. O estudo mais recente apontou, ainda, alterações na concentração de elementos como o fósforo disponível no solo, aumento de até 587%, evidenciando desequilíbrios nutricionais. Já a CTC foi classificada como média em vários locais. Assim, destaca-se a urgência de políticas públicas e assistência técnica voltadas à realidade local a fim de garantir a sustentabilidade da produção agrícola em áreas irrigadas do semiárido.

Palavras-chave: *Salinização. Sodificação. Irrigação. PST. Nexus+. Socioambiental.*

1 INTRODUCTION

Soil salinisation is an increasingly significant challenge for agricultural communities worldwide, impacting both productivity and environmental sustainability (Esteves; Suzuki, 2008; Pedrotti *et al.*, 2015; Tomaz *et al.*, 2020). This complex phenomenon, driven by natural factors and human activities, frequently occurs in semi-arid and arid regions within superficial soil layers (Azevedo *et al.*, 2017; Castro *et al.*, 2020; Pizarro, 1978; Ribeiro *et al.*, 2010; Saraiva Filho; Bonilla, 2022; Zhao *et al.*, 2017). Inadequate irrigation management (Richards, 1954), the absence or inadequacy of drainage systems (Maas; Grattan, 1999), excessive fertiliser application, and the continued use of water with limited quality all contribute to the accumulation of salts in the root zone (Bonilla *et al.*, 2019). These factors progressively degrade the physical, chemical, and biological integrity of soils, resulting in substantial losses (Brevik *et al.*, 2015; Daliakopoulos *et al.*, 2016; Medeiros *et al.*, 2012; Rengasamy, 2006; Saraiva Filho; Bonilla, 2022; Tomaz *et al.*, 2020).

As this is a dynamic process capable of evolving, regressing, or stabilising over time, continuous research is imperative to understand the dynamics of salt-affected soils. The importance of temporal analysis in studies of soil salinisation is highlighted by Shahid *et al.* (2015), who stress that understanding changes over time is vital for assessing the process's dynamics and for formulating effective mitigation strategies. At the local scale, relatively few studies have investigated salinisation, considering its particularities and specific impacts on agriculture and neighbouring communities. Beyond agronomic challenges,

soil salinisation presents notable socio-environmental implications, including effects on water quality, biodiversity, and community well-being that depend on these resources.

An integrated approach to these interconnected dimensions, as highlighted by Qadir *et al.* (2014), is fundamental for devising sustainable strategies that balance agricultural productivity, environmental conservation, and social well-being. In various semi-arid regions, technical assistance and rural extension programs have been identified as vital tools for promoting conservation practices, optimising water use, managing soil fertility effectively, and preventing soil degradation (Castro *et al.*, 2021; Pedrotti *et al.*, 2015). Systematic environmental monitoring, coupled with ongoing technical support and soil quality assessments, plays a crucial role in minimising issues related to salinisation and sodification, particularly in areas occupied by smallholder farmers facing technical and financial constraints (Bonilla *et al.*, 2019; Daliakopoulos *et al.*, 2016; Lopes *et al.*, 2008).

With regard to the Jacaré Curituba Settlement Project (PAJC), situated within the municipalities of Poço Redondo and Canindé de São Francisco, Sergipe, the identification of salt-affected soils in 2014 (Santos, 2015) has raised concerns regarding potential repercussions on the socio-economic and environmental conditions of the region. Accordingly, this study aims to address existing knowledge gaps in scientific understanding by undertaking a multitemporal analysis of soil salinisation within PAJC, with special emphasis on soil ion concentrations that impact salinisation and sodification processes, as well as elements that serve as indicators of soil quality. Such knowledge is essential for informing public policies and practices that promote local sustainability through targeted technical assistance.

2 MATERIALS AND METHODS

2.1 STUDY SITE

The Jacaré Curituba Settlement Project was established in 1997 and encompasses portions of the municipalities of Poço Redondo and Canindé de São Francisco. According to Santos (2015), the PAJC was recognised as one of the largest settlements in South America. This settlement resulted from the mobilisation of rural workers and family farmers advocating for land rights and access. Although it is currently known as PAJC, the settlement was initially referred to as Nova Califórnia. In accordance with the proposal by the Sergipe government, the PAJC comprises 134 land plots, with 80 designated for irrigated agriculture and 54 allocated to livestock development.

As the area was allocated for land reform, the original project was revised and structured as follows: implementation occurred in three phases, leading to the establishment of 36 agrovillages (Codevasf, 2021). Due to its objectives, a substantial proportion of the territory is dedicated to agricultural and livestock activities, particularly irrigated cultivation. In addition to irrigated pastures, the region cultivates crops such as okra, cassava, maize, beans, sunflower, guava, passion fruit, lettuce, watermelon, and pumpkin, facilitated by irrigation systems on naturally fertile land (Santos, 2019). From a pedogeomorphological perspective, the PAJC area features dissected reliefs, including hills, tabular interfluves, and pediplaned surfaces. In these regions, three soil classes are present: Luvisols, Neossols, and Regolithic soils.

The properties of Luvisols confer high productive potential due to their mineralogical richness in nutrients; however, this potential is influenced by irregular rainfall, predominantly occurring in May, June, and July during the winter season, with an average precipitation of 200 mm during this period (Silva, 2010). Among the 36 agrovillages, this study concentrates on two areas comprising four agrovillages: Nossa Senhora da Conceição, Braço Erguido, Samariva Daniel, and São José. These agrovillages exhibit typical activities associated with dryland and irrigated zones, thereby enabling an understanding of the dynamics of these regions concerning soil salinisation and sodification processes.

2.2 METHODOLOGICAL PROCEDURES

To identify the regions exhibiting issues related to soil quality, whether due to salinisation or nutrient concentrations that deviate from standard levels, samples from two periods (2014 and 2022) were utilised. Additionally, the spatial distribution of the data was taken into account, considering the most recent land-use and land-cover classes, property boundaries, and excluding areas such as legal reserves, residential clusters, and Agrovillages areas. All research adhered to the methodological procedures outlined in Figure 1.

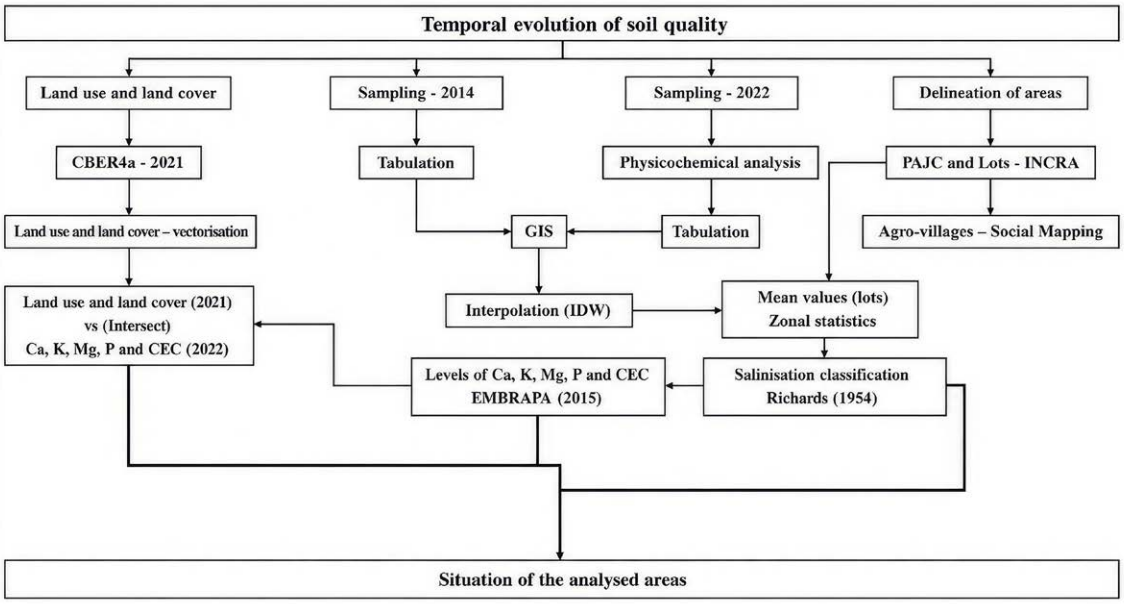

Figure 1 – Flowchart of the research methodology

Source: The authors.

2.3 COLLECTION, PREPARATION, AND LABORATORY ANALYSIS OF SOIL SAMPLES

Throughout the study, all sampling and laboratory procedures were conducted in accordance with the established methodology (Embrapa, 2011; Richards, 1954). The initial sampling took place in 2014 (Santos, 2015), with the subsequent sampling occurring in 2022. In both instances, soils were collected from 32 locations distributed across three agrovillages, as illustrated in Figure 2, at depths of 0-15 cm and 15-30 cm, resulting in a total of 64 composite soil samples.

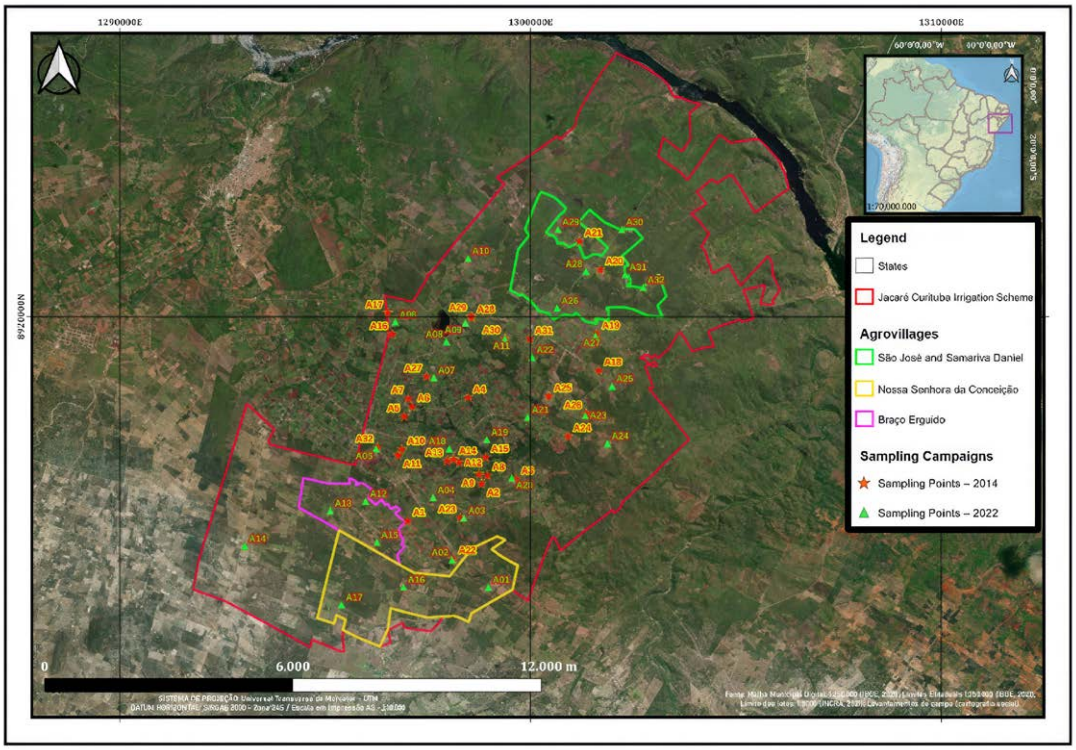

Figure 2 – Location of the agrovillages and sampling points

Source: The authors.

The collected material was transported to the Soil Remediation Laboratory at the Federal University of Sergipe. After oven-drying the samples at 40 °C, the samples were milled and sieved through a 2.00 mm (No. 10) mesh. Soil salinity was assessed following the methodology proposed by Richards (1954), wherein the calculations incorporated the analyses of the Exchangeable Sodium Percentage (ESP) outlined in Equation 1, as well as pH in distilled water and Electrical Conductivity (EC) measured in $dS \cdot m^{-1}$. The classification criteria for soils affected by salinity were categorised into four classes, as presented in Table 1.

$$\textbf{Equation 1} - \quad PST = \frac{Na^{+}}{Ca^{2+} + Mg^{2+} + K^{+} + Na^{+} + (H^{+} + Al)} \times 100$$

Table 1 – Classification of soils impacted by saline conditions

Class	*CE ($dS.m^{-1}$)*	*PST (%)*	*pH*
Non-saline	< 4	< 15	< 8.5
Saline	> 4	< 15	< 8.5
Saline-sodic	> 4	> 15	≥ 8.5
Sodic	< 4	> 15	≥ 8.5

Source: Richards (1954).

In addition to the variables used to classify soil salinisation and sodification, several other soil chemical properties were analysed, including Calcium (Ca^{2+}), Magnesium (Mg^{2+}), and Potassium (K^{+}), all of which are essential plant nutrients (Cardoso, 2009; Malavolta, 2008; Marschner, 2012). Cation Exchange Capacity (CEC), an important indicator of soil nutrient retention and availability (Embrapa, 2010), and the available phosphorus content (P), due to its significance in plant development (Horta; Torrent, 2010; Sasabuchi *et al.*, 2023), were also assessed. These variables are essential for assessing soil fertility and optimising crop productivity to maximise productivity and economic returns (Sengik, 2007). The classification adopted for Ca^{2+}, Mg^{2+}, K^{+}, CEC, and P, as presented in Tables 2 and 3, was proposed by Embrapa (2015).

Table 2 – Reference values used in the interpretation of soil analysis results

Element	*Classification (mmol$_c$.dm³)*		
	Low	*Moderate*	*High*
Ca2+	< 16	16 – 30	> 30
Mg2+	< 4	4 – 10	> 10
K+	< 0.77	0.77 – 1.53	> 1.53
CEC	< 50	50 - 150	> 150

Source: adapted from Embrapa (2015).

Table 3 – Reference values for available phosphorus (P) content in soil

Clay Content (g.kg^{-1})	*Textural class*	*Soil P content (mg.dm³)*		
		Low	*Moderate*	*Sufficient*
< 150	Sandy	0 - 10	10.1 – 20	> 20
150 – 350	Moderate	0 – 7	7.1 – 15	> 15
> 350 - < 600	Clayey	0 – 4	4.1 – 8	> 8

Source: Adapted from Embrapa (2015).

2.4 SPATIAL ANALYSIS AND AREA DELINEATION

As the Jacaré Curituba Settlement Project comprises plots distributed across several agrovillages, the analyses of the 32 sample regions were conducted through interpolation within the Geographic Information System (GIS) environment. This procedure involved estimating values for unsampled locations between sampling points (Mazzini; Schettini, 2009). The software employed was QGIS 3.2, using the Inverse Distance Weighting (IDW) interpolation method because of its suitability for the study area (Kravchenko; Bullock, 1999; Wollenhaupt *et al.*, 1994). As the primary objective of the research was to analyse the plots, mean values for each plot were subsequently extracted using the Zonal Statistics tool, based on the boundaries of each property.

The analysis focused on four agrovillages: Nossa Senhora da Conceição, Braço Erguido, Samariva Daniel, and São José. Activities such as livestock farming, dryland cultivation, and irrigated farming are conducted there. Despite the existence of the PAJC boundary and the plots, both obtained from Incra, the boundaries of the Agrovillages were not incorporated into official databases. Consequently,

the delimitation of the four Agrovillages was performed collaboratively with the community through social cartography (Acselrad; Coli, 2008; Herlihi; Knapp, 2003). Owing to uncertainty regarding the boundaries of Agrovillages São José and Samariva Daniel, both were merged into a single, contiguous area. The types of plots, dryland, irrigated, and livestock, were derived from Product 5 of the BRA/14/G32 PIMS 3066 Sergipe Project.

2.5 LAND-USE AND LAND-COVER MAPPING

Land-use and land-cover mapping was performed using a CBERS-4A image acquired in January 2021, with a spatial resolution of 2 metres. The image was obtained from the Brazilian National Institute for Space Research (Inpe). On-screen digitisation was carried out based on image shape, texture and colour, which defined the mapping units. The land cover and land use units were classified in Chart 1, based on a system that combined various forms of cover classification.

Chart 1 – Land use and land cover classes used

CLASS 1	*CLASS 2*
Water	Water bodies
Agricultural anthropic	Pasture
	Temporary crops
	Permanent crops
	Livestock production
Rural anthropic	Infrastructure
	Agrovillage
	Community facilities
	Rural housing
Natural vegetation	Caatinga
Degraded areas	Degraded areas

Source: The authors.

The adaptation principally adhered to the propositions of the classification systems established by Araújo Filho *et al.* (2007), Brito and Prudente (2005), as well as the Technical Manual of Land Use (IBGE, 2013). A two-level classification system was adopted. To ensure the validity of the areas, data obtained via fieldwork employing social cartography (Davalos *et al.*, 2024) were utilised.

3 RESULTS AND DISCUSSION

A total of 104 plots were analysed, consisting of 22 allocated to irrigation, 47 for livestock, and 35 for dryland activities. In the 2014 analysis, 32 lots, comprising 64 soil samples, exhibited soil salinity problems at the 0-15 cm depth, with 63 classified as saline and 1 as saline-sodic. It was observed that, in the Braço Erguido Agrovillage, 41 lots were identified, and in Nossa Senhora da Conceição, 23 lots. The salinisation observed is consistent with findings reported in other irrigated perimeters within the Brazilian Northeast (Lopes *et al.*, 2008; Souza *et al.*, 2000; Vasconcelos *et al.*, 2013).

Studies conducted in different regions have shown that the degree of salinisation is directly correlated with irrigation management, the efficacy of drainage systems, the quality of water utilised, and the fertilisation practices employed by farmers (Daliakopoulos *et al.*, 2016; Tomaz *et al.*, 2020). Consequently, although environmental factors play an important role in the development of salinisation, management practices frequently dictate the rate of its progression or mitigation over time. Therefore, continuous monitoring programs should be incorporated into the routine operations of irrigated regions, enabling preventive management actions before the occurrence of irreversible soil quality alterations (Daliakopoulos *et al.*, 2016; Pedrotti *et al.*, 2015).

In the 15-30 cm soil layer, the number of plots affected by salinity was comparatively lower: a total of 30 areas, all situated within the Braço Erguido Agrovillage (19 plots) and Nossa Senhora da Conceição (11 plots). It is important to note that, in regions affected by salinity and sodicity, there is a discernible tendency towards diminished physical and chemical soil quality, which adversely affects crop development (Corrêa *et al.*, 2003; Ribeiro *et al.*, 2009).

In addition to the detection of salts in the soil at depths of 0-15 cm, phosphorus deficiency (P) was identified in 42 plots distributed between Agrovillages Nossa Senhora da Conceição and Braço Erguido, which were classified as having low levels. This inadequate concentration of P directly impacts soil fertility and may result in decreased agricultural productivity (Castro *et al.*, 2019; Gkiougkis *et al.*, 2015; Pedrotti *et al.*, 2015; Santos *et al.*, 2018). Furthermore, an additional 38 plots situated in Agrovillage São José and Samariva Daniel were classified as having adequate phosphorus concentrations. The values of Ca^{2+}+, K^{+}, Mg^{2+}, and CEC indicated high concentration levels across all plots, consistent with the inherent soil characteristics of the region, attributable to the low degree of weathering and the climatic conditions prevailing in the area.

Concerning the concentrations of P in the soil at a depth of 15-30 cm, a total of 66 plots were classified as having low values. These plots are in the regions of Agrovillage Nossa Senhora da Conceição, comprising 25 plots, and Braço Erguido, encompassing 41 plots. The levels of Ca^{2+}+, K^{+}, Mg^{2+}, and CEC demonstrated similar behaviour to that observed in the 0-15 cm soil layer.

Between the 2014 and 2022 sampling periods, there were substantial changes in soil salinity. In 2022, neither the 0-15 cm nor the 15-30 cm soil layers exhibited issues related to salinity, with all plots classified as non-saline. This finding suggests improvements associated with the adoption of various management practices. This pattern aligns with previous findings by Oliveira (2005), who observed that in PAJC, among the areas affected by salinisation, landowners implemented measures such as reducing local irrigation, decreasing cultivation, installing drainage systems, and selecting specific crops to mitigate the process.

Reductions in salt concentration may stem from a combination of factors including modifications in irrigation practices, enhanced drainage, land use and occupation changes, interannual climatic variability, and the implementation of conservation management strategies (Castro *et al.*, 2021; Tomaz *et al.*, 2020). Consequently, any causal relationship between these variables and the observed outcomes should be approached with prudence.

Conversely, the continued presence of nutritional imbalances, particularly concerning available phosphorus, indicates that improvements in salinity indicators do not necessarily indicate the full restoration of the soil's chemical quality. This phenomenon underscores the notion that diverse pedological and agronomic processes can occur concurrently, necessitating monitoring strategies that encompass not only salinity but also the evolving dynamics of fertility and nutrient availability over time (Horta; Torrent, 2010; Sasabuchi *et al.*, 2023).

Despite the improvement in salinity, the phosphorus (P) levels continued to fall outside the optimal range in certain plots across both analysed soil layers. In the 0-15 cm layer, there were 13 plots classified

as moderate, distributed between Braço Erguido and Nossa Senhora da Conceição, alongside 91 plots with adequate levels. In the 15-30 cm layer, only three plots in Nossa Senhora da Conceição exhibited low levels, whereas 20 plots in Braço Erguido and Nossa Senhora da Conceição were classified as moderate. The observed improvement in both layers can be attributed to nutrient cycling within the soil, particularly the more pronounced recovery in the 0-15 cm layer. Additionally, soil management practices involving phosphate fertilisation have contributed to the increase in available phosphorus, given that this nutrient exhibits limited mobility in the soil, and repeated fertilisation enhances its soil levels.

Concentrations of Ca^{2+}, K^{+} and Mg^{2+} were classified as high in most plots across both soil layers, a pattern consistent with observations from the year 2014. In the 0-15 cm layer, CEC values were classified as moderate in 11 plots in Braço Erguido and Nossa Senhora da Conceição, alongside another 93 classified as high. Additionally, in the 15-30 cm layer, plots exhibiting moderate CEC values were identified, with 6 plots designated as moderate in Braço Erguido and Nossa Senhora da Conceição.

Despite the improvements observed between 2014 and 2022, the data indicated a phosphorus deficit in the soil, concentrated in the areas of the Agrovillages of Braço Erguido and Nossa Senhora da Conceição. The results also highlight substantial temporal variation in the levels of the analysed elements between 2014 and 2022, in both layers. Due to this variation, using 2014 as the baseline, the gains and losses of each plot were assessed in both depths, emphasising the plots with the greatest gains and losses.

Calcium concentrations in the 0-15 cm soil layer decreased in 68 plots, with the greatest reduction reaching 89.3%, decreasing from 239.7 to 25.6 $mmol_c.dm^{-3}$. Among the remaining 36 plots in Ca^{2+} levels, the largest increase was 22.9%, rising from 242.3 to 297.9 $mmol_c.dm^{-3}$. For K^{+} within the same depth, decreases were observed in 82 plots, some reaching approximately 82%, decreasing from 24.3 to 4.4 $mmol_c.dm^{-3}$. In contrast, 22 plots showed increases in K^{+} concentrations, with the largest increase being 42.6%, from 2.6 to 3.7 $mmolc.dm^{-3}$. Concerning Mg^{2+} in the 0-15 cm layer, concentrations decreased in 82 plots, with the most considerable loss of 83.6%, decreasing from 24.3 to 4.4 $mmol_c.dm^{-3}$. Among 22 plots that showed increased Mg^{2+} concentrations, the highest variation was 42.6%, rising from 2.6 to 3.7 $mmol_c.dm^{-3}$. Unlike the other elements, phosphorus (P) in the 0-15 cm layer, excluding two plots, showed predominantly positive changes, with increases of up to 587%, increasing from 4.7 to 32.2 $mg.dm^{-3}$.

In addition to the information regarding gains and losses in the concentrations of the analysed elements by plot, at 0-15 cm, it was observed, based on the mean concentrations observed in plots showing increases and decreases, that between 2014 and 2022 there was a trend of reduction in the concentrations of Ca^{2+} and K^{+}, relative stability of Mg^{2+} concentrations, and an increase in P levels in the soil, Table 4.

These results indicate considerable spatial variability in the distribution and concentration of the analysed elements within the study area. Despite the decline in Ca^{2+} levels and the relative stability of Mg^{2+} concentrations, these values remain elevated compared to the reference standards for Luvissols in the region, as identified by Fernandes *et al.* (2010). This supports the notion that such accumulation is anthropogenic in origin, possibly associated with long-term phosphate fertilisation. The decrease in the concentrations of Ca^{2+}, Mg^{2+}, and K^{+} within the 0-15 cm soil layer may reflect plant uptake by plants over time, as well as their leaching during measures undertaken to mitigate soil salinity, particularly through drainage procedures.

A similar analysis of the 15-30 cm soil layer, the results concerning average gains and losses, as shown in Table 4, revealed a different pattern compared to the upper layer for Mg^{2+}. In this layer, Ca^{2+} and K^{+} continued to exhibit a reduction in their concentrations, while P showed a more significant increase than that observed in the 0-15 cm layer. Conversely, Mg^{2+} in the 15-30 cm layer exhibited the opposite trend relative to the upper layer, with an increase in its concentration.

Table 4 – Mean increases and decreases of available Ca^{2+}, K^{+}, Mg^{2+} and P in the 0-15 cm soil layer between 2014 and 2022

	--	*Ca^{2+}	Ca (%)	*K^{+}	K (%)	*Mg^{2+}	Mg (%)	**P	P (%)
0 – 15 (cm)	increase	20.6	10.1	0.4	14.4	45.5	40.3	44.7	240.2
	decrease	110.7	45.7	5.7	47.2	53.0	46.2	4.5	11.1
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15 – 30 (cm)	increase	40.1	19.6	0.5	22.9	61.3	52.5	81.7	311.2
	decrease	85.0	37.9	5.3	64.2	48.0	38.1	0	0

*Source: The authors *(mmolc.dm-³); **(mg.dm-³).*

Plot-based analyses provide detailed information at the property level, whereas the analysis utilising the plot limit offers an understanding of the situation of the studied Agrovillages; on the other hand, broader spatial patterns can also be identified for certain information. In this context, the comparison of the results based on land-use and land-cover class, as illustrated in Figure 3, functions as a complementary perspective, aiming to facilitate a more comprehensive understanding of the findings.

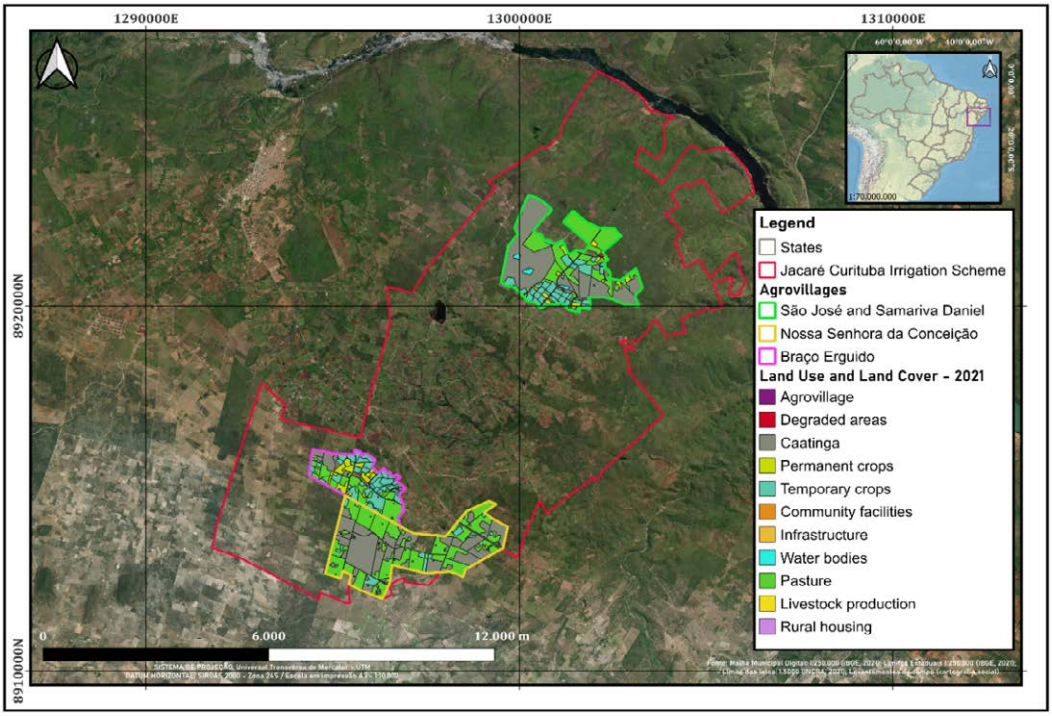

Figure 3 – Land-use and land-cover map (2021)

Source: The authors.

Spatial analysis of the 2022 dataset concentrations indicated no deficiencies related to Ca^{2+}, K^{+}, and Mg^{2+}. However, upon examining the minimum values, the minimum values indicate that certain areas exhibit calcium concentrations nearing classification as low (see Table 5 and Figure 4), suggesting localised nutrient depletion.

Table 5 – Minimum values of Ca^{2+}, K^{+} and Mg^{2} for 2022 according to land-use and land-cover class

Class 2	Ca2+ (mmolc.dm-³)		K+ (mmolc.dm-³)		Mg2+ (mmolc.dm-³)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Caatinga	27,4	58,3	2,0	1,8	20,5	26
Permanent crops	16,5	16,5	2,9	2,2	41,3	48,4
Temporary crops	60,3	62,6	3,0	2,0	22,7	28,3
Pasture	24,1	57,1	2,5	2,0	19,7	25,3
Livestock production	168,1	167	2,8	2,5	117,4	119

Classification according to Embrapa (2015): Red (low); Yellow (moderate); Green (high).

Source: The authors.

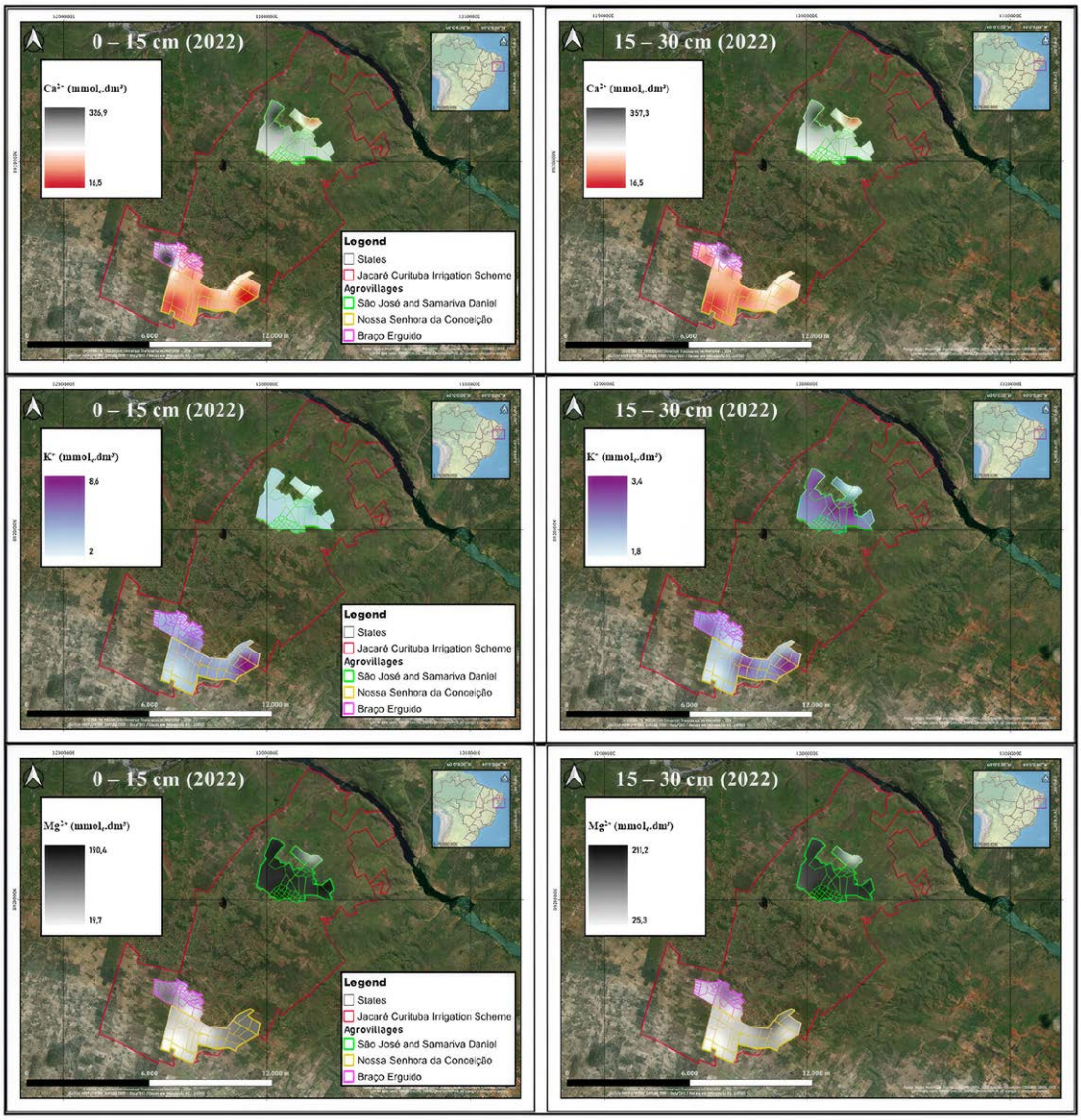

Figure 4 – Distribution of Ca^{2+}, K^{+}, and Mg^{2+} within the agrovillages

Source: The authors.

Despite the generally satisfactory classifications, an assessment based solely on the classification system proposed by Embrapa (2015) reveals substantial variability between the highest and lowest concentrations in both layers. Despite the consistent pattern of land-use and land-cover, the spatial distribution of the analysed elements' concentrations is highly heterogeneous. This irregularity can be attributed to the management practices adopted by individual farmers, as well as the use or non-use of fertilisers, the types employed, and the quantities applied to the soil.

Available phosphorus and CEC, as shown in Table 6 and Figure 5, were classified as moderate for most land-use classes. The concentrations at 15-30 cm depth were classified as low in several land-use classes, possibly due to the lack of phosphate fertiliser application, considering that Brazilian soils are generally deficient in phosphorus and generally require phosphorus supplementation through organic or mineral fertilisation.

Table 6 – Minimum P and CEC values (2022) according to land-use class by land use and land cover class

Class 2	*P (mg.dm^{-3})*		*CEC (mmol$_c$.dm^{-3})*	
	0-15 cm	*15-30 cm*	*0-15 cm*	*15-30 cm*
Caatinga	7,8	5,6	88,5	86,7
Permanent crops	8,8	9,1	143,2	136,7
Temporary crops	8,1	6,2	95,6	93,3
Pasture	7,6	5,4	96,3	86,3
Livestock production	212,4	274,9	296,5	299

Classification according to Embrapa (2015): Red (low); Yellow (moderate); Green (high).

Source: The authors.

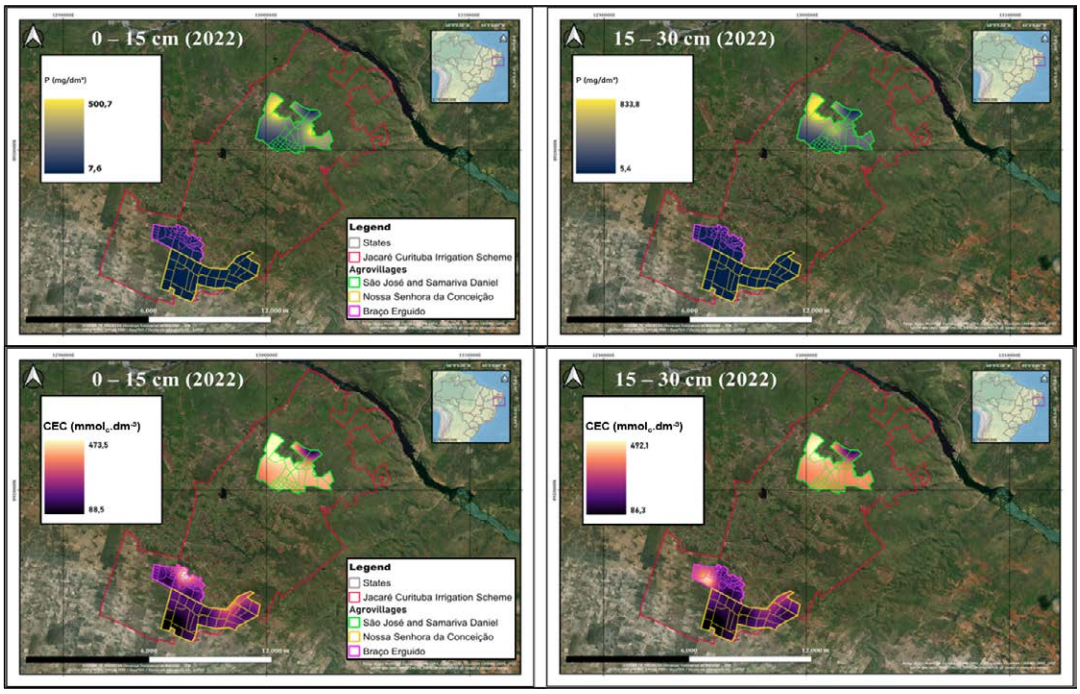

Figure 5 – Distribution of Phosphorus (P) and Cation Exchange Capacity (CEC) in the agrovillages

Source: The authors.

As analysed, there have been improvements in the concentrations of available P between 2014 and 2022. This has resulted in several areas previously classified with low P levels shifting to moderate and/or adequate levels; this process was observed in both layers. This increase, together with gains in the concentrations of Ca^{2+}, K^{+}, and Mg^{2+} in areas that already exhibited elevated levels, indicates excessive fertiliser application, one of the factors that can lead to increased salinisation of these soils. The indiscriminate use of inputs, especially potassium chloride, can, along with poor irrigation management, hinder plant development (Saibo; Ibraimo, 2022; Wanderley, 2009), as well as contribute to the salinisation process (Eloi *et al.*, 2011; Endo *et al.*, 2011; Martins *et al.*, 2017; Medeiros *et al.*, 2012), since the process is related to the increase in Ca^{2+} and K^{+} concentrations in the soil (Silva, 2014).

The fact that, in various areas, there is a concentration of certain elements at high levels reinforces the need for monitoring through specialised technical assistance. Although this study did not directly investigate the role of technical assistance services or the institutional management of PAJC, several works indicate that the sustainability of these enterprises depends on the integration of irrigation infrastructure, continuous technical support, environmental monitoring, and farmer training (Bonilla *et al.*, 2019; Castro *et al.*, 2021). Considering that these dimensions were not directly assessed in this work, their discussion should be understood as a theoretical contextualisation of the results obtained, rather than as empirical evidence produced by this research.

This monitoring should consider local sociocultural knowledge and be conducted using clear language, as communication can influence the effectiveness of activities (Alexandre, 2001). Ethnopedological practices may serve as facilitators in soil management (Lima *et al.*, 2011; Nezomba *et al.*, 2017). It is important to emphasise that the measures implemented should account for the environmental vulnerability to salinisation and sodification processes in Luvissols, which are attributed to their inherent natural characteristics (Castro; Santos, 2015; Silva *et al.*, 2010).

Notwithstanding the analysis, it is imperative to underscore that the current study possesses limitations that must be considered when interpreting the findings. The analysis was conducted through a multitemporal comparison of soil chemical attributes derived from surveys carried out in 2014 and 2022, without incorporating primary information regarding the management practices implemented by farmers during this interval. Aspects about irrigation management, fertiliser application, water quality, and the management strategies employed on the farms were not included in the analyses. Similarly, indicators related to technical assistance, institutional monitoring of the irrigated perimeter, or socio-economic factors potentially influencing producers' management decisions were not evaluated.

4 CONCLUDING REMARKS

The multitemporal analysis of the chemical attributes of the soil in the Jacaré Curituba Settlement Project revealed significant changes between 2014 and 2022. The results demonstrated that the salinity issues identified in the first sampling campaign were not observed in the most recent assessment, indicating changes in the chemical conditions of the soils in the analysed areas. However, imbalances in phosphorus availability persisted, along with considerable variations in the concentrations of some nutrients, highlighting that improvements in salinity indicators do not necessarily imply the complete recovery of the soil's chemical quality.

The comparison between the two periods also revealed significant spatial variability among the plots and across different land-use and land-cover classes, demonstrating that the dynamics of chemical attributes exhibit heterogeneous behaviour within the irrigated perimeter. This finding underscores the importance of conducting periodic soil quality assessments in multitemporal studies, thereby facilitating an understanding of the evolution of chemical processes in agricultural environments within the Brazilian semi-arid region.

The results obtained also demonstrated that the analysed attributes responded differently over the evaluated period, with a reduction in the average concentrations of some cations and a significant increase in available phosphorus in some of the studied areas. These changes indicate that different processes related to nutrient dynamics may occur simultaneously, reinforcing the need to interpret soil chemical quality in an integrated manner, considering multiple indicators and not just salinity parameters.

Although specialised literature demonstrates that factors such as irrigation management, fertilisation practices, technical assistance, the quality of the water used, and institutional management can influence the progression of salinisation processes in irrigated perimeters, these variables were not directly assessed in this research. Therefore, the results presented do not allow for establishing cause-and-effect relationships between the observed changes and specific management practices, limiting the conclusions to the evidence obtained through laboratory analyses.

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STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

The authors used Grammarly for Microsoft Office for language editing and stylistic polishing only. All scientific content, analysis, and intellectual input were developed and verified by the authors; we take full responsibility for the accuracy and integrity of the manuscript.

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Análise multitemporal da qualidade do solo em perímetro irrigado do semiárido brasileiro

Multitemporal analysis of soil quality in an irrigation scheme in the Brazilian semi-arid region

Elton Souza Oliveira [1]

Daniela Nogueira Soares [2]

Nelson Bernal Dávalos [3]

Juliana Dalboni Rocha [4]

Guadalupe Souza Sátiro [5]

Airon José da Silva [6]

[1] Doutorado em Geociências Aplicadas, Docente, Pesquisador, Centro das Humanidades, Universidade Federal do Oeste da Bahia, Barreiras, BA, Brasil
E-mail: esoliveira@ufob.edu.br

[2] Doutorado em Sociologia do Desenvolvimento, Professora, Programa de Mestrado em Gestão e Regulação em Recursos Hídricos; Pesquisadora, Centro de Desenvolvimento Sustentável, Universidade de Brasília, Brasília, DF, Brasil
E-mail: danielanogueiracds@gmail.com

[3] Doutorado em Desenvolvimento Sustentável, Pesquisador, Centro de Desenvolvimento Sustentável, Universidade de Brasília, Brasília, DF, Brasil
E-mail: neleduberdav@gmail.com

[4] Doutorado em Desenvolvimento Sustentável, Professora Visitante, Curso de Engenharia de Energia, Campus Gama/FCTE/UnB, Universidade de Brasília, Brasília, DF, Brasil
E-mail: dalboni.unb@gmail.com

[5] Doutorado em Desenvolvimento Sustentável, Pesquisadora, Centro de Desenvolvimento Sustentável, Universidade de Brasília, Brasília, DF, Brasil
E-mail: guadalupesatiro@gmail.com

[6] Doutordo em Agronomia, Docente, Departamento de Engenharia Agronômica, Universidade Federal de Sergipe, São Cristóvão, SE, Brasil
E-mail: aironjs@gmail.com

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ARTICLE - VARIA

RESUMO

A expansão dos projetos de irrigação no semiárido brasileiro, viabilizada pelo uso das águas do Rio São Francisco, impulsionou iniciativas como o Projeto de Assentamento Jacaré Curituba (PAJC), em Sergipe. Implantado em solos suscetíveis à salinização e sodificação, e sem assistência técnica adequada, o PAJC enfrentou sérios problemas, afetando sua produtividade agrícola. Embora os sinais de salinização identificados em 2014 tenham sido mitigados até 2022, ainda persistem áreas com desequilíbrio de sais e sódio. O estudo mais recente apontou, ainda, alterações na concentração de elementos como o fósforo disponível no solo, aumento de até 587%, evidenciando desequilíbrios nutricionais. Já a CTC foi classificada como média em vários locais. Assim, destaca-se a urgência de políticas públicas e assistência técnica voltadas à realidade local a fim de garantir a sustentabilidade da produção agrícola em áreas irrigadas do semiárido.

Palavras-chave: Salinização. Sodificação. Irrigação. PST. Nexus+. Socioambiental.

ABSTRACT

The expansion of irrigation projects in the Brazilian semi-arid region, supported by water abstraction from the São Francisco River, has led to initiatives such as the Jacaré Curituba Settlement Project (PAJC) in Sergipe. Established on soils vulnerable to salinisation and sodification and developed without adequate technical support, the PAJC encountered significant challenges that compromised agricultural productivity. Although the signs of salinisation identified in 2014 had largely been mitigated by 2022, areas exhibiting salt and sodium imbalances remain. The most recent survey also revealed substantial changes in the concentration of soil nutrients, particularly available phosphorus, with increases of up to 587%, thereby highlighting persistent nutritional imbalances. The cation exchange capacity (CEC) was classified as moderate at several sampling locations. Consequently, there is an urgent need for public policies and technical assistance tailored to local conditions to ensure the long-term sustainability of agricultural production in irrigated areas of the Brazilian semi-arid region.

Keywords: *Salinisation. Sodification. Irrigation. ESP. Nexus+. Socio-environmental.*

1 INTRODUÇÃO

A salinização do solo representa um desafio crescente para as comunidades agrícolas em diversas regiões do mundo, afetando a produtividade e a sustentabilidade ambiental (Esteves; Suzuki, 2008; Pedrotti *et al.*, 2015; Tomaz *et al.*, 2020). Esse fenômeno complexo, influenciado por fatores naturais e atividades humanas, ocorre frequentemente em regiões semiáridas e áridas nas camadas superficiais do solo (Azevedo *et al.*, 2017; Castro *et al.*, 2020; Pizarro, 1978; Ribeiro *et al.*, 2010; Saraiva Filho; Bonilla, 2022; Zhao *et al.*, 2017).

O uso inadequado da irrigação (Richards, 1954), a ausência ou deficiência de sistemas de drenagem (Maas; Grattan, 1999), a aplicação excessiva de fertilizantes e a utilização contínua de águas com restrições de qualidade favorecem o acúmulo de sais na zona radicular (Bonilla *et al.*, 2019), comprometendo progressivamente a qualidade física, química e biológica dos solos e acarretando perdas (Brevik *et al.*, 2015; Daliakopoulos *et al.*, 2016; Medeiros *et al.*, 2012; Rengasamy, 2006; Saraiva Filho; Bonilla, 2022; Tomaz *et al.*, 2020). Por se tratar de um processo complexo e que evolui, regride ou se estabiliza ao longo do tempo, é importante que os estudos sejam realizados de forma contínua para compreender a dinâmica do sistema de solos afetados por sais.

A relevância da análise temporal no estudo da salinização do solo é enfatizada por Shahid *et al.* (2015), que argumentam que a compreensão das mudanças ao longo do tempo é essencial para avaliar a dinâmica desse processo e desenvolver estratégias de mitigação eficazes. No âmbito local, é notória a carência de estudos que investiguem a salinização, considerando suas particularidades e impactos

específicos na agricultura e nas comunidades circunvizinhas. Além dos desafios agronômicos, a salinização do solo também acarreta implicações socioambientais de grande relevância.

Entre essas implicações destacam-se os impactos sobre a qualidade da água, a biodiversidade local e o bem-estar das comunidades dependentes desses recursos. A abordagem integrada dessas dimensões, conforme destacado por Qadir *et al.* (2014), é fundamental para desenvolver estratégias sustentáveis que conciliem a produção agrícola com a conservação ambiental e o bem-estar social. Em diferentes regiões semiáridas, programas de assistência técnica e extensão rural têm sido apontados como instrumentos fundamentais para a adoção de práticas conservacionistas, racionalização do uso da água, manejo adequado da fertilidade e prevenção da degradação dos solos (Castro *et al.*, 2021; Pedrotti *et al.*, 2015). O acompanhamento sistemático das condições ambientais, aliado à assistência técnica continuada e ao monitoramento dos indicadores de qualidade do solo, contribui para minimizar problemas relacionados à salinização e sodificação, especialmente em áreas ocupadas por agricultores familiares sujeitos a limitações técnicas e financeiras (Bonilla *et al.*, 2019; Daliakopoulos *et al.*, 2016; Lopes *et al.*, 2008).

No contexto específico do Projeto de Assentamento Jacaré Curituba (PAJC), localizado nos municípios de Poço Redondo e Canindé de São Francisco – Sergipe, a presença de solos afetados por sais identificados em 2014 (Santos, 2015) tem despertado preocupações, dado o potencial de repercussão nas condições socioeconômicas e ambientais da região.

Dessa forma, o trabalho buscou preencher uma lacuna no conhecimento científico ao realizar uma análise multitemporal do processo de salinização do solo no PAJC, destacando ainda sua situação relativa à concentração de íons que exercem influência sobre o processo de salinização e sodificação do solo e elementos que possam caracterizá-lo quanto à sua qualidade. A compreensão dessas informações é crucial para orientar políticas públicas e práticas que promovam a sustentabilidade local por meio da assistência técnica qualificada.

2 MATERIAIS E MÉTODOS

2.1 ÁREA DE ESTUDO

O Projeto de Assentamento Jacaré Curituba tem seu surgimento datado de 1997, abrangendo parte dos municípios de Poço Redondo e Canindé de São Francisco. Segundo Santos (2015), o PAJC foi reconhecido como um dos assentamentos mais extensos da América do Sul. Essa ocupação foi resultado do processo de mobilização de trabalhadores rurais e agricultores familiares pelo direito à propriedade e ao acesso à terra.

Apesar de hoje ser conhecido como PAJC, o assentamento, anteriormente, era denominado de Nova Califórnia. Com a proposição do governo de Sergipe, o PAJC passou a contar com 134 lotes empresariais, sendo 80 destinados para agricultura irrigada e 54 para o desenvolvimento da atividade pecuária. Como a finalidade da área era a destinação à reforma agrária, o projeto original sofreu alterações, passando a ser estruturado da seguinte forma: implantação em três etapas, o que resultou no surgimento de 36 agrovilas (Codevasf, 2021).

Devido à finalidade do PAJC, parte significativa do território está destinada à atividade agropecuária, em especial ao plantio em áreas irrigadas. Além das pastagens irrigadas, a área conta ainda com o cultivo de quiabo, mandioca, milho, feijão, girassol, goiaba, maracujá, alface, melancia e abóbora. Essas atividades são desenvolvidas graças à presença de sistemas de irrigação em um terreno naturalmente fértil (Santos, 2019).

Tratando dos aspectos pedogeomorfológicos, a área do PAJC está situada sobre relevos dissecados em colinas e interflúvios tabulares e em superfície pediplanada. Nessas áreas encontram-se três classes de solos, sendo elas: Luvissolos Crômicos, Neossolos Litólicos e Regolíticos. As características dos Luvissolos conferem a eles alto potencial produtivo, devido à composição mineralógica rica em nutrientes, porém, esse potencial é afetado pela irregularidade de chuvas, concentradas nos meses de maio, junho e julho, na estação do inverno (Silva, 2010), com uma média de 200 mm de chuva nesse período.

Entre as 36 agrovilas, o presente estudo centrou-se em duas áreas que compreendem quatro agrovilas, sendo elas: Nossa Senhora da Conceição, Braço Erguido, Samariva Daniel e São José. Essas agrovilas possuem atividades típicas de áreas de sequeiro e irrigadas, o que permite o entendimento da dinâmica dessas áreas no que tange ao processo de salinização e sodificação do solo.

2.2 PROCEDIMENTOS METODOLÓGICOS

Para a identificação das áreas que apresentam problemas relativos à qualidade do solo, devido à salinização ou concentrações de nutrientes fora dos padrões de normalidade, foram utilizadas amostras de dois períodos (2014 e 2022), bem como a espacialização dos dados levando em consideração o tipo de uso e cobertura do solo mais recente, bem como o limite das propriedades, desconsiderando as áreas de reservas legal e aglomerados residenciais, área das Agrovilas. Toda a pesquisa seguiu os procedimentos metodológicos da Figura 1.

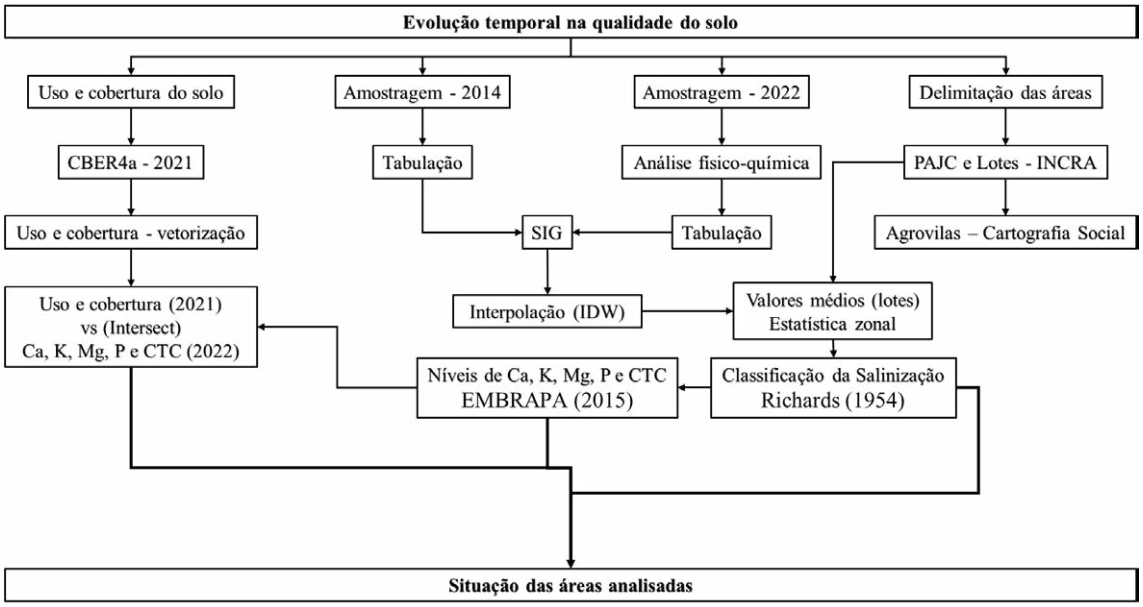

Figura 1 – Organograma dos procedimentos metodológicos

Fonte: Os autores.

2.3 COLETA, PREPARO E ANÁLISE LABORATORIAL DAS AMOSTRAS DE SOLO

Para o estudo, todos os procedimentos de amostragem e laboratoriais foram realizados seguindo a mesma metodologia (Embrapa, 2011; Richards, 1954). A primeira amostragem foi realizada em 2014 (Santos, 2015), já a atual é referente ao ano de 2022. Em ambas as situações, foram coletados solos de

32 áreas distribuídos entre três agrovilas, Figura 2, nas profundidades de 0-15 e 15-30 cm, totalizando 64 amostras compostas de solo.

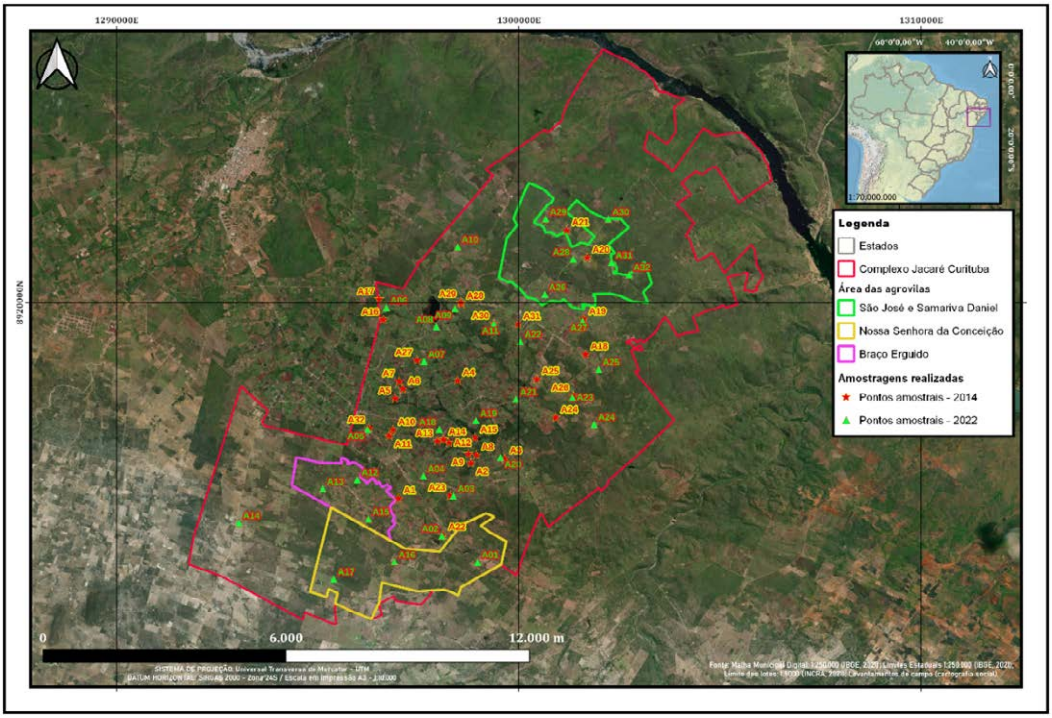

Figura 2 – Localização das Agrovilas e pontos amostrais
Fonte: Os autores

O material coletado foi encaminhado ao Laboratório de Remediação de Solos da Universidade Federal de Sergipe. Após a secagem em estufa a 40ºC, as amostras foram destoradas e passadas em peneira de 2,00 mm (n° 10).

A análise da salinização seguiu o proposto por Richards (1954). Para o cálculo, foram utilizadas as análises do Percentual de Sódio Trocável (PST) – Equação 1 – pH em água destilada e Condutividade Elétrica (CE) em $dS.m^{-1}$. Os limiares utilizados para a classificação dos solos afetados por sais foram ranqueados em quatro classes (Tabela 1).

$$\textbf{Equação 1} - \quad PST = \frac{Na^{+}}{Ca^{2+} + Mg^{2+} + K^{+} + Na^{+} + (H^{+} + Al)} \times 100$$

Tabela 1 – Classificação de solos afetados por sais

Classe	*CE ($dS.m^{-1}$)*	*PST (%)*	*pH*
Sem problemas de sais	< 4	< 15	< 8,5
Salinos	> 4	< 15	< 8,5
Salino-Sódico	> 4	> 15	≥ 8,5

Classe	CE ($dS.m^{-1}$)	PST (%)	pH
Sódicos	< 4	> 15	≥ 8,5

Fonte: Richards (1954).

Além das variáveis de classificação de salinização e sodificação do solo, outras variáveis foram analisadas, como o Cálcio (Ca^{2+}), Magnésio (Mg^{2+}) e Potássio (K^{+}), que fazem parte do grupo de nutrientes para as plantas (Cardoso, 2009; Malavolta, 2008; Marschner, 2012), a Capacidade de Troca Catiônica (CTC), que é capaz de indicar as condições para a nutrição das plantas (Embrapa, 2010), e o teor de fósforo disponível (P) devido à sua importância para o desenvolvimento das plantas (Horta; Torrent, 2010; Sasabuchi *et al.*, 2023). Essas informações são preponderantes para a determinação das condições ideais para o desenvolvimento das plantas, de forma a alcançar a capacidade máxima produtiva e econômica (Sengik, 2007). A classificação utilizada para o Ca^{2+}, Mg^{2+} e K^{+}, CTC e P (Tabelas 2 e 3), foi a proposta pela Embrapa (2015).

Tabela 2 – Valores de referência utilizados para interpretação de resultados de análise de solo

Elemento	Classificação ($mmol_c.dm^3$)		
	Baixo	Médio	Alto
Ca^{2+}	< 16	16 – 30	> 30
Mg^{2+}	< 4	4 – 10	> 10
K^{+}	< 0,77	0,77 – 1,53	> 1,53
CTC	< 50	50 - 150	> 150

Fonte: Adaptado de Embrapa (2015).

Tabela 3 – Valores de referência para teor de fósforo disponível (P) no solo

Teor de Argila ($g.kg^{-1}$)	Classe textural	Teor de P no solo ($mg.dm^3$)		
		Baixo	Médio	Adequado
< 150	Arenosa	0 - 10	10,1 – 20	> 20
150 – 350	Média	0 – 7	7,1 – 15	> 15
> 350 - < 600	Argilosa	0 – 4	4,1 – 8	> 8

Fonte: Adaptado de Embrapa (2015).

2.4 ESPACIALIZAÇÃO DOS DADOS E DELIMITAÇÃO DAS ÁREAS

Como o Projeto de Assentamento Jacaré Curituba está dividido em lotes, distribuídos em Agrovilas, para a realização das análises das 32 áreas amostrais, foram interpolados em ambiente de Sistema de Informação Geográfica (SIG). Esse procedimento consistiu em estimar valores para os vazios existentes entre os pontos amostrais (Mazzini; Schettini, 2009). O software utilizado foi o Qgis 3.2, e o método foi o Inverso do Quadrado da Distância (IDW), devido a seus benefícios (Kravchenko; Bullock, 1999; Wollenhaupt *et al.*, 1994). Como o foco da pesquisa foi obter uma análise dos lotes, posteriormente, utilizando os limites de cada propriedade, foram extraídos os valores médios para cada uma das áreas por meio da ferramenta de Estatística Zonal.

As análises se restringiram às áreas de quatro agrovilas onde ocorrem atividades de pecuária, plantio de sequeiro e irrigado, sendo elas as Agrovilas Nossa Senhora da Conceição, Braço Erguido, Samariva Daniel e São José. Apesar da existência do limite do PAJC e dos lotes, ambos adquiridos com o Incra, os limites das Agrovilas não existiam em base de dados oficiais, nesse sentido foi realizada junto à comunidade, por meio da cartografia social (Acselrad; Coli, 2008; Herlihi; Knapp, 2003), a delimitação das áreas das quatro Agrovilas (Lindoso, 2022). Devido a um conflito entre os reais limites das Agrovilas São José e Samariva Daniel, elas foram aglutinadas em uma área única e contínua. Já as modalidades dos lotes: sequeiro, irrigado e pecuária foram adquiridos do Produto 5, do Projeto BRA/14/G32 PIMS 3066 Sergipe.

2.5 MAPEAMENTO DE USO DE COBERTURA DO SOLO

Para o mapeamento do uso e cobertura do solo, foi utilizada a imagem CBER4a, referente ao mês de janeiro de 2021, com resolução espacial de 2 metros. A imagem foi adquirida no site do Instituto de Pesquisas Espaciais (Inpe). O procedimento realizado para a vetorização em tela considerou os padrões de forma, textura e cor da imagem, constituindo assim as unidades de mapeamento. As unidades de cobertura de uso do solo foram classificadas (Quadro 1) com base em um sistema que combinou diversas formas de classificação da cobertura.

Quadro 1 – Classes de uso e cobertura do solo utilizadas

CLASSE 1	*CLASSE 2*
Água	Massa d'água
Antrópica agrícola	Pastagem
	Cultura temporária
	Cultura permanente
	Pecuária
Antrópica rural	Infraestrutura
	Agrovila
	Espaços sociais
	Residência rural
Vegetação natural	Caatinga
Áreas degradadas	Áreas degradadas

Fonte: Os autores.

Adaptação essa que seguiu, principalmente, as proposições do sistema de classificação de Araújo Filho *et al.* (2007), Brito e Prudente (2005) e Manual Técnico de Uso da Terra (IBGE, 2013). Esse processo de classificação obedeceu a dois **níveis de** organização. Para a validação das áreas, foram utilizados dados levantados em campo por meio da cartografia social (Davalos *et al.*, 2024).

3 RESULTADOS E DISCUSSÃO

Ao todo foram analisados 104 lotes, sendo 22 destinados à irrigação, 47 à pecuária e 35 para atividades de sequeiro. Na análise relativa ao ano de 2014, 32 lotes (64 amostras de solo) apresentaram problemas devido à presença de sais no solo para a camada 0-15 cm, sendo 63 classificados como salinos e 1 como salino-sódico. Na Agrovila Braço Erguido foram identificados 41 lotes e em Nossa Senhora da

Conceição, 23 lotes. A salinização identificada vai ao encontro do que se tem observado em outros perímetros irrigados no Nordeste brasileiro (Lopes *et al.*, 2008; Souza *et al.*, 2000; Vasconcelos *et al.*, 2013).

Estudos realizados em diferentes contextos demonstram que a intensidade da salinização está diretamente relacionada ao manejo da irrigação, à eficiência dos sistemas de drenagem, à qualidade da água utilizada e às práticas de adubação adotadas pelos agricultores (Daliakopoulos *et al.*, 2016; Tomaz *et al.*, 2020). Dessa forma, embora fatores ambientais constituam importante condicionante para o desenvolvimento da salinização, são as práticas de manejo que frequentemente determinam sua velocidade de evolução ou sua mitigação ao longo do tempo. Por essa razão que programas permanentes de monitoramento devem integrar a rotina dos perímetros irrigados, permitindo intervenções preventivas antes que ocorram alterações irreversíveis na qualidade do solo (Daliakopoulos *et al.*, 2016; Pedrotti *et al.*, 2015).

Na camada 15-30 cm, o quantitativo de lotes com problemas de sais no solo foi menor, um total de 30 áreas, todas localizadas também nas Agrovilas Braço Erguido, 19 lotes, e Nossa Senhora da Conceição, 11 lotes. Destaca-se que, nas áreas acometidas pela salinidade e sodicidade, existe uma tendência em apresentar menor qualidade física e química do solo, interferindo no processo de desenvolvimento das culturas (Corrêa *et al.*, 2003; Ribeiro *et al.*, 2009).

Além da presença de sais no solo, em 0-15 cm, foi constatado déficit de Fósforo (P) em 42 lotes distribuídos entre as Agrovilas Nossa Senhora da Conceição e Braço Erguido, estando essas áreas classificadas com o nível baixo. Essa baixa concentração de P interfere diretamente na fertilidade dos solos e pode acarretar perdas na produção (Castro *et al.*, 2019; Gkiougkis *et al.*, 2015; Pedrotti *et al.*, 2015; Santos *et al.*, 2018). Ainda, foram identificados outros 38 lotes localizados nas Agrovilas São José e Samariva Daniel que apresentaram níveis considerados adequados. Já os valores de Ca^{2+}, K^{+}, Mg^{2+} e CTC apresentaram alto nível de concentração em todos os lotes, condizentes com a característica do solo da área, devido ao baixo grau de intemperismo e condições climáticas da região.

Sobre as concentrações de P no solo, em 15-30 cm, 66 lotes apresentaram valores classificados como baixo, todos nas áreas das Agrovilas Nossa Senhora da Conceição, 25 lotes, e Braço Erguido, 41 lotes. Os valores de Ca^{2+}, K^{+}, Mg^{2}+ e CTC apresentaram o mesmo comportamento da camada 0-15 cm.

Entre a amostragem de 2014 e 2022, houve alterações quanto à presença de sais no solo. Em 2022, tanto na camada 0-15 cm quanto em 15-30 cm, não foram identificados problemas relativos à salinidade do solo, ficando todas as áreas classificadas como sem problemas de sais, indicando que houve uma possível melhora em relação às práticas adotadas, padrão similar ao encontrado anteriormente por Oliveira (2005), onde no PAJC foi identificado que, entre as áreas acometidas pelo processo de salinização, os proprietários tomaram medidas de redução da irrigação local, redução do cultivo, realização de drenagem na área e utilização de cultivo específico para controle do processo.

As reduções na concentração de sais podem decorrer da combinação entre alterações nas práticas de irrigação, incremento da drenagem, mudanças no uso e ocupação do solo, variações climáticas interanuais e adoção de práticas de manejo conservacionistas (Castro *et al.*, 2021; Tomaz *et al.*, 2020). Assim, qualquer relação causal entre essas variáveis e os resultados observados deve ser interpretada com cautela.

Por outro lado, a permanência de desequilíbrios nutricionais, especialmente relacionados ao fósforo disponível, evidencia que a melhoria dos indicadores de salinidade não implica necessariamente a recuperação integral da qualidade química do solo. Esse comportamento reforça que diferentes processos pedológicos e agronômicos podem ocorrer simultaneamente, exigindo estratégias de monitoramento que considerem não apenas a salinidade, mas também a dinâmica da fertilidade e da disponibilidade de nutrientes ao longo do tempo (Horta; Torrent, 2010; Sasabuchi *et al.*, 2023).

Apesar da melhora quanto à salinidade, o P ainda apresentou níveis fora do ideal em alguns lotes para ambas as camadas analisadas. Em 0-15 cm houve lotes com níveis classificados como médio, um total de 13 áreas distribuídas entre Braço Erguido e Nossa Senhora da Conceição, e outras classificadas como adequado, 91 lotes. Já em 15-30 cm, apenas três lotes apresentaram níveis baixos, em Nossa Senhora da Conceição e outros 20 lotes com níveis enquadrados como médio, em Braço Erguido e Nossa Senhora da Conceição. A recuperação observada para ambas as camadas possui relação com a ciclagem de nutrientes no solo, o que explica a melhor recuperação em 0-15 cm. O manejo do solo com adubação fosfatada também contribuiu para o aumento do P disponível, uma vez que esse nutriente é pouco móvel no solo, e adubações sucessivas contribuem para a melhoria de seus níveis.

Em relação aos elementos de Ca^{2+}, K^{+} e Mg^{2+}, os lotes apresentaram concentrações classificadas como alta em ambas as camadas, padrão mantido em relação ao ano de 2014. Já o CTC em 0-15 cm apresentou 11 lotes classificados como nível médio, em Braço Erguido e Nossa Senhora da Conceição, e outros 93 como nível alto. Ainda, na camada 15-30 cm foram identificadas áreas com níveis de CTC fora do adequado, sendo seis lotes classificados como níveis médios, em Braço Erguido e Nossa Senhora da Conceição.

Apesar da melhora observada entre 2014 e 2022, os dados demonstraram que existe um déficit de P no solo, concentrado nas áreas das Agrovilas do Braço Erguido e Nossa Senhora da Conceição. Destaca-se, ainda, variação significativa nos níveis dos elementos analisados entre os anos de 2014 a 2022, para ambas as camadas. Devido a essa variação, tomando 2014 como ano de referência, foram aferidos os ganhos e as perdas para cada lote, em ambas as profundidades, destacando os lotes com maiores ganhos e perdas.

O Ca^{2+} em 0-15 cm apresentou, em 68 lotes, redução em sua concentração, com as maiores perdas na ordem de 89,3%, passando de 239,7 para 25,6 $mmol_c.dm^3$. Entre os 36 lotes que apresentaram acréscimo nos níveis de concentração de Ca^{2+}, o maior ganho ficou em 22,9%, de 242,3 para 297,9 $mmol_c.dm^{-3}$. Para o K^{+} em 0-15 cm, as perdas ocorreram em 82 lotes, alcançando em alguns casos a ordem de 82%, passando de 24,3 para 4,4 $mmolc.dm^{-3}$. Entre os 22 lotes que apresentaram ganhos nas concentrações de K^{+}, o maior aumento foi de 42,6%, de 2,6 para 3,7 $mmol_c.dm^{-3}$. Já o Mg^{2+} em 0-15 cm apresentou redução nas concentrações em 61 lotes, sendo a maior perda de 83,6%, variando de 120,3 para 19,7 $mmol_c.dm^{-3}$. Entre os 43 lotes que apresentaram ganhos em sua concentração, a maior variação foi 62,1%, de 117,8 para 191 $mmolc.dm^{-3}$. Diferentemente dos outros elementos, o P em 0-15 cm, com exceção de dois lotes, apresentou predominantemente variação positiva, com ganhos na ordem de 587%, passando de 4,7 para 32,2 $mg.dm^{-3}$.

Além das informações relativas aos ganhos e perdas nas concentrações dos elementos analisados por lotes, em 0-15 cm, foi constatado, a partir da concentração média das áreas positivas (ganhos) e negativas (perdas), que entre 2014 e 2022 houve uma tendência de redução nas concentrações de Ca^{2+} e K^{+}, manutenção dos níveis de Mg^{2+} e um incremento nos níveis de P no solo (Tabela 4).

Essa informação indica a inexistência de um equilíbrio na distribuição/concentração dos elementos analisados na área de estudo. Apesar da redução do Ca^{2+} e praticamente a manutenção nas concentrações do Mg^{2+}, foi observado que os valores se encontram altos, se comparados com os valores de referência para os Luvissolos da região identificados por Fernandes *et al.* (2010), corroborando que esse acúmulo é de origem antrópica, possivelmente pela adubação fosfatada. A redução dos valores de Ca^{2+}, Mg^{2+} e K^{+} na camada de 0-15 cm pode estar associada à absorção desses nutrientes pelas plantas ao longo do tempo e sua lixiviação na tentativa de redução da salinidade dos solos quando foi feita a drenagem.

Ao se realizar a mesma análise, apresentada anteriormente, para a camada 15-30 cm, os resultados dos ganhos e perdas médias (Tabela 4) apresentaram comportamento diferente da camada superior para o Mg^{2+}. Nessa camada, o Ca^{2+} e o K^{+} continuaram apresentando redução em suas concentrações, e o P

um aumento maior que o identificado em 0-15 cm. Já o Mg^{2+} em 15-30 cm apresentou comportamento inverso ao da camada superior, com ganhos em sua concentração.

Tabela 4 – Ganhos e perdas médias do Ca^{2+}, K^{+}, Mg^{2+} e P disponível em 0-15 cm entre 2014 e 2022

	--	*Ca^{2+}	Ca (%)	*K^{+}	K (%)	*Mg^{2+}	Mg (%)	**P	P (%)
0 – 15 (cm)	Ganhos	20,6	10,1	0,4	14,4	45,5	40,3	44,7	240,2
	Perdas	110,7	45,7	5,7	47,2	53,0	46,2	4,5	11,1
--	--	--	--	--	--	--	--	--	--
15 – 30 (cm)	Ganhos	40,1	19,6	0,5	22,9	61,3	52,5	81,7	311,2
	Perdas	85,0	37,9	5,3	64,2	48,0	38,1	0	0

*(mmolc.dm-³); **(mg.dm-³)

Fonte: Os autores.

Se por um lado a análise utilizando o limite dos lotes proporciona uma noção da situação das Agrovilas estudadas, por outro pode-se gerar uma generalização de algumas informações. Nesse sentido, a comparação dos resultados a partir das classes de uso e cobertura do solo (Figura 3) serve como um complemento no sentido de proporcionar maior entendimento a respeito dos resultados.

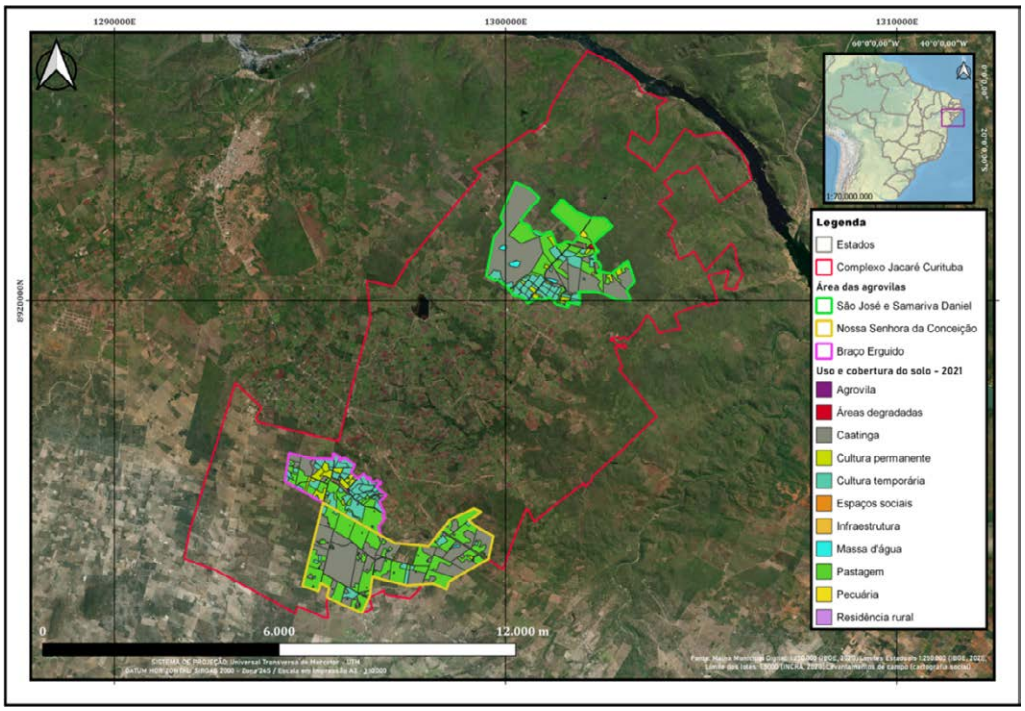

Figura 3 – Uso e cobertura do solo – 2021

Fonte: Os autores.

Após a espacialização dos dados de 2022, os níveis médios indicaram a inexistência de problemas relativos ao Ca^{2+}, K^{+} e Mg^{2+}. Porém, ao se analisar os valores mínimos, é possível identificar áreas onde as concentrações estão próximas de serem classificadas como baixa, para o Ca^{2+} (Tabela 5 e Figura 4), indicando uma situação fora do adequado.

Tabela 5 – Valores mínimos de Ca^{2+}, K^{+} e Mg^{2+} de 2022 por classe de uso e cobertura do solo

Classe 2	*Ca^{2+} ($mmol_c.dm^{-3}$)*		*K^{+} ($mmol_c.dm^{-3}$)*		*Mg^{2+} ($mmol_c.dm^{-3}$)*	
	0-15 cm	*15-30 cm*	*0-15 cm*	*15-30 cm*	*0-15 cm*	*15-30 cm*
Caatinga	27,4	58,3	2,0	1,8	20,5	26
Cultura permanente	16,5	16,5	2,9	2,2	41,3	48,4
Cultura temporária	60,3	62,6	3,0	2,0	22,7	28,3
Pastagem	24,1	57,1	2,5	2,0	19,7	25,3
Pecuária	168,1	167	2,8	2,5	117,4	119

Classificação segundo Embrapa (2015) – Vermelho (baixo); Amarelo (médio); Verde (alto).

Fonte: Os autores.

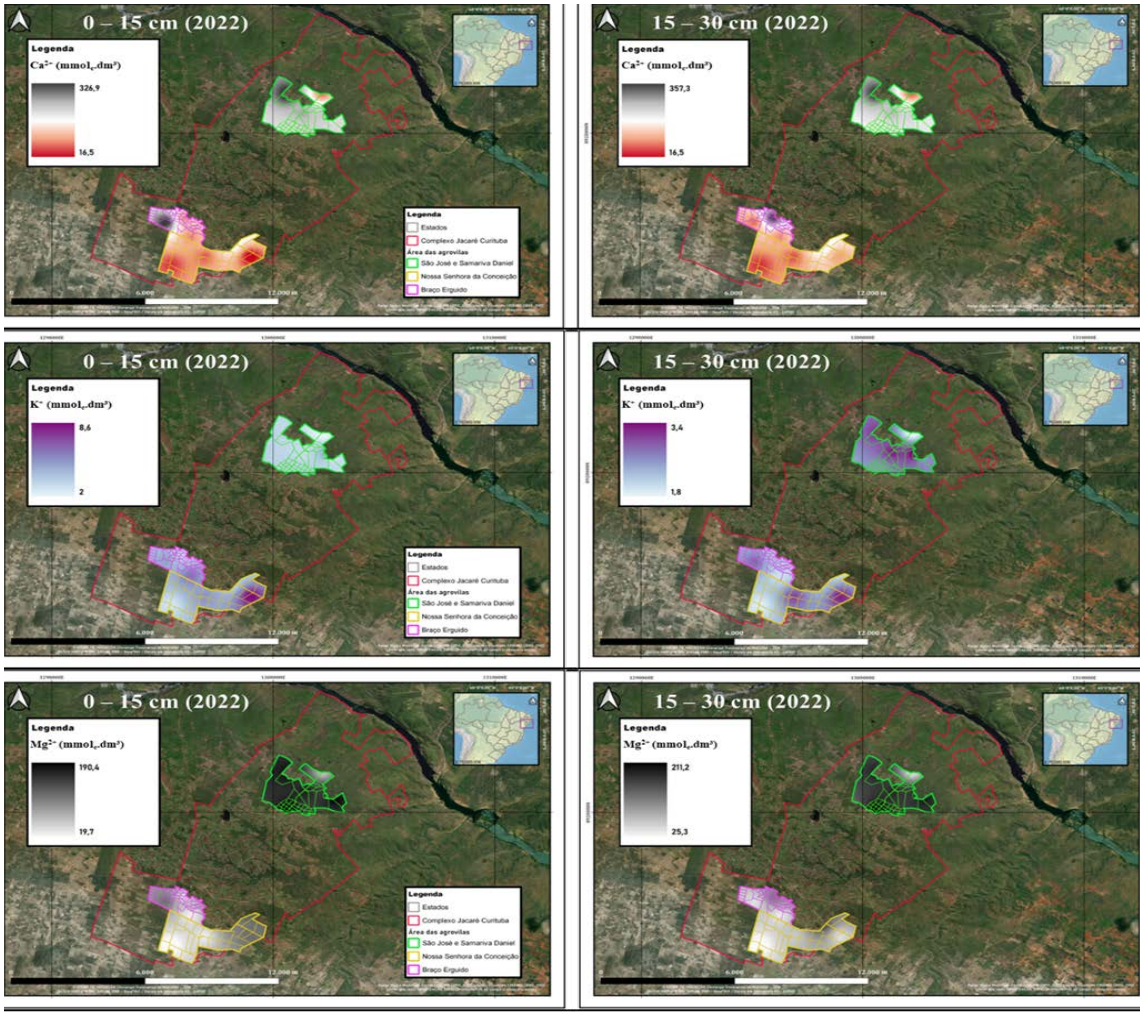

Figura 4 – Distribuição do Ca^{2+}, K^{+} e Mg^{2+} nas Agrovilas

Fonte: Os autores.

Apesar da aparente normalidade, se analisada apenas a classificação proposta pela Embrapa (2015), para ambas as camadas é perceptível a disparidade entre as maiores e as menores concentrações. Para o mesmo padrão de uso e cobertura do solo, não existe uma distribuição regular na concentração dos

elementos analisados, isso pode ser justificado pelo nível tecnológico adotado por cada produtor, uso ou não de fertilizantes, quais os tipos usados e as quantidades aplicadas no solo.

Tanto o P disponível quanto a CTC (Tabela 6 e Figura 5) ficaram classificados como médio para quase todas as classes de uso, apresentando concentrações classificadas como baixa, em 15-30 cm, em parte das áreas classes, possivelmente pela não aplicação de adubo fosfatado, pois no geral os solos brasileiros são pobres em P e necessitam ser supridos via adubação orgânica ou mineral.

Tabela 6 – Valores mínimos de P e CTC de 2022 por classe de uso e cobertura do solo

Classe 2	*P (mg.dm^{-3})*		*CTC (mmol$_c$.dm^{-3})*	
	0-15 cm	*15-30 cm*	*0-15 cm*	*15-30 cm*
Caatinga	7,8	5,6	88,5	86,7
Cultura permanente	8,8	9,1	143,2	136,7
Cultura temporária	8,1	6,2	95,6	93,3
Pastagem	7,6	5,4	96,3	86,3
Pecuária	212,4	274,9	296,5	299

Classificação segundo Embrapa (2015) – Vermelho (baixo); Amarelo (médio); Verde (alto).

Fonte: Os autores.

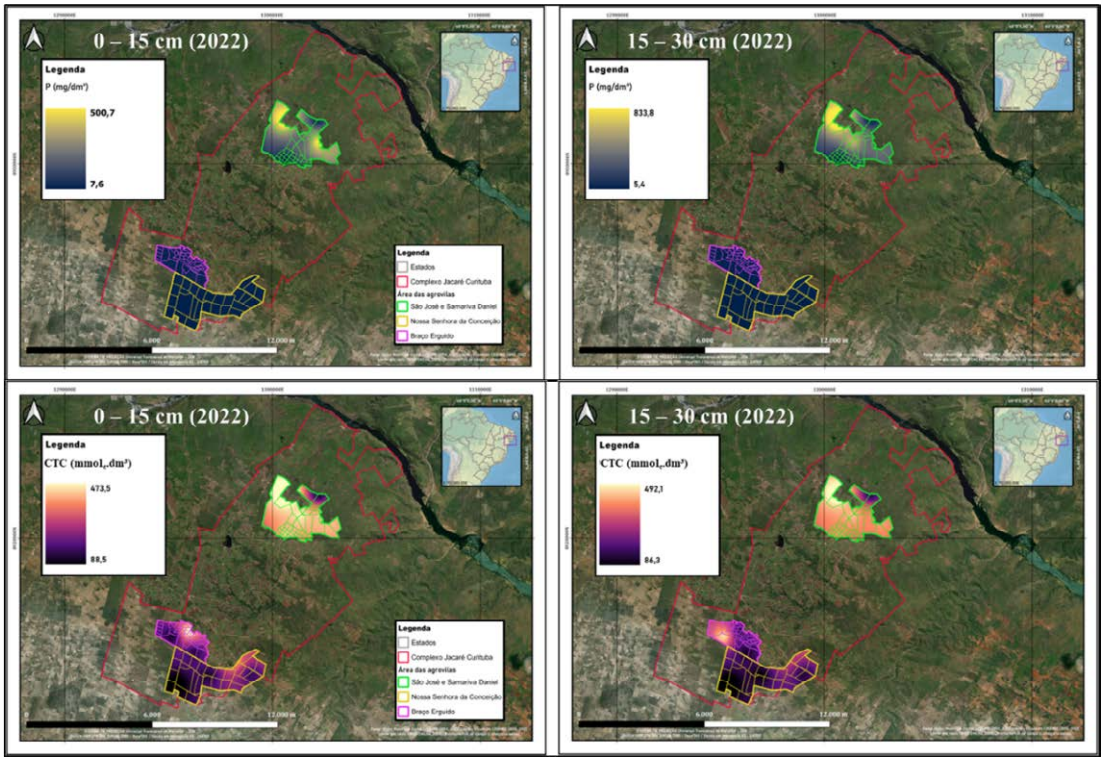

Figura 5 – Distribuição do P e CTC nas Agrovilas

Fonte: Os autores.

Conforme analisado, houve melhorias nas concentrações dos níveis de P disponível entre 2014 e 2022. Isso fez com que diversas áreas anteriormente classificadas com baixo nível de P passassem para o

nível médio e/ou adequado. Esse processo foi observado em ambas as camadas. Esse aumento, junto com os ganhos nas concentrações de Ca^{2+}, K^{+} e Mg^{2+}, em áreas que já apresentavam níveis altos, é um indicativo da aplicação excessiva de fertilizantes, um dos fatores que podem levar ao aumento da salinização desses solos. A utilização indiscriminada de insumos, em especial à base de cloreto de potássio, pode, juntamente com o mau manejo da irrigação, prejudicar o desenvolvimento de plantas (Saibo; Ibraimo, 2022; Wanderley, 2009), além de contribuir com o processo de salinização (Eloi *et al.*, 2011; Endo *et al.*, 2011; Martins *et al.*, 2017; Medeiros *et al.*, 2012), uma vez que este tem relação com o aumento de Cl^{-} e K^{+} no solo (Silva, 2014).

O fato de em diversas áreas existir concentração de alguns elementos com níveis altos reforça a necessidade de um acompanhamento por meio de assistência técnica especializada. Embora o presente estudo não tenha investigado diretamente a atuação dos serviços de assistência técnica nem a gestão institucional do PAJC, diversos trabalhos apontam que a sustentabilidade desses empreendimentos depende da integração entre infraestrutura de irrigação, acompanhamento técnico contínuo, monitoramento ambiental e capacitação dos agricultores (Bonilla *et al.*, 2019; Castro *et al.*, 2021). Considerando que essas dimensões não foram diretamente avaliadas neste trabalho, sua discussão deve ser compreendida como contextualização teórica dos resultados obtidos e não como evidência empírica produzida pela presente pesquisa.

Esse acompanhamento deve considerar o conhecimento sociocultural local e ser realizado por meio de uma linguagem clara, uma vez que a comunicação pode interferir na manutenção das atividades (Alexandre, 2001), visto que práticas etnopedológicas podem ser um facilitador no manejo do solo (Lima *et al.*, 2011; Nezomba *et al.*, 2017). Vale destacar que as medidas a serem tomadas devem levar em consideração a susceptibilidade ambiental ao processo de salinização e sodificação dos Luvissolos decorrentes de suas características naturais (Castro; Santos, 2015; Silva *et al.*, 2010).

Apesar da análise, é importante destacar que o presente estudo apresenta limitações que devem ser consideradas na interpretação dos resultados. A análise foi fundamentada na comparação multitemporal de atributos químicos do solo obtidos em campanhas realizadas nos anos de 2014 e 2022, não contemplando informações primárias sobre as práticas de manejo adotadas pelos agricultores ao longo desse intervalo. Aspectos relacionados ao manejo da irrigação, ao uso de fertilizantes, à qualidade da água utilizada e às estratégias de manejo empregadas nas propriedades não puderam ser incorporados às análises realizadas. Da mesma forma, não foram avaliados indicadores referentes à assistência técnica, ao acompanhamento institucional do perímetro irrigado ou aos fatores socioeconômicos que podem influenciar as decisões de manejo adotadas pelos produtores.

4 CONSIDERAÇÕES FINAIS

A análise multitemporal dos atributos químicos do solo no Projeto de Assentamento Jacaré Curituba evidenciou alterações significativas entre os anos de 2014 e 2022. Os resultados demonstraram que os problemas relacionados à salinidade identificados na primeira campanha de amostragem não foram observados na avaliação mais recente, indicando mudanças nas condições químicas dos solos das áreas analisadas. Entretanto, permaneceram desequilíbrios relacionados à disponibilidade de fósforo e variações expressivas nas concentrações de alguns nutrientes, evidenciando que a melhoria dos indicadores de salinidade não representa, necessariamente, a recuperação integral da qualidade química do solo.

A comparação entre os dois períodos revelou, ainda, elevada variabilidade espacial entre os lotes e entre as diferentes classes de uso e cobertura da terra, demonstrando que a dinâmica dos atributos químicos apresenta comportamento heterogêneo dentro do perímetro irrigado. Esse resultado reforça a importância da realização de avaliações periódicas da qualidade do solo em estudos multitemporais,

permitindo compreender a evolução dos processos químicos em ambientes agrícolas inseridos no semiárido brasileiro.

Os resultados obtidos também evidenciaram que os atributos analisados responderam de maneira distinta ao longo do período avaliado, com redução nas concentrações médias de alguns cátions e incremento expressivo do fósforo disponível em parte das áreas estudadas. Essas alterações indicam que diferentes processos relacionados à dinâmica dos nutrientes podem ocorrer simultaneamente, reforçando a necessidade de interpretar a qualidade química do solo de forma integrada, considerando múltiplos indicadores e não apenas os parâmetros relacionados à salinidade.

Embora a literatura especializada demonstre que fatores como manejo da irrigação, práticas de fertilização, assistência técnica, qualidade da água utilizada e gestão institucional possam influenciar a evolução dos processos de salinização em perímetros irrigados, essas variáveis não foram avaliadas diretamente nesta pesquisa. Dessa forma, os resultados apresentados não permitem estabelecer relações de causa e efeito entre as alterações observadas e práticas específicas de manejo, restringindo as conclusões às evidências obtidas por meio das análises laboratoriais realizadas.

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Viability of distributed generation for small consumers in Brazil through an availability-cost exemption for systems up to 1.5 kW

Viabilidade da geração distribuída para pequenos consumidores no Brasil por meio da isenção do custo de disponibilidade para sistemas de até 1,5 kW

Tiago Argollo Silva [1]

Daduí Cordeiro Guerrieri [2]

[1] *Master's Degree in Production and Systems Engineering, Doctoral Student, Centro Federal de Educação Tecnológica Celso Suckow da Fonseca (Cefet/RJ), Rio de Janeiro, RJ, Brazil*
E-mail: tiago_argollo@hotmail.com

[2] *Doctorate in Aerospace Engineering, Professor, Centro Federal de Educação Tecnológica Celso Suckow da Fonseca (Cefet/RJ), Rio de Janeiro, RJ, Brazil*
E-mail: dadui.guerrieri@cefet-rj.br

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ABSTRACT

The application of public policies to promote Distributed Generation (DG) in Brazil is an example of the diffusion of clean energy; however, this growth is concentrated in certain consumer profiles. This study evaluates the economic feasibility of small residential Photovoltaic Distributed Generation (PVDG) systems and proposes a regulatory adjustment to make them viable. The economic feasibility was assessed by simulating Net Present Value (NPV) and payback indicators for small residential systems across 51 Brazilian distribution utilities, using open data from the Brazilian National Electric Energy Agency (Aneel). The results show that small residential systems, especially those serving consumers with 80–170 kWh/month, have the least favourable economic performance under the current rules. To address this imbalance, the study proposes creating a new subgroup (DG-II-0) for systems up to 1.5 kW that are exempt from the availability cost. Simulations indicate that this change would improve the NPV and Payback period, making distributed generation more attractive to low-income families. The proposed adjustment aligns with Brazil's goal of eradicating energy poverty and with international commitments to a fair and inclusive energy transition.

Keywords: Distributed generation. Regulation. Net-metering. Electricity tariffs. Availability cost. Brazil

RESUMO

A aplicação de políticas públicas para promover a Geração Distribuída (GD) no Brasil é um exemplo de difusão de energia limpa. No entanto, esse crescimento apresenta uma concentração da difusão em determinados perfis de consumidores. Este estudo avalia a viabilidade econômica de sistemas

residenciais de Geração Distribuída Fotovoltaica (GDFV) e propõe um ajuste regulatório para torná-los economicamente viáveis. A viabilidade econômica foi avaliada por meio da simulação do Valor Presente Líquido (VPL) e dos indicadores de retorno do investimento para pequenos sistemas residenciais em 51 concessionárias brasileiras, com base em dados abertos da Aneel. Os resultados mostram que os sistemas residenciais de pequeno porte, especialmente aqueles que atendem consumidores com consumo entre 80 e 170 kWh/mês, apresentam o desempenho econômico menos favorável sob as regras atuais. Para corrigir esse desequilíbrio, o estudo propõe a criação de um novo subgrupo (DG-II-0) para sistemas de até 1,5 kW isentos do custo de disponibilidade. As simulações indicam que essa mudança melhoraria o VPL e o prazo de retorno, tornando a geração distribuída mais atraente para famílias de baixa renda. O ajuste proposto está alinhado com a meta do Brasil de erradicar a pobreza energética e com os compromissos internacionais para uma transição energética justa e inclusiva.

Palavras-chave: *Geração distribuída. Regulamentação. Medição líquida. Tarifas de eletricidade. Custo de disponibilidade. Brasil.*

1 INTRODUCTION

The use of clean energy has increased rapidly over the past few years. The IEA report showed that for every $1 invested in fossil fuels, $1.7 is invested in clean sources (IEA, 2023b). Despite the sector's growth, there are still barriers to overcome. The 2023 IEA Global Hydrogen Review report highlights that, despite interest in investing in low-emission hydrogen, the sector still needs political support to grow (IEA, 2023a). The 2023 Breakthrough Agenda report shows that the investment levels of the countries that made commitments at COP26 are below what is needed to meet international climate goals (Irena, 2023). Another point is energy poverty. The report Irena (2022) shows that high fossil fuel prices result in energy poverty. In this context, it is evident that there is still a long way to go.

The Brazilian government has implemented measures to encourage clean energy. The application of public policies to promote Distributed Generation (DG) in Brazil is an example of the successful diffusion of clean energy. This type of generation aligns with international climate goals because it relies on low-impact sources. According to data from the Distributed Generation Brazilian Association (ABGD), Distributed Generation (DG) reached 19 GW in February 2023, about 70% of the installed solar energy capacity (ABGD, 2023). The DG expansion process began in 2012 with the implementation of the Normative Resolution 482 (Aneel, 2012). This regulation facilitated the transition of energy consumers into prosumers, granting individuals connected to the electric grid the capacity to function as generators. Among the rules established by the resolution, the energy compensation system was the main driver of DG, as it provided net compensation, with all injected energy fully compensated. These rules allowed prosumers to pay only the availability cost, since all the energy consumed was produced (Aneel, 2012; Brazil, 2022). This initiative to implement a compensation system to promote the diffusion of DG has occurred in a few countries. In the 1990s, the Feed-in Tariff (FIT), another type of financial compensation system to stimulate DG growth, was implemented in Germany (Castro; Dantas, 2018; Darghouth *et al.*, 2011; Ramírez *et al.*, 2017).

Stakeholders in the Brazilian electricity sector identified the need to change the DG compensation system, as its continuation was having negative impacts on the sector. One of the main consequences highlighted was the increase in electricity rates for consumers who chose not to adopt DG. In 2022, Law 14,300 was enacted to establish new rules for DG and served as the basis for new DG regulations in Brazil (Brazil, 2022). As a result, the main changes involved adjustments to the DG compensation system, under which compensation would no longer be full, to reduce this impact (Silva, 2022). As expected, the new DG rules slowed the sector's growth, as the changes reduced the amount of energy compensated, negatively affecting the economic indicators of DG projects. The need for changes was not limited to Brazil; other countries also underwent this process (Castro; Dantas, 2018).

Some studies have examined these changes in Brazil's compensation system. These articles compare economic indicators for DG systems under the compensation system of the previous rules with those under the legislation in force. Neto *et al.* (2023) compare Law 14,300 with earlier rules. They analyse from which consumption profile it is advantageous for the prosumer to produce 100% of the energy consumed. According to them, there is a 34% advantage over the previous rules. However, it is not advantageous for prosumers who consume 150 kWh or less per month to produce 100% of their energy. It is beneficial for all others with a capacity above this range. Iglesias and Vilaça (2022) analyse economic indicators, such as levelized cost of energy (LCOE) and payback periods, for DG systems, considering the scenarios under Law 14,300 and the previous Resolution rules. In both scenarios, the indicators showed economic viability, but DG was more attractive under Resolution 482. Pillot *et al.* (2018) evaluate the parity between energy from the electricity grid and energy from DG through the LCOE in the southern region of Brazil. The analysis showed that 2 kW systems are not economically viable; only systems above 7 kW are. Gomes *et al.* (2018) analyse LCOE by consumption range for households across all Brazilian energy utilities. The results showed that, in some cases, parity can only be achieved with consumption above 1,000 kWh per month. In the best-case scenario, the parity is achieved for consumption above 200 kWh per month. Utilities such as Cemig and Coelba present economic feasibility for systems starting at 350 kWh, which is within the average, considering all the utilities analysed in the article. Although the results vary, the indicators for low-consumption households are worse in all cases and, in some cases, are even economically unviable.

Other studies focus on DG solutions for low-income consumers, such as de Sermarini *et al.* (2024), which proposes using DG to reduce social inequalities. The proposal includes household migration and participation in the social energy tariff policy and DG. The Net Present Value (NPV) of households with the social tariff was compared with that of households using DG. For most municipalities, the NPV of DG was better than that of the social tariff. Vale *et al.* (2017) draw on Brazilian housing public policy, conducting studies of economic indicators to help households participating in this program become prosumers. They conclude that a particular Brazilian region has advantages in the indicators.

In this context, this article aims to identify opportunities for improvement in the DG compensation system in Brazil, with a focus on promoting equal economic benefits across different groups of prosumers. To achieve this objective, this study proposes changes to the current energy compensation model and estimates economic indicators for the proposed scenario, comparing them with those of the current model.

This article offers relevant contributions to both the formulation of public policies and the advancement of the academic literature on DG. In the context of energy policy, it seeks to support public decision-makers by proposing improvements to the current compensation system. From a theoretical perspective, the study explores the use of the availability cost as an instrument to encourage small residential consumers to participate in DG. This cost, defined as the minimum amount paid by low-voltage consumers in Brazil, is also adopted in other countries, which expands the potential for international application of the proposals presented here. Previous studies have addressed the availability cost as an opportunity for improvement, focusing on an efficient tariff structure (Ibanez-Lopez *et al.*, 2017; Sioshansi, 2016). However, these studies sought efficient allocation methods that maximise efficiency in the DG compensation system. In contrast, this article proposes an approach aimed at equitable charging of availability costs between consumers with lower and higher consumption, based on an analysis of the economic effects on these groups. In addition, the results obtained are in line with the UN Sustainable Development Goal 7 (SDG 7), which aims to ensure universal access to reliable, sustainable, and modern energy (ONU, 2024).

The article is structured into six sections. Section 2 contextualises the current DG scenario in Brazil. Section 3 presents the methodological framework. Section 4 analyses the economic performance indicators by system size. Section 5 proposes adjustments to the DG compensation rules and discusses

their expected benefits. Finally, Section 6 summarises the main findings and highlights policy implications.

2 CURRENT PANORAMA OF DISTRIBUTED GENERATION IN BRAZIL

The expansion of distributed generation in Brazil began with Normative Resolution No. 482/2012, which established the net metering system and allowed consumers to act as generators (Aneel, 2012). Subsequently, Resolution No. 687/2015 raised power limits, extended the credit period, and created new participation models, accelerating the spread of distributed generation. However, the current model has led to cross-subsidies and infrastructure impacts, prompting regulatory adjustments. In this context, Law No. 14,300/2022 and its implementing regulations under Resolution No. Resolution 1,059/2023 redefined the net metering system, gradually reducing the amount of energy subject to net metering and introducing partial billing for distribution costs. Thus, it is evident that the regulatory framework for distributed generation in Brazil has been continuously modified to balance incentives for expansion with the sector's economic sustainability (Brazil, 2022). After the law's rollout, installations plunged in 2023 and have not regained previous growth, despite falling residential photovoltaic systems (PVDG) prices (Greener, 2023), highlighting the reform's impact.

Figure 1 illustrates the distribution of residential PVDG in Brazil based on data published by the Brazilian National Electric Energy Agency (Aneel), taking into account all residential installations up to the end of 2024 (Aneel, 2024). The curve is generated from an estimate of the probability density function, which allows us to visualise the most common power levels among the systems analysed.

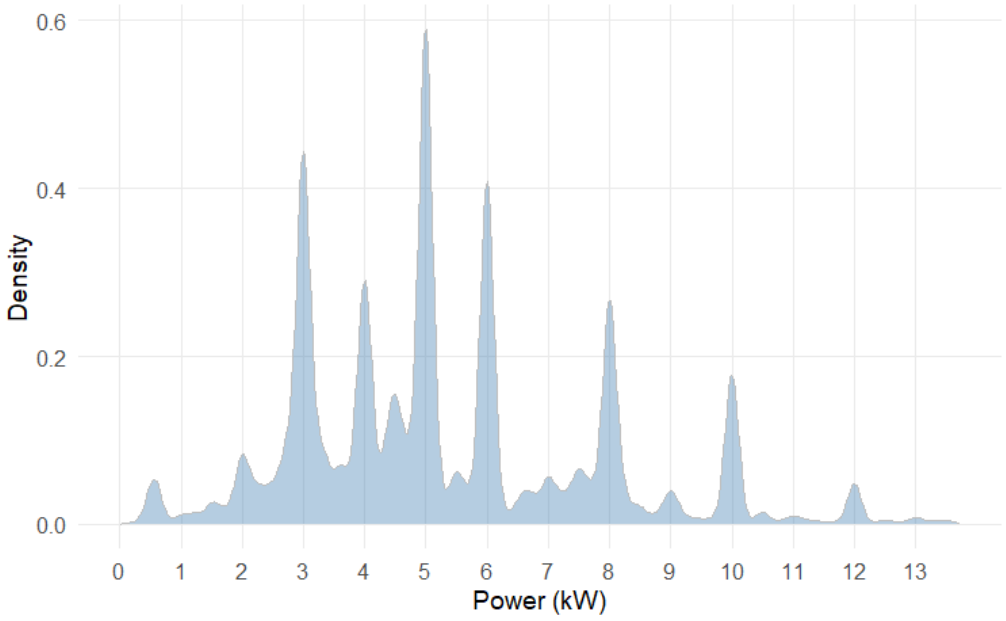

Figure 1 – Residential Photovoltaic Distributed Generation (PVDG) systems distribution by power band from data collected between 2012 and 2024

Source: The authors, based on Aneel (2024).

The smoothed curve reveals multiple peaks, with emphasis on a significant concentration around 5 kW, suggesting that this range represents the most common profile among Brazilian prosumers. It also shows peaks in systems with power from 3 kW to 8 kW; systems in this range exceed 1,851,942 units installed out of a total of 2,582,358 PVDG units. PVDG systems with capacities above 10 kW can

produce around 1,000 kWh/month. However, households with this consumption profile represent a minority in Brazil, which helps to explain the low share of these systems in the residential PVDG market. At the other extreme, systems up to 2 kW also have limited participation, despite their generation potential (approximately 200 kWh/month) being well aligned with the country's predominant residential consumption profile (Aneel, 2024). According to EPE (2026a), the average electricity consumption of Brazilian households is around 170 kWh/month, suggesting that PVDG systems in this power range would be sufficient to meet this demand. Nevertheless, the systems with the highest market penetration are those around 5 kW, whose generation capacity can reach up to three times the national household average (Aneel, 2024). This contrast highlights that, although households with lower average consumption represent a vast and underexplored market, current PVDG expansion in Brazil has been concentrated in larger systems.

This mismatch between the consumption profile of households and that of PVDG adopters occurs in several countries. The review by Konzen, Best, and de Castro (2024) shows that this mismatch arises because the financial gains are concentrated among larger consumers: the compensation rules in force favour higher-capacity systems, whereas smaller systems receive substantially lower economic benefits. This pattern reveals both distributive and recognition injustice, since the benefits of PVDG are concentrated in higher-income, higher-consumption segments. At the same time, the vast contingent of low-consumption households remains economically excluded.

3 METHODOLOGY

This study is an economic feasibility assessment based on secondary, open-access data published by Aneel covering the period from 2012 to 2025 (Aneel, 2024). These data are publicly available and updated daily by the responsible institutions. As the research relies exclusively on public secondary data and does not involve human subjects or personal data, ethics committee approval was not required.

3.1 Methods for calculating economic indicators

The economic performance of PVDG systems is commonly assessed using NPV and payback indicators (Allan *et al.*, 2015; De Doile *et al.*, 2021; Iglesias; Vilaça, 2022). While NPV captures the long-term profitability of the investment by discounting future cash flows, the payback provides a straightforward measure of how quickly the initial investment can be recovered, thus offering complementary perspectives for decision-making.

To calculate the economic indicators, certain assumptions were defined:

- The compensation rules of the DG-II group were considered (Brazil, 2022);
- All prosumers were considered from the B group (Brazil's low-voltage consumer class), residential consumers (Aneel, 2023c);
- It was considered that all injected energy was compensated in 1 year;
- An annual linear reduction of 0.8% in the production of the PV system, distributed over a 25-year lifetime, as specified in the PV module datasheets, was considered;
- A discount rate (r) of 8% was considered, which is recommended by Brazilian Energy Research Company (EPE) for this type of study (EPE, 2022);
- An increase in energy tariffs of 10% per year was considered. This is the average rate of increase in residential tariffs over the past ten years, taken as a reference (Aneel, 2023a);

- A lifetime of 25 years, corresponding to the period over which the photovoltaic modules are guaranteed to retain at least 80% of their rated performance, was assumed;
- Tariff values were defined based on the latest tariff review approved by Aneel for each utility (Aneel, 2023d);
- The levied tax compensation on the energy tariff was not considered.

To calculate the economic indicators, it is necessary to estimate each photovoltaic system's energy generation. Aneel's Normative Resolution No. 1,059 establishes an equation to calculate the average generation of a PVDG system in Brazil (Aneel, 2023b):

$$Eg = Pot \cdot FC \cdot 24 \cdot 30 \quad (1)$$

where is the average monthly energy production in kWh, the installed power of the PVDG system, the solar capacity factor (16%), 24 the number of hours in a day, and 30 the number of days in a month. Equation 1 was used to calculate all energy generation.

The amount invested was calculated by:

$$VF_0 = Pot \cdot VW \quad (2)$$

where VF_o is the invested amount for the implementation of the PVDG system, and the unit value of the PVDG system price, in R$/kW (Greener, 2023).

The value of the energy generated over the course of a year was calculated by

$$VF_x = VC \cdot Eg \cdot 12 \quad (3)$$

where is the amount of the compensated energy tariff, as defined in the premises. In this amount, the distribution costs (TUSD-Fio B, the Brazilian distribution-network usage tariff) are discounted, as specified in the DG-II group's compensation rules (Brazil, 2022). To determine the TUSD-Fio B values, data from the calculation memories of the tariff processes for the analysed utilities were considered (Aneel, 2023d).

Finally, the NPV can be calculated by substituting Equations 2 and 3 into the standard NPV equation:

$$\sum_{t=0}^{25} \frac{VFx}{(1+r)^t} - VF_0 \quad (4)$$

where is the discount rate. The NPV is the sum of the valuation over the system's 25-year service life. The year 2024 was designated as Year 0, using the tariff rate applicable to that year.

Paybacks were calculated based on the cash flow presented in Equation 4. Payback is defined as the year in which revenue exceeds the amount invested, i.e., when cash flow becomes positive. Discounted payback was calculated by considering the value of money over the 25 years analysed.

Based on the distribution shown in Figure 1, the economic analysis focused on residential prosumers with the highest prevalence of installations. It also included 0.5 kW and 1.0 kW systems, which are the specific focus of this research.

3.2 METHODS FOR PROPOSING CHANGES TO THE COMPENSATION SYSTEM

To identify opportunities for improvement in the PVDG compensation system, we evaluated the distribution of the main components of prosumers' electricity rates. The percentage shares of the availability cost, the TUSD-Fio B component, and the offset energy in the utility rates examined in this article were analysed. The percentages were calculated based on the rate structure established by Aneel (Aneel, 2023d).

Following the analysis, an adjustment to the credit compensation mechanism was proposed, specifically targeting prosumers with PVDG systems of up to 1.5 kW. Systems with this capacity supply the necessary energy to households with an average consumption of approximately 170 kWh/month. Law 14,300/2022 classifies prosumers into three groups: DG-I, DG-II, and DG-III: DG-I group refers to prosumers who joined distributed generation before 7 January 2023 and therefore remain under the previous compensation system; the DG-II group comprises prosumers with PVDG systems of up to 500 kW that migrated to the new framework in January 2023; and the DG-III group comprises prosumers with PVDG systems between 500 kW and 3 MW that migrated after the transition date (Brazil, 2022). The suggested modification introduces a fourth category by subdividing the DG-II group into two subgroups: DG-II-0, which covers systems up to 1.5 kW, and DG-II-1, which comprises systems between 1.6 kW and 500 kW. The central proposal is to exempt DG-II-0 systems from the availability charge, thereby increasing the economic attractiveness of investments in this segment. The 1.5 kW limit was defined based on three criteria: (i) the distribution of PVDG installations by system size; (ii) the economic performance indicators addressed; and (iii) the predominant consumer profile in the country.

3.3 METHODS FOR ASSESSING THE ECONOMIC IMPACT ON UTILITIES

In a scenario where the DG-II-0 group exists, the utilities will no longer be remunerated for the availability cost of that group. To assess this impact, the following equation will be used:

where is the number of DG-II-0 prosumers, is the full value of the electricity tariff, and is the availability cost. The number of prosumers was obtained from Aneel (2024). The tariff values were provided by Aneel (2023d). The availability cost was determined based on Neto *et al.* (2023). This study establishes a relationship between average monthly consumption and the type of connection for the consumer unit.

4 ECONOMIC EVALUATION OF INVESTMENTS IN PHOTOVOLTAIC DISTRIBUTED GENERATION (PVDG)

Figure 2 presents the distribution of the estimated Net Present Values (NPV) for photovoltaic systems of different capacities, based on data from 51 Brazilian electricity distribution utilities. Since tariff structures and TUSD-Fio B charges vary across utilities, it is essential to simulate economic indicators for the entire set of utilities to capture regional heterogeneity. Boxplots visualise both median financial

returns and their dispersion, highlighting how the economic attractiveness of PVDG projects varies with system size and local regulatory conditions.

There is a clear trend of growth in NPV as installed capacity increases, with medians ranging from values close to zero in 0.5 kW and 1 kW systems to more than R$ 100 thousand in 10 kW systems. This evolution shows that, although smaller systems are aligned with the average consumption profile of Brazilian families, their financial attractiveness is limited. The 3 kW to 5 kW systems have more positive and consistent NPVs among utilities; these systems can provide gains of 3 to 6 times the amount invested. On the other hand, smaller systems, such as 0.5 kW, do not reach the levels of investment in any of the cases analysed. These results reinforce the mismatch between the residential consumption profile and the systems most commonly installed.

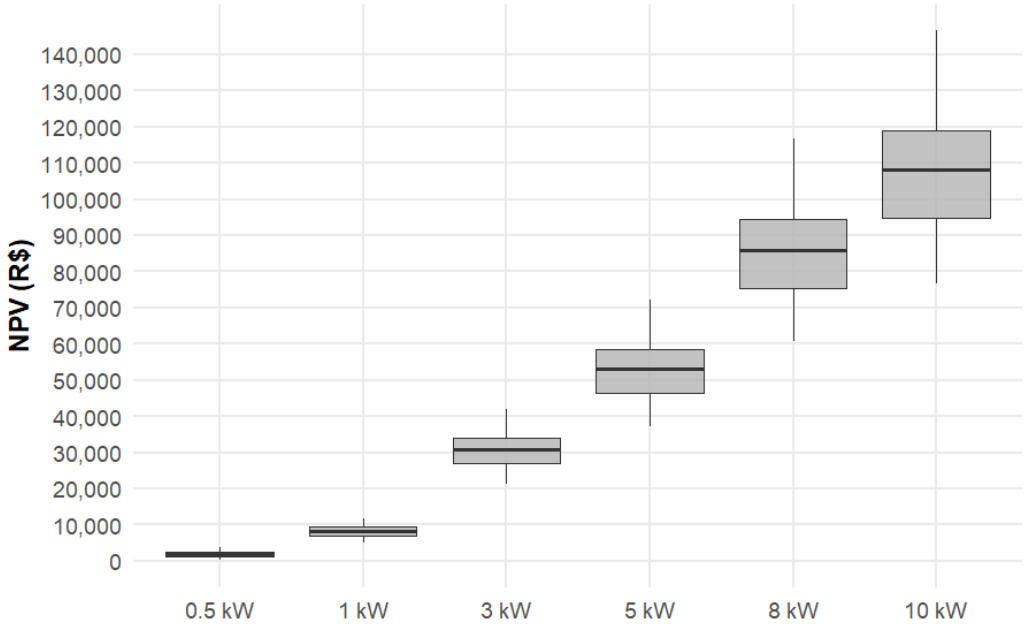

Figure 2 – Statistical analysis of NPV by installed capacity in predominant PVDG Systems
Source: The authors, based on Aneel (2024).

Figure 3 shows the distribution of the estimated payback periods for residential photovoltaic systems of different powers, considering the set of 51 electricity utilities in Brazil. A clear trend of reduced payback is observed as installed capacity increases. In 0.5 kW systems, the average payback period exceeds 15 years, reaching more than 20 years in some cases, indicating the low attractiveness of this segment. Even in 1 kW systems, paybacks remain relatively high, around 8 to 10 years.

From 3 kW, payback becomes significantly faster, between 3 and 5 years, which represents a range considered very competitive in economic feasibility analyses of distributed generation projects. For larger systems, such as 8 kW and 10 kW, payback stabilises around 3 years, with low dispersion among utilities, indicating greater consistency and predictability for investors. This dynamic helps explain the predominance of medium and large systems in the Brazilian residential market, to the detriment of smaller systems, even though these are more aligned with the average consumption profile of families.

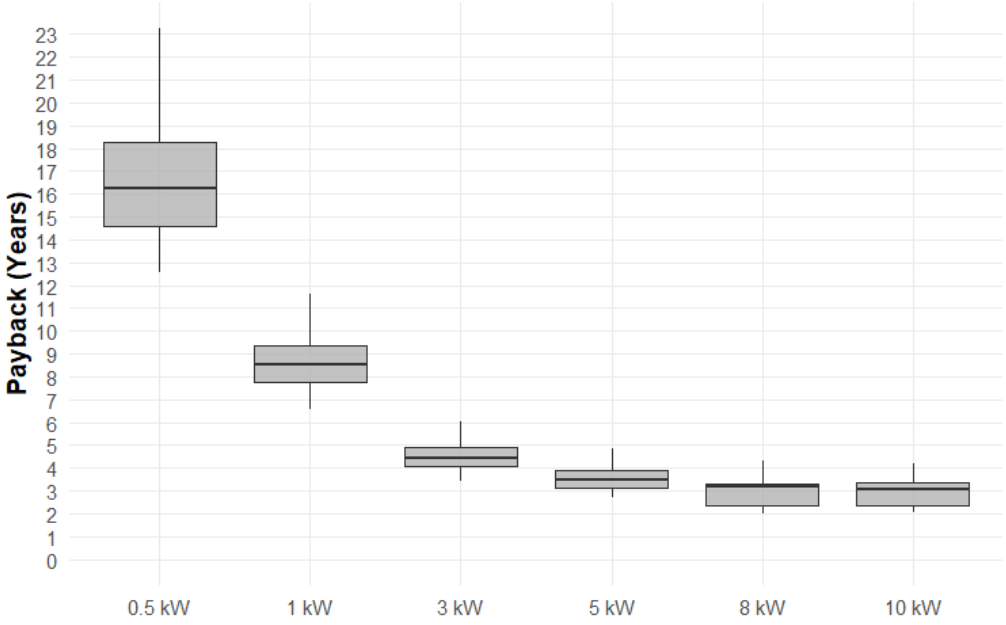

Figure 3 – Statistical analysis of paybacks by installed capacity in predominant PVDG Systems

Source: The authors, based on Aneel (2024).

The analysis of NPV and payback indicators converges on the same conclusion: low-power systems are economically unattractive, either due to low profitability (NPV close to zero) or a long payback period (payback over 15 years). On the other hand, medium- and large-scale systems not only generate a higher NPV but also have significantly shorter payback periods, generally less than five years. This combination of higher profitability and lower time risk strengthens the appeal of these systems in the market, corroborating the distribution of PVDG systems shown in Figure 1.

The differences observed in the economic indicators among the utilities analysed are largely due to variations in electricity tariffs across the country. Energy tariffs range from R$ 577.90/MWh to R$ 978.30/MWh, considering the latest revision (Aneel, 2023d). Energy tariffs can also help explain the uneven growth among utilities, as they directly impact economic indicators. For example, Cemig's tariff is R$ 858.58/MWh, while Copel's is R$ 630.51/MWh. Cemig is the utility with the largest number of prosumers in the country, followed by Copel. In addition to explaining the heterogeneity among indicators, energy tariffs can serve as an input to explain uneven regional growth, given that each utility has a large concession area. The state of Minas Gerais, where the Cemig utility is located, accounts for 9.47% of Brazilian residential installations, while the state of Paraná, where the Copel utility is located, accounts for 6.74%. Therefore, tariff analysis can be a key factor in understanding not only the heterogeneity of indicators but also aid in studies of regional inequality in the PVDG market in Brazil.

The analysis of economic indicators shows that, under the remuneration framework established by Law 14,300, PVDG remains more attractive for higher-capacity systems, whereas smaller systems exhibit limited economic viability. These findings are consistent with previous studies (Gomes *et al.*, 2018; Iglesias; Vilaça, 2022; Neto *et al.*, 2023; Pillot *et al.*, 2018), which emphasise that economic performance is a decisive factor in shaping PVDG adoption patterns. As highlighted by Chueca *et al.* (2023), favourable economic returns are key drivers of the diffusion of PVDG technologies. In this context, the predominance of residential systems with capacities between 4 kW and 8 kW in Brazil can be explained by the fact that these configurations achieve the most advantageous balance of investment recovery and profitability, reinforcing their position as the segment with the greatest economic attractiveness.

Thus, the joint analysis of economic indicators highlights an important contradiction. Although small systems are theoretically more adequate to the average consumption of Brazilian families, their low economic attractiveness limits their diffusion. Medium and large systems, on the other hand, which go beyond the average consumption profile, have a greater market share precisely because they combine fast returns and high NPV, positioning themselves as the most dynamic segment in the expansion of distributed photovoltaic generation in the country.

5 ASSESSMENT OF THE DG-II-0 PROPOSAL AND ITS IMPACTS

Figure 4 shows the percentage breakdown of the energy tariff for prosumers across six power levels and three utilities, where the components correspond to TUSD-Fio B, net-metered energy, and availability cost. An analysis of the tariff composition reveals that the relative weight of the availability cost decreases as the capacity of the distributed solar photovoltaic system increases. At the same time, the proportion of net-metered energy expands. This highlights the regressive nature of the availability cost, which disproportionately affects smaller residential systems.

The availability cost accounts for most of the remaining amount to be paid by a prosumer when analysing households with lower consumption. For prosumers with PVDG systems from 0.5 kW to 1.5 kW, the availability cost can represent up to 40% of energy costs (depending on the utility company). That analysis highlights an opportunity to improve the compensation framework established by Law 14,300 by reducing the availability cost for consumer groups where its impact is greater. Such an adjustment would strengthen the economic viability of PVDG systems for these households, making the investment more attractive.

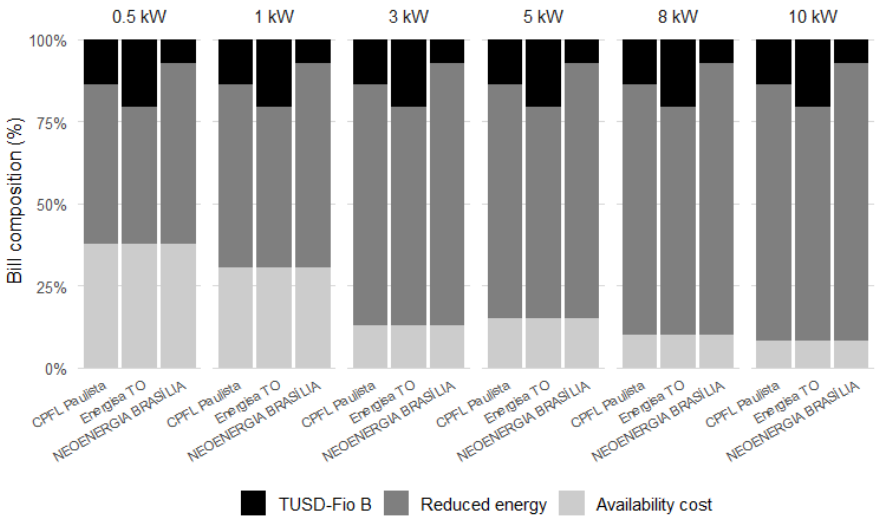

Figure 4 – Percentage composition of energy billing in PVDG systems by installed capacity

Source: The authors, based on Aneel (2024).

The proposed creation of a DG-II-0 subgroup, exempt from availability cost, directly addresses this imbalance and aligns distributed generation policy with broader social and energy transition goals. By improving the economic viability of systems up to 1.5 kW, the measure could stimulate adoption among average residential consumers, reduce inequalities in access to renewable technologies, and

help mitigate energy poverty. Moreover, by targeting a segment that represents a large share of Brazilian households, the proposal highlights a pathway for reconciling economic efficiency with social equity in the future of distributed generation in Brazil.

5.1 ASSESSMENT OF THE ECONOMIC INDICATORS OF DG-II-0

To assess the impacts of the proposed regulatory change for prosumers classified in the DG-II-0 subgroup, NPV and payback indicators were simulated for photovoltaic systems designed to supply residential consumers with monthly demands of 80 kWh and 170 kWh. The calculations followed the methodological framework described in Section 3, excluding the availability cost, as proposed in this study. The analysis compared the resulting economic indicators under both the current regulatory framework and the proposed modification, thereby quantifying the economic effects of the exemption.

Figure 5 compares the economic performance of residential PVDG systems under the current regulatory framework (Law 14,300) and the proposed exemption of the availability cost. The graph on the left shows the distribution of Net Present Values (NPV) for two representative consumption profiles: 80 kWh/month and 170 kWh/month. The results indicate a substantial improvement in financial returns under the proposed scheme. For the 80 kWh/month group, the median NPV nearly doubles compared to the current regulation, reflecting the strong effect of the availability cost on low-consumption households. For the 170 kWh/month profile, the proposal also leads to significant gains, with median NPVs rising to values that reinforce the economic viability of investment in photovoltaic systems.

The graph on the right of Figure 5 presents the corresponding payback periods. For the 80 kWh/month group, the proposal reduces the payback horizon from approximately 18 years under Law 14,300 to around 13 years, moving the payback of projects away from the technical useful life of photovoltaic systems. For the 170 kWh/month profile, the effect is even more favourable: payback periods fall below 10 years in most cases, reaching values around 7 years, which strengthens investment attractiveness and aligns with international benchmarks for PVDG adoption.

Overall, these results highlight that exempting the availability cost for systems up to 1.5 kW balances the distribution of economic benefits, in which smaller consumers are disproportionately penalised. By improving both NPV and payback indicators, the proposed measure enhances the economic feasibility of PVDG for average residential consumers, promoting broader social inclusion and supporting the diffusion of renewable technologies in Brazil.

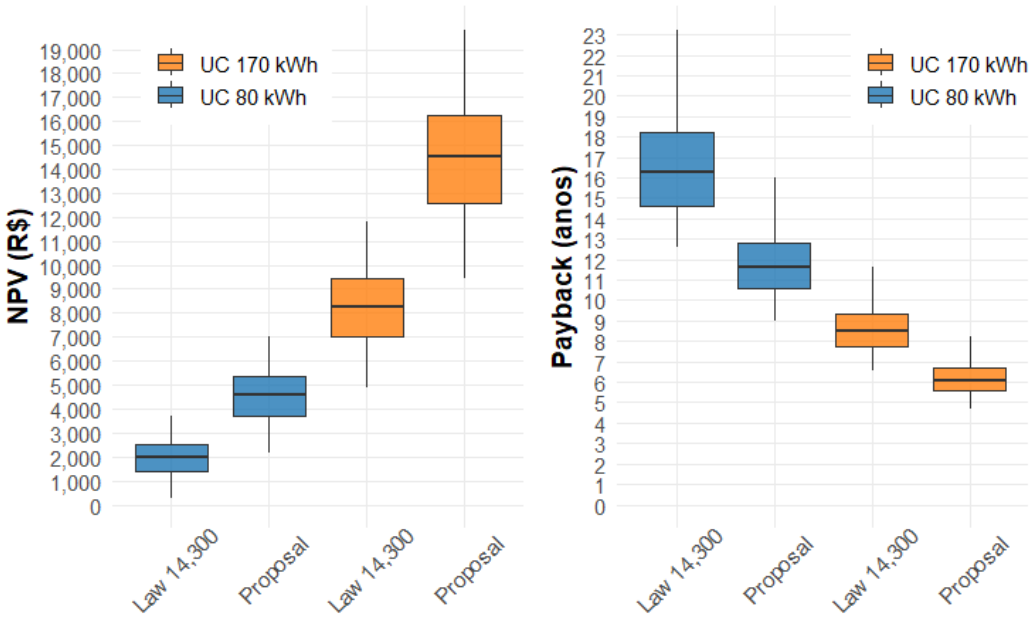

Figure 5 – NPV and Payback of PVDG systems for consumer unit 80 kWh and consumer unit 170 kWh: comparative analysis between Law 14,300 and an alternative proposal

Source: The authors, based on Aneel (2024).

Another important point is the PVDG system's ability to reduce a home's energy costs. Figure 6 shows the percentage reduction in electricity bills for residential consumers with monthly demands of 80 kWh and 170 kWh, comparing the current regulatory framework (Law 14,300) with the proposed exemption of the availability cost. The results show that, under the present rules, bill reductions remain relatively modest, with median values around 55% for the 80 kWh group and 58% for the 170 kWh group. In contrast, the proposed design markedly improves consumer outcomes, raising reductions to levels above 80% in both consumption profiles.

This difference highlights the unequal nature of the availability cost, which disproportionately penalises low-consumption households by limiting the share of consumption that can be offset by distributed generation. By removing this fixed charge for systems up to 1.5 kW, the proposal equalises the benefits across consumer segments, substantially increasing the portion of electricity bills that can be compensated.

Furthermore, for families in group DG-II-0, which tend to have lower incomes according to *Empresa de Pesquisa Energética* (2021), the reduction in the monthly energy bill is especially important. It reveals how the PVDG can reduce these households' monthly expenses, with an immediate and concrete impact. In many cases, this effect may be more relevant to investment decisions than traditional indicators such as NPV or payback, which focus on long-term financial returns. Small monthly savings can make a big difference for these families.

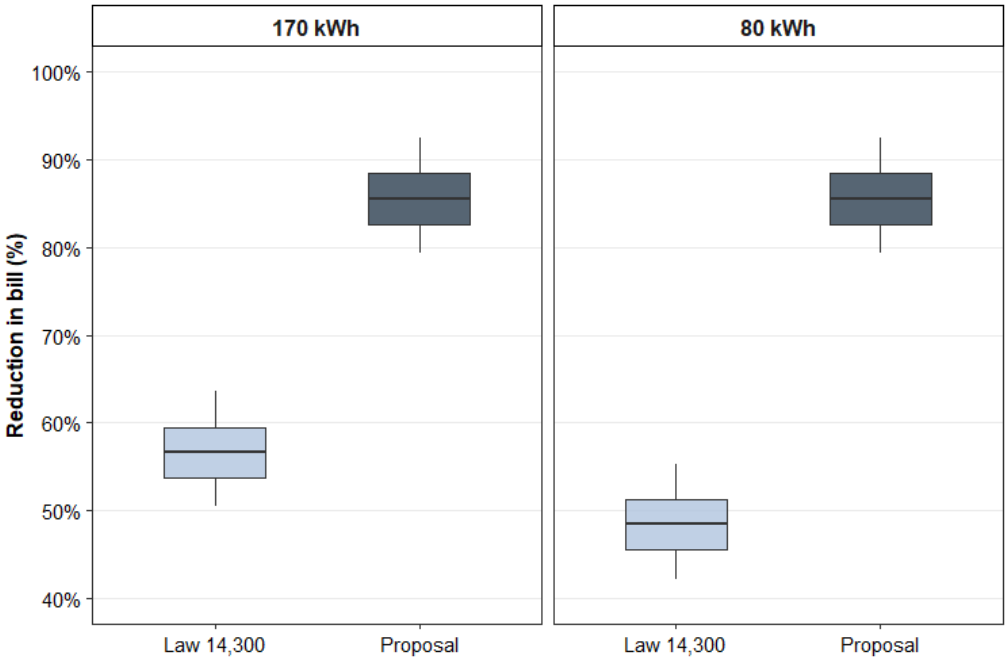

Figure 6 – Comparison of the percentage reduction in the energy bill for consumer unit 80 kWh and consumer unit 170 kWh under Law 14,300 and Alternative Proposal

Source: The authors, based on Aneel (2024).

The changes in the compensation mechanism suggested in this article can improve the economic indicators of the group of prosumers studied. Since economic indicators will become more attractive to this group, these improvements encourage greater inclusion of the average Brazilian consumer in the use of PVDG.

5.2 BROADER IMPACTS OF THE PROPOSAL

In this article, the term "general impacts" refers to the effects that changes may have on stakeholders. These include impacts on utilities that provide electricity distribution services; on companies that integrate PVDG projects; on civil society, which may be affected by subsidies; and on the government, which has diverse interests and responsibilities across its various spheres.

Figure 7 shows the twenty utilities that have the largest number of systems classified as DG-II-0. Analysing these systems by utilities, it is observed that most of these installations are concentrated in six of them. Approximately 80% of the installations in this power limit are included in the network of these six utilities, out of a total of 51. This indicates that, in a significant portion of the utilities, the proposed changes can have a substantial impact on the number of prosumer installations in group DG-II-0, because in most concession areas, the number of prosumers with this consumption profile is very small.

Figure 7 also helps us measure implementation costs of the change, as it shows the number of households that will no longer pay the availability cost. For most utilities, this impact would be small at first. However, due to the proposed changes, the adoption rate is expected to increase, as discussed here.

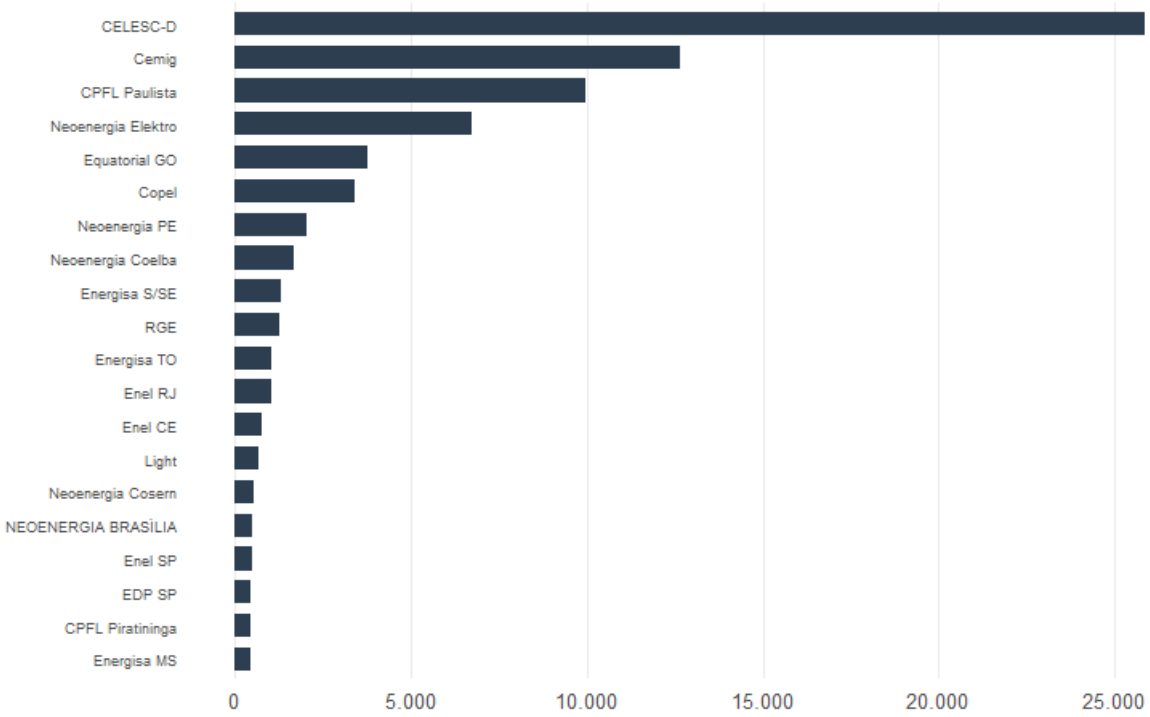

Figure 7 – Top 20 utilities with the most installations classified as DG-II-0

Source: The authors, based on Aneel (2024).

Using Equation 5, it is possible to estimate the impact on a utility's current cost with the proposed changes. Considering the utility company Cemig, for instance, a one-year subsidy would total R$ 6,260,387.58. This utility would be the second most impacted by the proposal, as it not only has a large number of prosumers with this profile, but also has one of the highest tariffs in the country. This amount would represent a subsidy of R$ 495.64/year for each prosumer of this distributor. For comparison, consider consumers participating in the Social Electricity Tariff (TSEE) program. In terms of energy consumption, the consumption profile of group DG-II-0 is similar to that of families eligible for the TSEE. In 2024, the TSEE subsidy granted approximately R$ 6.4 billion in discounts. The program benefited 17.4 million consumer units. The TSEE subsidy per consumer unit was approximately R$ 367.81. Comparing the TSEE subsidy with the cost of this article's proposal, the values per consumer unit are similar. Furthermore, the study by de Sermarini et al. (2024) evaluated the migration of participants from the TSEE program to the PVDG program, showing that, in several cases, economic viability is evident. In this context, the changes proposed in this article can complement de Sermarini et al. (2024)'s proposal, as they improve the compared indicators.

Law 14,300 also created the Social Renewable Energy Program (PERS), which aims to invest in the installation of photovoltaic systems and other renewable sources for low-income consumers. Although Law 14,300/2022 requires the establishment of the PERS, it does not provide details on the program's implementation. This study can assist public policymakers in regulating PERS, as some consumers with the DG-II-0 profile also have a low-income profile.

Another important point of government interest is that Brazil has committed to advancing indicators related to energy poverty, with particular emphasis on the economic accessibility indicator, which measures the share of households whose electricity expenses exceed 10% of their income. The national target is to eliminate this condition (EPE, 2026b). A considerable portion of these households overlaps

with the consumer group most impacted by the availability cost, placing them at the intersection of energy poverty and DG policy. Expanding PVDG access to this segment would not only alleviate the economic burden of electricity costs but also directly contribute to achieving Brazil's policy objective of eradicating energy poverty, in alignment with the Sustainable Development Goals, particularly SDG 7 (Affordable and Clean Energy) and SDG 10 (Reduced Inequalities). Ensuring inclusion of this segment within the DG framework, therefore, supports a more socially balanced and equitable energy transition.

6 CONCLUSION

This study investigated the asymmetric effects of the availability cost established by Law 14,300/2022 on PVDG consumers in Brazil. The analysis revealed that the current compensation framework disproportionately penalises low-consumption households, especially those whose average monthly energy use is below 170 kWh. Although these consumers represent the majority of Brazilian households, they are the least likely to access PVDG systems due to unfavourable economic indicators resulting from the availability cost. This structural imbalance generates an asymmetric pattern within the DG sector, where smaller systems face higher relative costs, discouraging the participation of residential consumers with limited income.

To address this inequality, this paper proposes creating a new regulatory subgroup, DG-II-0, encompassing prosumers with PVDG systems up to 1.5 kW of installed capacity. Economic simulations of NPV and payback across 51 distribution utilities demonstrated that exempting this subgroup from the availability cost would significantly enhance investment feasibility. The NPV of systems serving 80–170 kWh/month consumers would approximately double under the proposed framework, while the payback period could be reduced by up to five years. These results suggest that the proposed adjustment could make distributed generation economically viable for a broader portion of Brazilian households.

Beyond the economic outcomes, the proposal has broader implications for energy policy and social equity. By correcting a structural imbalance that disproportionately penalises low-consumption households, the measure aligns distributed generation policy with the principles of distributive justice and with Brazil's broader goals of mitigating energy poverty. Encouraging adoption among this consumer segment not only expands the DG market but also promotes a more inclusive energy transition (González *et al.*, 2023), consistent with Sustainable Development Goal 7 (Affordable and Clean Energy) and Goal 10 (Reduced Inequalities).

It is also important to acknowledge some limitations of this study. The economic indicators were estimated under fixed assumptions, notably a single capacity factor of 16%, a constant discount rate of 8% per year, a constant annual tariff adjustment of 10% per year, and the exclusion of taxes levied on the energy bill; moreover, the analysis does not incorporate the modelling of adoption or demand elasticity. Because the discount rate and the tariff-adjustment rate directly affect the NPV and payback estimates, variations in these parameters could make the proposed change to the compensation system more or less efficient: higher tariff adjustments or lower discount rates would tend to increase the advantage of the DG-II-0 exemption, whereas the opposite combination would reduce it. A systematic sensitivity analysis of these assumptions was beyond the scope of this study and is therefore recommended as future work to assess the robustness of the proposal across alternative economic and regulatory scenarios.

Future investigations could employ adoption modelling techniques to analyse the DG-II-0 group under the proposed regulatory framework, quantifying how increased economic attractiveness may influence diffusion patterns, spatial heterogeneity in adoption rates, and the long-term equilibrium of the DG compensation mechanism.

In conclusion, the creation of a DG-II-0 subgroup exempt from the availability cost represents a feasible and socially desirable regulatory innovation. By reconciling economic efficiency with distributive equity, the proposal offers a pathway for enhancing both the economic sustainability and the social legitimacy of distributed generation in Brazil.

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STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

The authors used Claude (Anthropic) for language editing and stylistic polishing only. All scientific content, analysis, and intellectual input were developed and verified by the authors; we take full responsibility for the accuracy and integrity of the manuscript.

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Public perception of meat production and deforestation in the Brazilian Amazon[1]

Percepção da população sobre a produção de carne e o desmatamento na Amazônia brasileira

Rodrigo Borille [1]

Luccas Simon Kist [2]

Simone Bueno Camara [3]

Tanice Andreatta [4]

[1] PhD in Animal Science/Animal Production, Associate Professor, Department of Animal Science and Biological Sciences, Federal University of Santa Maria (UFSM), Santa Maria, RS, Brazil
E-mail: rodrigo.borille@ufsm.br

[2] Animal Scientist, Federal University of Santa Maria (UFSM), Santa Maria, RS, Brazil
E-mail: luccaskist@yahoo.com.br

[3] PhD in Rural Extension, Associate Professor, State University of Rio Grande do Sul (UERGS), Santa Maria, RS, Brazil
E-mail: simonebuenocamara@gmail.com

4 PhD in Rural Development, Professor, Postgraduate Programme in Agribusiness, Federal University of Santa Maria (UFSM), Santa Maria, RS, Brazil
E-mail: tani.andreatta@hotmail.com

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ABSTRACT

The study analyses public perception of the relationship between meat production and deforestation in the Brazilian Amazon. A structured questionnaire was administered to 314 respondents, and data were analysed using exploratory factor analysis and cluster analysis, which identified three distinct groups. The findings indicate widespread recognition of the economic importance of meat production, especially in Group 1, but divergent views on its relationship with deforestation. Group 2 showed greater environmental awareness, rejecting meat associated with deforestation and recognising livestock farming as a relevant cause of environmental degradation. Group 3, with lower purchasing power, was more willing to consume products from deforested areas, possibly due to economic constraints. Although Brazil has relatively robust environmental legislation, respondents perceived it as ineffective

because of a lack of enforcement. Findings suggest that education, income, and access to information contribute to shaping environmental perceptions and consumer behaviour.

Keywords: Livestock. Brazilian Amazon. Forest. Environment. Consumption.

RESUMO

Este estudo analisa a percepção da população sobre a relação entre a produção de carne e o desmatamento da Amazônia. A pesquisa foi aplicada a 314 respondentes por meio de um questionário estruturado, com análise fatorial exploratória e análise de cluster, que identificaram três grupos distintos. Os resultados indicam reconhecimento generalizado da importância econômica da produção de carne, especialmente no grupo 1, mas também divergências quanto à sua relação com o desmatamento. O grupo 2 apresentou maior consciência ambiental, rejeitando carne associada ao desmatamento e reconhecendo a pecuária como causa relevante da degradação ambiental. Já o grupo 3, com menor poder aquisitivo, mostrou-se mais permissivo quanto ao consumo de produtos oriundos de áreas desmatadas, possivelmente devido a restrições econômicas. Apesar de o Brasil ter uma legislação ambiental considerada robusta, a percepção dos respondentes é de ineficiência pela falta de fiscalização. Conclui-se que escolaridade, renda e acesso à informação contribuem para a formação de percepções ambientais e do comportamento do consumidor.

Palavras-chave: *Agropecuária. Amazônia. Floresta. Meio ambiente. Consumo.*

1 INTRODUCTION

Deforestation in the Brazilian Amazon[2] remains one of the world's most significant environmental challenges, resulting from the interaction among economic, political, and social factors. Since the 1970s, rates of forest loss have increased due to agricultural expansion, logging, fires, population growth, and public policies that encouraged settlement in previously sparsely populated areas (Arraes *et al.*, 2012). Deforestation in the Brazilian Amazon involves the long-term removal of forest cover, primarily driven by livestock production, large-scale agriculture, and slash-and-burn practices (Klimowicz; Angelsen, 1998; Rivero *et al.*, 2009).

Among these drivers, cattle ranching has consistently been identified as the primary historical cause of deforestation in the Brazilian Amazon. Early studies demonstrated that the expansion of cattle ranching led to the conversion of extensive forest areas into pasture, particularly from the 1970s onwards (Fearnside, 2005; Margulis, 2003). Subsequent research reinforced this conclusion by showing that the expansion of cattle ranching is closely associated with infrastructure development, the expansion of the agricultural frontier, public policies, and institutional weaknesses (Nepstad *et al.,* 2014; Walker *et al.*, 2013). Historical and spatial analyses further indicate that, between 1985 and 2020, nearly 65 million hectares of forests and savannas in the Legal Amazon were converted into agricultural land, with conversion to pasture accounting for most of this land-use change (Barona *et al.,* 2010; Santos *et al.,* 2021; Stabile *et al.,* 2020). Although soybean cultivation also contributes to deforestation, most studies agree that its contribution is largely indirect or complementary, whereas direct forest conversion into pasture remains more prevalent (Barona *et al.,* 2010).

Nevertheless, the literature also emphasises that cattle ranching alone does not fully account for the complexity of deforestation. Mesquita (2006) argues that regional differences in land-use dynamics must be considered, as activities such as soybean, oil palm and sugarcane cultivation, charcoal production, eucalyptus plantations, and timber extraction have become important drivers in specific areas of the Brazilian Amazon. Thus, while cattle ranching remains the primary historical driver, deforestation results from multiple interacting processes whose relative importance varies across regions.

This process is further complicated by the structure of the market for cattle-derived products. Walker *et al.* (2013) demonstrate that deforestation in the Brazilian Amazon is not driven exclusively by international demand, since the Brazilian domestic market accounts for a substantial share of demand for cattle-derived products, including beef, dairy products, and by-products. In addition, Hoelle (2017) shows that, in certain contexts in the Brazilian Amazon, beef is more than simply a food product, functioning as a symbol of prosperity, social status, nutritional value, and economic development. Such cultural meanings help legitimise the expansion of cattle ranching and make its environmental consequences less salient (Kröger, 2020).

While earlier studies focused primarily on identifying the biophysical and economic determinants of deforestation, more recent research has shifted towards understanding its social dimensions. Particular attention has been paid to how consumers perceive the relationship between meat production and forest loss and how socioeconomic characteristics, cultural values, education, and access to information shape these perceptions (Ferrante *et al.,* 2024; Hötzel *et al.,* 2022; Liu *et al.,* 2023). This shift reflects the field's evolving view that environmental outcomes are influenced not only by production systems but also by consumer behaviour and public support for conservation policies.

Public perceptions are also shaped by media narratives. Ladle *et al.* (2010) demonstrate that Brazilian newspapers tend to frame deforestation in the Brazilian Amazon as a consequence of domestic economic development, whereas international media more frequently emphasise the role of global commodity supply chains, particularly those involving beef and soy. More recently, De Souza (2021), Oliveira *et al.* (2022), and Souza *et al.* (2023) show that digital media have intensified disputes surrounding environmental information by simultaneously disseminating scientific evidence and misinformation, thereby influencing the extent to which the public considers official deforestation data reliable.

Growing environmental concern has also influenced the governance of livestock supply chains. Consumer pressure, together with demands from international buyers and environmental organisations, has encouraged major meatpacking companies to adopt zero-deforestation commitments and traceability systems (Gibbs *et al.,* 2015; Rajão *et al.,* 2020; Walker *et al.,* 2013). These initiatives have contributed to reducing purchases from properties where recent deforestation had occurred and improving environmental monitoring (Gibbs *et al.,* 2015). However, important limitations remain. Indirect suppliers, cattle laundering, and weaknesses in traceability continue to undermine the effectiveness of voluntary agreements (Carvalho *et al.,* 2019). Moreover, sustainable food choices are strongly influenced by socioeconomic conditions, as lower-income consumers often prioritise affordability over environmental attributes (Hötzel *et al.,* 2022; Wilkinson, 2008).

Finally, recent modelling studies suggest that reducing beef consumption could help reduce greenhouse gas emissions and pressure for pasture expansion (Parzianello *et al.,* 2024). Nevertheless, Donoso *et al.* (2024) argue that sustained reductions in deforestation in the Brazilian Amazon depend not only on changes in consumption patterns but also on stronger environmental governance, well-designed land-use policies, effective enforcement by public institutions, and transparent supply chains.

The complexity of this issue, together with changing dietary patterns and the economic importance of livestock farming, highlights the need to better understand public perceptions of the relationship between meat production and deforestation in the Brazilian Amazon. Such perceptions can influence food choices, support for environmental policies, and the effectiveness of sustainability initiatives within agri-food systems. Therefore, this study aims to analyse public perceptions of the relationship between meat production and deforestation in the Brazilian Amazon by identifying distinct perception profiles and examining how socioeconomic characteristics influence these perceptions. Section 2 presents the research methods, Section 3 discusses the main findings, and Section 4 summarises the study's conclusions and implications.

2 RESEARCH METHODS

The data for this study were collected using a questionnaire designed to identify respondents' perceptions of meat production and deforestation in the Brazilian Amazon. The questionnaire consisted of two distinct sections: the first focused on respondents' sociodemographic characteristics and meat consumption habits, including age group, gender, educational level, and place of residence. The second section was designed to examine respondents' perceptions of various aspects of meat production and deforestation in the Brazilian Amazon.

The questionnaire was created using Google Forms® and circulated via social media platforms and email between 25 July and 1 August 2022. Before beginning the questionnaire, participants were presented with an informed consent form describing the study objectives, the voluntary nature of participation, and the measures adopted to ensure data confidentiality and participant anonymity. Only those who provided informed consent were allowed to proceed with the survey.

The questionnaire consisted primarily of closed-ended questions. Perception-related items were measured using a five-point Likert scale: 1 = strongly disagree; 2 = partially disagree; 3 = neither agree nor disagree; 4 = partially agree; and 5 = strongly agree.

A total of 314 valid responses were collected. Most participants resided in Southern Brazil, particularly in the state of Rio Grande do Sul. The study employed a non-probability convenience sampling strategy. Under this approach, participants are selected based on ease of access and willingness to participate rather than through random selection; consequently, individuals in the target population do not have a known probability of being included in the sample (Mattar, 2001). Although this sampling method does not permit statistical generalisation to the target population, it is widely used in exploratory studies to identify patterns, opinions, and perceptions within a specific group of respondents.

In addition to basic descriptive statistics, including means and frequencies, exploratory factor analysis (EFA) and cluster analysis were conducted. EFA was used to reduce the original set of variables to a smaller number of composite variables based on the pattern of variance within the dataset. Each resulting component represents a combination of the original variables (Hair Jr. *et al.,* 2005).

Cluster analysis, a multivariate technique, was used to group individuals according to similarities in their characteristics. According to Hair Jr. *et al.* (2005), this method forms clusters in which individuals are relatively similar to one another, while the clusters themselves are distinct. In this study, hierarchical cluster analysis was conducted using Ward's method, with the squared Euclidean distance employed as the distance measure.

3 RESULTS AND DISCUSSION

3.1 FACTOR STRUCTURE OF PERCEPTIONS OF MEAT PRODUCTION AND DEFORESTATION IN THE BRAZILIAN AMAZON

This subsection first presents the rotated component matrix (Table 1) and the total variance explained (Table 2), both obtained through exploratory factor analysis. These results were then used to form the clusters and identify respondents' profiles based on their views on meat production and deforestation. The KMO value was 60.5%, indicating a minimally acceptable level of sampling adequacy.

Table 1 – Rotated component matrix

Factor name	*Questionnaire item*	*Factors*			*Communality*
		1	*2*	*3*	
Perceptions of meat production and deforestation	Meat production is the leading cause of Deforestation	0.842			0.739
	Reducing meat consumption reduces deforestation	0.835			0.721
	Meat production is important to the Brazilian economy	-0.719			0.525
Consumer behaviour regarding deforestation	Would you consume grains associated with deforestation?		0.975		0.961
	Would you consume meat associated with deforestation?		0.972		0.961
Legislation and meat consumption	If environmental legislation were better suited to protecting the environment, would you consume meat or more meat?			0.802	0.648
	Brazil has inadequate legislation on deforestation			0.745	0.579

Extraction Method: Principal component analysis.

Note: Three components were extracted.

Source: Authors' calculation based on the survey data (2026).

Table 1 presents the results of the exploratory factor analysis (EFA), which identified three main components, and displays the factor loadings and communalities.

The first factor, "Perceptions of meat production and deforestation", reflects a contrast between environmental and economic issues. Positive factor loadings indicate a stronger perception that meat production is the leading cause of deforestation. Conversely, the negative loading suggests an inverse relationship: the more strongly individuals perceive meat production as an environmental problem, the less likely they are to recognise its economic importance, and vice versa.

The second factor, "Consumer behaviour regarding deforestation", indicates consistency in respondents' consumption choices; that is, those who reject grains associated with deforestation also reject meat with the same association.

The third factor, "Legislation and meat consumption", reveals a conditional stance in which meat consumption depends on respondents' confidence in environmental legislation. At the same time, respondents scoring high on this factor tend to consider the current legislation inadequate. Thus, this pattern suggests that their reservations concern not meat consumption in principle, but the lack of clear environmental safeguards.

Table 2 – Total variance explained

Factor	*Initial Eigenvalues*		
	Total	*% of variance*	*Cumulative %*
1	2.484	35.479	35.479
2	1.602	22.880	58.359

Factor	Initial Eigenvalues		
	Total	% of variance	Cumulative %
3	1.049	14.992	73.351

Extraction Method: Principal component analysis.

Source: Authors' calculation based on the survey data (2026).

The results of the EFA indicated a statistically robust factor structure in terms of both the individual factor loadings and the total variance explained. The cumulative variance explained (73.35%) demonstrates that the three-factor model adequately represents respondents' perceptions and provides effective dimensionality reduction with minimal loss of information. Furthermore, the distribution of explained variance across the factors suggests that no single factor dominates the model. Instead, the three factors represent distinct but complementary dimensions, reinforcing the multidimensional nature of perceptions of deforestation and meat production.

3.2 SAMPLE CHARACTERISTICS BY CLUSTER

With respect to gender (Table 3), Group 1 had a lower proportion of men (42%) than women (58%), and the same pattern was observed in Groups 2 and 3. However, the proportion of men in Group 1 was considerably higher than in Groups 2 and 3. Groups 2 and 3 were very similar in terms of gender distribution, with women accounting for approximately 70% and men for 26%.

Table 3 – Sample characteristics by group

Gender	Group 1	Group 2	Group 3
Female	58% (101)	71.7% (43)	72.6% (53)
Male	42% (73)	26.7% (16)	26% (19)
Other	0% (0)	1.7% (1)	1.4% (1)
Total	**100% (174)**	**100% (60)**	**100% (73)**
Age group			
18–20 years	5.7% (10)	5% (3)	4.1% (3)
21–25 years	10.9% (19)	11.7% (7)	16.4% (12)
26–30 years	8.6% (15)	6.7% (4)	12.3% (9)
31–35 years	17.2% (30)	13.3% (8)	5.5% (4)
36–40 years	12.1% (21)	15% (9)	13.7% (10)
41–45 years	16.1% (28)	18.3% (11)	6.8% (5)
46–50 years	10.9% (19)	8.3% (5)	13.7% (10)
51 years or older	18.4% (32)	21.7% (13)	27.4% (20)
Total	**100% (174)**	**100% (60)**	**100% (73)**
Educational attainment			
No higher education	31.6% (55)	16.6% (10)	21.9% (16)
Undergraduate education	22.9% (40)	18.3% (11)	30.1% (22)
Postgraduate education	45.4% (79)	65% (39)	47.9% (35)
Total	**100% (174)**	**100% (60)**	**100% (73)**
Monthly income (in Brazilian minimum wages			
Less than one minimum wage	4.5% (8)	6.6% (4)	12.3% (9)

Gender	*Group 1*	*Group 2*	*Group 3*
1–2 minimum wages	10.3% (18)	20% (12)	15% (11)
2–3 minimum wages	19.5% (34)	13.3% (8)	15% (11)
3–5 minimum wages	24.1% (42)	31.6% (19)	32.8% (24)
5–10 minimum wages	28.7% (50)	20% (12)	19.1% (14)
10–20 minimum wages	12.6% (22)	8.3% (5)	5.4% (4)
Total	**100% (174)**	**100% (60)**	**100% (73)**
Meat consumption			
No	1.7% (3)	6.7% (4)	2.7% (2)
Yes	98.2% (171)	93.3% (56)	97.2% (71)
Total	**100% (174)**	**100% (60)**	**100% (73)**
Residence in a rural area			
No	51.1% (89)	56.6% (34)	53.4% (39)
Yes	48.8% (85)	43.3% (26)	46.5% (34)
Total	**100% (174)**	**100% (60)**	**100% (73)**

Note: In 2022, the Brazilian minimum wage corresponded to R$1,212.00 per month (Brazil, 2021)

Source: Authors' calculation based on the survey data (2026).

Regarding age distribution across the groups (Table 3), 42.4% of respondents in Group 1 were aged 18–35, while 57.6% were aged 36 or older. In Group 2, 36.7% were aged 18–35 and 63.3% were 36 or older. Similarly, in Group 3, 38.3% of respondents were aged 18–35, whereas 61.7% were aged 36 or older. Group 2 had the highest proportion of respondents aged 36 or older, while Groups 1 and 3 showed similar age distributions. Group 3 included a greater proportion of respondents aged 51 or older.

Regarding educational attainment (Table 3), Group 1 had the highest proportion of respondents with no higher education and the lowest proportion of respondents with postgraduate education. In contrast, Group 2 had the highest proportion of respondents with postgraduate education and the lowest proportion of respondents with no higher education.

Income distribution also differed across the groups (Table 3). In Group 1, 58.4% of respondents reported a monthly income of up to five minimum wages, whereas 41.6% reported earning between five and 20 minimum wages. In Group 2, 71.5% reported an income of up to five minimum wages and 28.5% reported earning between five and 20 minimum wages. Similarly, in Group 3, 75.2% reported an income of up to five minimum wages, while only 24.8% reported earning between five and 20 minimum wages. These findings indicate that Group 1 had the highest overall income profile among the three groups, whereas Group 3 had the lowest.

The differences observed in meat consumption and socioeconomic characteristics provide important insights into the social differentiation of public perceptions of deforestation in the Brazilian Amazon. Although only 2.86% of the total sample reported not consuming meat, Group 2 had the highest proportion of respondents who did not consume meat (6.7%), as well as the highest proportion of respondents with postgraduate education and the lowest proportion of individuals who had ever resided in rural areas. In contrast, Group 1 had higher income levels and a greater proportion of men, whereas Group 3 had lower income levels but otherwise shared socioeconomic characteristics similar to those of Group 2.

These differences should be interpreted within the broader context of the literature on meat consumption and deforestation in the Brazilian Amazon. Historical and spatial studies consistently identify cattle ranching as the primary driver of deforestation in the Brazilian Amazon (Barona *et*

al., 2010; Santos *et al.*, 2021; Walker *et al.*, 2013). Although Group 2 had the largest proportion of respondents who did not consume meat, the overwhelming majority of respondents across all groups reported consuming meat. This finding is consistent with Hötzel *et al.* (2022), who argue that Brazilian consumers increasingly value environmentally responsible meat production but continue to prioritise attributes such as price, quality, taste, and food safety. Consequently, environmental concerns coexist with cultural and economic preferences that sustain high levels of meat consumption.

Socioeconomic conditions also appear to shape environmental perceptions. The higher educational attainment observed in Group 2 is consistent with evidence reported by Liu *et al.* (2023), who found that individuals with higher levels of education, women, and individuals with low levels of meat consumption tend to express greater concern about the ethical and environmental impacts of livestock production. Similarly, Ferrante *et al.* (2024) showed that education plays a decisive role in increasing awareness and engagement with forest conservation in the Amazon. These findings suggest that education contributes not only to greater access to information but also to a more critical understanding of the relationship between food systems and environmental degradation.

Conversely, the lower income levels observed in Group 3 may suggest that economic constraints hinder consumers' ability to take environmental factors into account when making food choices. As argued by Wilkinson (2008), lower-income consumers often prioritise affordability and food security over sustainability attributes. Thus, differences in environmental perceptions should not be interpreted solely as differences in environmental awareness but also as reflections of unequal socioeconomic conditions that constrain consumer choices.

The literature further shows that consumer perceptions can shape the governance of livestock supply chains. Increasing domestic and international concern about deforestation has encouraged major meatpacking companies to exclude suppliers associated with recent deforestation and to adopt traceability systems (Walker *et al.,* 2013). In the Brazilian Amazon, these agreements have contributed to reducing purchases from properties where recent deforestation had occurred, increasing the number of rural properties registered in Brazil's environmental land monitoring system, and lowering deforestation rates among direct suppliers (Gibbs *et al.,* 2015). These findings indicate that public opinion can influence market behaviour by increasing the reputational risks faced by companies operating in the livestock sector.

Nevertheless, these governance advances remain incomplete. Zero-deforestation agreements primarily monitor direct suppliers, whereas indirect suppliers continue to represent a significant blind spot in the supply chain, thereby enabling practices such as cattle laundering and the transfer of animals between compliant and non-compliant properties (Gibbs *et al.,* 2015; Skidmore *et al.,* 2021). Furthermore, Walker *et al.* (2013) estimated that a substantial proportion of cattle slaughter remains associated with informal or unregulated markets, which are largely insulated from consumer pressure. Consequently, reducing deforestation in the Brazilian Amazon requires more than changes in consumer behaviour. As argued by Stabile *et al.* (2020), effective conservation depends on the integration of public policies, land tenure regularisation, enforcement of the Brazilian Forest Code (the country's main legal framework governing land use and native vegetation on rural properties), sustainable livestock intensification, technical assistance for producers, and stronger environmental governance throughout the supply chain.

3.3 PERCEPTIONS OF MEAT PRODUCTION AND DEFORESTATION IN THE BRAZILIAN AMAZON

This subsection presents the results concerning respondents' perceptions of the relationship between meat production and deforestation across the groups identified by the cluster analysis. Table 4 summarises respondents' perceptions of meat production, deforestation, environmental legislation, the economic

importance of meat production, and the truthfulness of media coverage. Taken together, the results indicate clear differences among the groups, which may reflect socioeconomic, educational, and cultural factors.

Table 4 – Respondents' perceptions of meat production, deforestation in the Brazilian Amazon, and related issues by group

Questionnaire item	*Groups*	*Level of agreement*				
		Strongly disagree	*Partially disagree*	*Neither agree nor disagree*	*Partially agree*	*Strongly agree*
Meat production is the leading cause of deforestation	1	63.8% (111)	24.1% (42)	6.3% (11)	5.8% (10)	0% (0)
	2	0% (0)	1.7% (1)	11.7% (7)	60% (36)	26.7% (16)
	3	11% (8)	21.9% (16)	16.4% (12)	34.3% (25)	16.4% (12)
Meat production in the Brazilian Amazon plays a significant role in Brazil's meat supply	1	29.9% (52)	24.1% (42)	26.4% (46)	14.9% (26)	4.6% (8)
	2	5% (3)	16.7% (10)	35% (21)	26.7% (16)	16.7% (10)
	3	21.9% (16)	8.2% (6)	34.2% (25)	23.3% (17)	12.3% (9)
Reducing meat consumption reduces deforestation	1	71.8% (125)	20.1% (35)	4% (7)	3.4% (6)	0.6% (1)
	2	0% (0)	0% (0)	8.3% (5)	43.3% (26)	48.3% (29)
	3	6.8% (5)	6.8% (5)	19.2% (14)	45.2% (33)	21.9% (16)
Grain production causes deforestation	1	19.5% (34)	16.1% (28)	14.4% (25)	33.9% (59)	16.1% (28)
	2	5% (3)	3.3% (2)	5% (3)	41.7% (25)	45% (27)
	3	5.5% (4)	9.6% (7)	12.3% (9)	35.6% (26)	37% (27)
If environmental legislation were better suited to protecting the environment, would you consume meat or more meat?	1	35.6% (62)	12% (21)	36.7% (64)	8% (14)	7.4% (13)
	2	21.6% (13)	8.3% (5)	28.3% (17)	30% (18)	11.6% (7)
	3	24.6% (18)	10.9% (8)	30.1% (22)	28.7% (21)	5.4% (4)
The media tell the truth about deforestation in the Brazilian Amazon.	1	39.6% (69)	30.4% (53)	10.3% (18)	13.7% (24)	5.7% (10)
	2	26.6% (16)	18.3% (11)	8.3% (5)	26.6% (16)	20% (12)
	3	31.5% (23)	10.9% (8)	13.6% (10)	20.5% (15)	23.2% (17)
Meat production is important to the Brazilian economy	1	0.6% (1)	2.3% (4)	0.6% (1)	17.8% (31)	78.7% (137)
	2	8.3% (5)	5% (3)	8.3% (5)	43.3% (26)	35% (21)
	3	0% (0)	8.2% (6)	8.2% (6)	28.8% (21)	54.8% (40)
Would you consume meat associated with deforestation?	1	31.6% (55)	19% (33)	23.6% (41)	15.5% (27)	10.3% (18)
	2	76.7% (46)	21.7% (13)	1.7% (1)	0% (0)	0% (0)
	3	5.5% (4)	2.7% (2)	31.5% (23)	49.3% (36)	11% (8)

Questionnaire item	Groups	Level of agreement				
		Strongly disagree	Partially disagree	Neither agree nor disagree	Partially agree	Strongly agree
Would you consume grains associated with deforestation?	1	29.9% (52)	21.8% (38)	23% (40)	15.5% (27)	9.8% (17)
	2	81.7% (49)	16.7% (10)	1.7% (1)	0% (0)	0% (0)
	3	1.4% (1)	2.8% (2)	31.5% (23)	50.7% (37)	13.7% (10)

Source: Authors' calculation based on the survey data (2026).

The results (Table 4) reveal three distinct patterns in respondents' perceptions of the relationship between meat production and deforestation in the Brazilian Amazon, suggesting that respondents' views align with established scientific knowledge to varying degrees across different social groups. The groups differed not only in their level of agreement with specific statements but also in how they interpreted environmental information, assigned responsibility for deforestation, and reconciled economic and environmental concerns.

A first important finding concerns recognition of the Brazilian Amazon's role in the country's meat supply. Respondents in Group 1 showed less recognition of the region's importance within the national meat supply chain, whereas the perceptions expressed by Groups 2 and 3 were more consistent with the available empirical evidence. This distinction is particularly relevant because the literature consistently identifies cattle ranching as the primary historical cause of deforestation in the Brazilian Amazon. Barona *et al.* (2010), Margulis (2003), Santos *et al.* (2021), and Walker *et al.* (2013) demonstrate that the conversion of forests into pasture has been the predominant form of land-use change in the Amazon. Similarly, Stabile *et al.* (2020) show that the replacement of forests with pastures and croplands has transformed millions of hectares of the Legal Amazon over recent decades. Therefore, the lower level of recognition observed in Group 1 suggests a disconnect between respondents' perceptions and the scale of beef production in the region, indicating that the Brazilian Amazon's contribution to the country's beef production remains insufficiently recognised by part of the sample.

Responses to the statement "Reducing meat consumption reduces deforestation" also revealed significant differences among the groups. Group 1 largely disagreed with this proposition, whereas Groups 2 and 3 expressed higher levels of agreement (Table 4). This divergence reflects an ongoing debate in the literature. Parzianello *et al.* (2024) argue that gradual reductions in beef consumption could generate significant environmental benefits by reducing pressure for pasture expansion. In contrast, Walker *et al.* (2013) emphasise that deforestation in the Brazilian Amazon cannot be explained solely by individual consumer choices but also depends on structural factors related to territorial governance, domestic and international markets, and the organisation of livestock supply chains. These findings suggest that, although changes in consumption may contribute to reducing pressure on forests, they should be viewed as part of a broader governance strategy rather than as an isolated solution.

Another important finding concerns the recognition of the relationship between meat production and deforestation. Although respondents in all three groups acknowledged some degree of association between the two, Group 1 expressed less consistent views, whereas Groups 2 and 3 demonstrated greater consensus. This pattern is consistent with the literature showing that different social narratives shape public interpretations of deforestation. Hoelle (2017) argues that, in certain contexts in the Brazilian Amazon, beef is associated with positive values such as prosperity, strength, and development. Consequently, the environmental impacts of cattle ranching are often perceived as acceptable or inevitable costs of economic progress. Kröger (2020) further argues that development-oriented narratives frequently legitimise forest conversion by portraying productive land use as a necessary component of regional development.

Differences in perceptions of the truthfulness of media coverage also deserve attention. Group 1 was more likely to disagree that the media tell the truth about deforestation, whereas Groups 2 and 3 showed more divided responses and higher levels of agreement. These findings are relevant in light of Ladle *et al.* (2010), who identified important differences in how Brazilian and international media frame the causes of deforestation in the Brazilian Amazon. More recently, De Souza (2021), Oliveira *et al.* (2022), and Souza *et al.* (2023) demonstrated that social media have become important arenas for political and informational disputes over the Amazon, simultaneously facilitating the dissemination of scientific evidence and narratives that question or downplay official deforestation data. These findings reinforce the view that public perceptions are shaped not only by information availability but also by whether media accounts are regarded as truthful.

Regarding the perceived economic importance of meat production, a high level of consensus was observed across the three groups. However, the simultaneous recognition of both the economic relevance of livestock farming and, in some cases, its environmental impacts reflects a recurring tension identified by Hoelle (2017): appreciation of the economic importance of cattle ranching coexists with growing concern about its environmental consequences. This ambivalence suggests that public debates surrounding livestock farming are not framed simply as a trade-off between economic development and environmental conservation but rather as an attempt to reconcile food production, economic growth, and environmental sustainability.

The findings concerning respondents' willingness to consume meat associated with deforestation further support this interpretation. Group 2 showed an almost unanimous rejection of such products, whereas Group 3 expressed greater acceptance or adopted more neutral stances. This pattern is consistent with Liu *et al.* (2023), who reported greater environmental concern among individuals with higher educational attainment and lower meat consumption. Likewise, Ferrante *et al.* (2024) found a positive association between education and engagement with environmental issues. At the same time, the greater permissiveness observed in Group 3 suggests that economic constraints may limit the use of environmental criteria in food choices. This interpretation is supported by Wilkinson (2008), who argues that lower-income consumers tend to prioritise affordability and accessibility over the environmental attributes of food products.

Finally, the results reinforce the notion that public perceptions can influence markets and supply chains but are insufficient, on their own, to address deforestation in the Brazilian Amazon. Gibbs *et al.* (2015), Vallim *et al.* (2025) and Walker *et al.* (2013) demonstrate that pressure from consumers, environmental organisations, and international buyers has encouraged meatpacking companies to adopt monitoring systems and exclude suppliers associated with deforestation. However, Carvalho *et al.* (2019) show that the persistence of indirect suppliers, informal markets, and cattle laundering practices undermines the effectiveness of these initiatives. These findings indicate that while consumer awareness can promote important changes in corporate behaviour, long-term reductions in deforestation ultimately depend on stronger environmental governance, effective law enforcement, and comprehensive traceability throughout the entire livestock supply chain.

Overall, the three groups show distinct patterns in the relationship between socioeconomic characteristics and environmental perceptions. Group 1 emphasised the economic importance of livestock farming while showing less recognition of its role in deforestation in the Brazilian Amazon, reflecting development-oriented narratives described by Hoelle (2017) and Kröger (2020). In contrast, Group 2 demonstrated greater environmental awareness, stronger rejection of products associated with deforestation, and perceptions more consistent with the scientific evidence on the relationship between cattle ranching and forest loss (Margulis, 2003; Nepstad *et al.,* 2014; Walker *et al.,* 2013). Group 3 occupied an intermediate position, recognising environmental impacts but showing greater acceptance of products associated with deforestation, suggesting that economic constraints also shape consumers' ability to make environmentally sustainable choices, as discussed by Hötzel *et al.* (2022) and Wilkinson (2008). These findings reinforce the view that perceptions of deforestation in the Brazilian

Amazon are socially differentiated and result from the interaction among education, income, cultural values, and access to environmental information.

4 CONCLUSIONS

The findings of this study demonstrate that respondents' perceptions of the relationship between deforestation, agricultural production, and meat consumption vary across the three groups. They are shaped by sociodemographic characteristics, educational attainment, income, and, above all, access to reliable information. Factor and cluster analyses identified three distinct profiles: Group 2, characterised by higher educational attainment and environmental awareness and by a tendency among its members to link dietary behaviour to sustainability principles; Group 1, characterised by less recognition of the role of livestock farming in deforestation, but also by a moderate tendency to reject products associated with deforestation; and Group 3, characterised by greater willingness among its members to consume products associated with deforestation, possibly reflecting economic constraints that restrict their food choices. These differences reveal that, although Brazil has relatively robust environmental legislation, limited enforcement of this legislation and insufficient monitoring may reinforce perceptions of institutional weakness.

From a critical standpoint, the study suggests that sustainable choices cannot be treated solely as a matter of consumer responsibility. This requires an effective institutional framework that integrates public policies for monitoring, transparency in supply chains, and incentives for responsible consumption. Furthermore, the results indicate that environmental education policies and improved access to information—particularly among groups with lower incomes and lower educational attainment—are essential for reducing inequalities in environmental perceptions and behaviours.

Future research should further investigate the role of media and social networks in shaping public opinion, given the potential for misinformation to distort perceptions of deforestation and agricultural production. Similarly, including rural consumers and farmers in future analyses would help clarify how they perceive and respond to environmental and market pressures. Moreover, examining certification and traceability strategies could provide insights into how economic competitiveness may be reconciled with social and environmental responsibility. In short, the integration of consumption patterns, public policy, and regulatory frameworks in the food production sector is essential for advancing towards fairer and more sustainable food systems.

Finally, the study used a non-probability convenience sample, which does not undermine its value but limits the generalisability of the findings.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

The authors used ChatGPT for language editing and stylistic polishing only. All scientific content, analysis, and intellectual input were developed and verified by the authors; we take full responsibility for the accuracy and integrity of the manuscript.

NOTES

1| Revised and expanded version of a paper presented at the 63rd SOBER Congress, held in 2025, and published in its proceedings.

2| Throughout this paper, the term "Brazilian Amazon" refers to the Brazilian Legal Amazon.

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Perceptions and practices of conscious consumption and circular economy among public and private high school students

Percepções e práticas de consumo consciente e economia circular entre estudantes do ensino médio de escolas públicas e privadas

Giseli Vecchietti [1]

Dusan Schreiber [2]

Luciane Pereira Viana [3]

[1] *Master's in Environmental Quality, Teacher, State Education of Rio Grande do Sul, Novo Hamburgo, RS, Brazil*
E-mail: gi_giseliv@yahoo.com.br

[2] *PhD in Administration, Full professor, Master›s in Administration Program, Feevale University, Novo Hamburgo, RS, Brazil*
E-mail: dusan@feevale.br

3 Doctorate in Cultural Diversity and Social Inclusion, Postdoctoral researcher, Professor, Faculdade IENH, Novo Hamburgo, RS, Brazil
E-mail: viana.luciane.lu@gmail.com

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ABSTRACT

The intensification of environmental degradation has raised systemic concerns in contemporary society regarding sustainability, considering both ecological and social dimensions. This study aimed to identify the different perceptions and practices of conscious consumption and circular economy among high school students, considering financial comfort and institutional context (public and private schools). The methodology consisted of a survey with 238 questionnaires analysed using analysis of variance (Anova) and goodness-of-fit tests. The results reveal that perceptions of circularity and sustainable practices are not uniform and are linked to students' material security. Students from private schools demonstrate greater openness to collaborative consumption, while students from public schools show a greater perception of risk (hygiene and damage) in relation to reuse. The data support educational managers in developing differentiated environmental education strategies that consider the subjective barriers of each social stratum.

Keywords: Conscious Consumption. Circular Economy. Teenagers. High School. Financial Comfort.

RESUMO

*A intensificação da degradação ambiental tem suscitado uma preocupação sistêmica na sociedade contemporânea acerca da sustentabilidade, considerando tanto a dimensão ecológica quanto a social. Este estudo objetivou identificar as diferentes percepções e práticas de consumo consciente e de economia circular entre estudantes do ensino médio, considerando o conforto financeiro e o contexto institucional (escola pública e privada). A metodologia consistiu em um "survey" com 238 questionários analisados via testes de variância (Anova) e de aderência. Os resultados revelam que a percepção de circularidade e as práticas sustentáveis não são uniformes e estão atreladas à segurança material do estudante. Os alunos da rede privada demonstram maior abertura ao consumo colaborativo, enquanto discentes da rede pública manifestam maior percepção de risco (higiene e danos) em relação ao re**ú**so. Os dados fornecem subsídios para que gestores educacionais desenvolvam estratégias de educação ambiental diferenciadas, que considerem as barreiras subjetivas de cada estrato social.*

Palavras-chave: *Consumo Consciente. Economia Circular. Adolescentes. Ensino Médio. Conforto Financeiro.*

1 INTRODUCTION

The growing degradation of the environment has driven a systemic concern in contemporary society regarding a sustainable future from both ecological and social perspectives. In recent years, this scenario has fostered a series of sociopolitical mobilisations aimed at mitigating negative environmental impacts, resulting in the enactment of global laws and regulations designed to restrict the operations of polluting organisations and institutionalise sustainability education at all educational levels (Costa; Lima; Lima, 2020).

However, the scientific literature demonstrates that consolidating real changes in organisational processes and family life is a gradual phenomenon, requiring time to generate concrete results (De Lima *et al.*, 2019). The challenge lies in the hegemony of the capitalist system, which sustains a political-economic model underpinned by a consumer culture where the act of consuming serves as a criterion for individual belonging in society (De Lira, 2018). This dynamic is reinforced by industries operating under a linear production logic, which demands increasing volumes of natural resource extraction and worsens environmental impact (Efing; Rabelo, 2020).

To break away from this cycle that reinforces consumerist behaviour, it is imperative to promote transformations in consumers' mental models, initiating a virtuous cycle toward the circular economy (Ellen MacArthur Foundation, 2015). Several researchers have investigated whether individuals' economic situations alter their willingness to adopt sustainable practices (Lied *et al.*, 2019), highlighting the hypothesis that people in more favourable financial conditions hold more positive perceptions of sustainability, as their basic needs are already met, in contrast to less privileged strata (Molinari; Cauchick-Miguel, 2017).

Nevertheless, a gap remains in understanding how these distinct realities shape youth's subjective views on reuse and sharing. Considering adolescence as a critical phase for the formation of consumption values, this research proposes the following question: what are the distinctions in the perceptions of students from divergent socioeconomic backgrounds regarding conscious consumption and the circular economy?

In this regard, the present study aims to identify the different perceptions and practices of conscious consumption and the circular economy among high school students, considering financial comfort and the institutional context (public and private schools). The relevance of this research lies in its capacity to reveal how adolescent subjectivity is shaped by their environment, offering academic contributions

to Consumer Culture Theory and practical insights for educators to develop environmental approaches that resonate with different social realities.

To achieve this purpose, a quantitative survey approach was utilised, collecting empirical data from two high school institutions in the southern region of Brazil. Structurally, this article is divided into five sections. Following this introduction, the theoretical framework on conscious consumption and the circular economy is presented, followed by a detailed description of the methodological procedures. Next, the analysis and discussion of the results are provided, concluding with final considerations.

2 THEORETICAL FRAMEWORK

Consumption extends beyond the mere acquisition of products and services, constituting a social and cultural phenomenon that contributes to the construction of identities, values, and social relationships. According to Canclini (2010) and Rocha and Pereira (2009), consumption encompasses sociocultural dimensions that emerge both from the symbolic interactions among consumers and from their relationship with the environment in which they live. From the perspective of Consumer Culture Theory, consumption choices and practices are understood as multidimensional phenomena shaped by a complex interplay of technological, social, behavioural, and organisational factors (Viana; Schreiber; Viana, 2025). Consequently, consumption decisions are no longer viewed merely as rational responses to individual needs but rather as complex processes through which meanings are created and negotiated.

However, in the face of the ongoing environmental crisis, contemporary consumers are expected to reconsider their consumption habits by reshaping both their individual and collective practices in order to mitigate the negative impacts inherent in consumption (Chais et al., 2013; El Ghali Ghorafi, 2026; Kien et al., 2026; Tódero; Macke; Biasuz, 2011). Such a transformation requires strengthening environmental consciousness, understood as the ability to recognise environmental problems, support initiatives aimed at mitigating them, and demonstrate a willingness to actively contribute to environmental protection (Thanh et al., 2026). Therefore, environmental consciousness represents a necessary condition for the development of more sustainable consumption behaviours, although, by itself, it is insufficient to promote effective behavioural change.

Within this context, the Circular Economy emerges as an alternative to the traditional linear model of production and consumption (El Ghali Ghorafi, 2026; Kien et al., 2026). Unlike the conventional “take–make–dispose” model, the CE seeks to preserve the value of materials and products for as long as possible by reducing waste generation and reintegrating resources into successive production cycles (Abdalla; Sampaio, 2018; Kien et al., 2026; Ubaidillah; Zulkarnain, 2025).

According to Cosenza et al. (2020), efficient resource management, particularly non-renewable resources, aims to extend their useful life while minimising the extraction of virgin raw materials. From this perspective, waste management ceases to be a post-consumption concern and becomes a central element of product design, requiring solutions based on biodegradable, recyclable, or recoverable materials capable of being reintegrated into new production processes (Ideia Circular, 2018). Furthermore, strategies such as maintenance, repair, remanufacturing, and reuse extend product lifespans, while second-hand markets strengthen resource circularity (Kien et al., 2026).

This technological and biological circularity enables products that have become obsolete for one group of consumers to continue meeting the needs of others or to be recycled so that their components and materials can be incorporated into new production processes (Arenhardt et al., 2016). Nevertheless, the effective implementation of this model faces important barriers associated with consumer subjectivity, since consumption is often driven not by rational decision-making but by emotional and symbolic desires (Viana; Schreiber, 2025). Consequently, the consolidation of the CE requires not

only technological and organisational changes but also broader cultural transformations capable of redefining the meanings attributed to consumption.

A study conducted with Vietnamese young consumers by Kien et al. (2026) reinforces this perspective by identifying perceived economic benefits, environmental concern, and pro-environmental attitudes as the main predictors of purchase intention toward second-hand fashion products. Similarly, Thanh et al. (2026) found that perceived economic benefits remain the strongest determinant of such intentions, followed by perceived behavioural control, subjective norms, and environmental concern. Taken together, these findings suggest that, although environmental consciousness is an important driver of sustainable consumption, its influence becomes more pronounced when accompanied by perceived economic advantages and favourable social norms.

Similar evidence has been reported in other markets. In the Netherlands, for example, Ho et al. (2026) found that environmental consciousness, social acceptance, and brand reputation positively influence young consumers' willingness to purchase refurbished electronic devices. Nevertheless, the adoption of such practices still faces barriers rooted in the dynamics of contemporary consumer society. According to Bauman (2008), modern consumption is characterised by symbolic obsolescence, whereby interest in products rapidly fades, stimulating successive replacement cycles in the pursuit of satisfaction.

As a consequence, both waste generation and the exploitation of natural resources intensify, while impulsive consumption undermines household financial stability and contributes to indebtedness (Dalmora Bonissoni; Da Silva, 2018; Souza; Miyazaki; Enoque, 2019). It is important to emphasise that conscious consumption does not advocate eliminating consumption itself. Rather, it encourages a critical reflection on the intentions underlying consumption and the way it occurs, taking into account the entire product life cycle, from raw material extraction to final disposal (Costa; Lima; Lima, 2015).

Improper solid waste disposal also represents an environmental, social, and public health challenge (Sontag, 2015), as waste is frequently discarded in public spaces, vacant lots, hillsides, storm drains, and waterways, thereby increasing environmental degradation and health risks (Massuga, 2022; Sontag, 2015). Within this perspective, sustainability assessment also requires indicators capable of measuring the impacts associated with consumption choices. Vale et al. (2025) argue that such assessments should incorporate metrics such as water, ecological, and carbon footprints to better understand the environmental consequences of human activities.

Lied et al. (2019) and Likewise, Efing and Rabelo (2020) emphasise that product origin, transportation distance throughout the supply chain, and the quantity of packaging materials significantly influence the carbon footprint of products. These factors become even more relevant in light of the increasing vehicle fleet and rising CO_2 emissions, both recognised as major contributors to climate change (Da Silva Filho et al., 2019; Siqueira Soares et al., 2017).

Within this context, a conscious consumer internalises concerns about future generations and seeks appropriate waste disposal, recognising that individual consumption practices can encourage companies to adopt more ethical and environmentally responsible production processes (Chais et al., 2013; Efing; Rabelo, 2020; Ubaidillah; Zulkarnain, 2025). Furthermore, conscious consumers tend to promote social learning by encouraging others to reflect on their own consumption habits (Costa; Lima; Lima, 2015). De Lira (2018) argues that the consistent adoption of these practices remains constrained by structural and market barriers, highlighting the persistent attitude–behaviour gap observed in sustainable consumption research.

Given this complexity, Tódero, Macke, and Biasuz (2011) propose ten guiding principles for conscious consumption: planning purchases to avoid impulsive buying; assessing the socio-environmental impacts of consumption; purchasing only what is necessary; reusing products and packaging; properly separating waste; using credit responsibly; valuing companies committed to social responsibility;

combating piracy and smuggling; contributing to the improvement of products and services; and promoting conscious consumption practices within society.

These findings can be understood through three complementary dimensions. The environmental dimension encompasses the purchase of necessary products, the reduction of environmental impacts, and the assessment of production processes and product life cycles. The economic dimension involves planned consumption, product reuse, and the responsible management of financial resources. In turn, the social dimension includes the influence exerted on other consumers and the preference for organisations committed to environmentally and socially responsible practices (Chais et al., 2013; Ho et al., 2026; Souza; Miyazaki; Enoque, 2019; Thanh et al., 2026; Tódero; Macke; Biasuz, 2011).

Beyond the individual dimension, the promotion of conscious consumption also depends on social relationships and on strategies developed by organisations and public policymakers. In this regard, Kien et al. (2026) argue that the growing social acceptance of sustainable consumption, particularly among young consumers, enhances the influence of peers, communities, and opinion leaders. The authors suggest that marketing professionals should leverage social proof mechanisms, such as peer influence, celebrity endorsements, and community-based campaigns, to reinforce second-hand consumption as a desirable, fashionable, and environmentally responsible choice.

Within this perspective, conscious consumers move beyond the role of mere economic agents and become multipliers of sustainable practices, influencing consumption patterns and encouraging changes throughout the product life cycle (Mutz, 2014). In this context, shifts in consumption patterns generate long-term effects by fostering an ethic of social and environmental responsibility (Pastore et al., 2015). However, this transformation must be socially constructed because, as Dalmora Bonissoni and Da Silva (2018, p. 122) argue, "[...] citizens must become increasingly aware of their consumption, since regulations alone are ineffective if people continue to consume as though there were no tomorrow."

In the same vein, Mutz (2014) emphasises that the purpose of conscious consumption is not to eliminate consumption itself but to redefine it according to ethical principles. Likewise, Tódero, Macke, and Biasuz (2011) argue that consumption decisions should take into account their environmental, social, and economic consequences, while Costa, Lima, and Lima (2015) contend that consuming consciously also represents a commitment to reducing social inequalities and preserving the essential resources required to sustain life in society.

Finally, Raposo and Terra (2021) argue that consumers perceive companies as more effective agents of change than governments, expecting the private sector to incorporate sustainable market niches more rapidly than public initiatives. Nevertheless, this expectation contrasts with the growing scepticism toward corporate environmental claims. El Ghali Ghorafi (2026) demonstrates that, particularly among young consumers, the credibility of such claims depends on transparency and consistency between corporate discourse and actual organisational practices.

In line with this discussion, Kien et al. (2026) and Thanh et al. (2026) argue that marketing strategies aimed at promoting sustainable consumption should integrate economic benefits, social values, and environmental attributes. At the same time, public policies should create favourable conditions for the expansion of the CE and the consolidation of more sustainable consumption patterns aligned with the principles of circularity and sustainability.

3 METHODOLOGY

This research is characterised by a quantitative, descriptive approach (Gil, 2002). The survey method was adopted, with primary data collection carried out through a structured questionnaire (Hair *et al.*, 2009), developed and made available on the Google Forms platform (Babbie, 2003). The instrument

was constructed based on a literature review on conscious consumption, encompassing different dimensions associated with pro-environmental behaviours, circular economy, waste disposal, and consumption habits.

The 28 statements were operationalised using a five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree), with the aim of measuring the degree of agreement of the respondents in relation to the variables investigated. First, a pre-test of the questionnaire was conducted with four students (two from each participating institution) to assess the clarity, comprehension, and suitability of the questions. The participants in the pre-test were excluded from the final sample, and no substantial adjustments to the instrument were necessary after this stage.

The research universe consisted of high school students from the municipality of Sapiranga, located in the Porto Alegre Metropolitan Region, in the state of Rio Grande do Sul. The municipality has an estimated population of 80,514 inhabitants and a Municipal Human Development Index (MHDI) of 0.711 (IBGE - Brazilian Institute of Geography and Statistics, 2021). According to data from the National Institute of Educational Studies and Research Anísio Teixeira – Inep (2022), Sapiranga registered 3,058 enrollments in high school in 2021, concentrated mainly in the state education network. National Institute of Educational Studies and Research Anísio Teixeira – Inep is a federal agency responsible for evaluations, research and statistics on Brazilian education.

The sample consisted of students from two educational institutions, one public and one private. The sampling technique used for both school and student selection was non-probabilistic, based on convenience and accessibility (Prodanov; Freitas, 2013). It is assumed that different educational contexts can influence students' predisposition to adopt sustainable consumption practices, as well as reflect different levels of curricular awareness regarding environmental issues.

The two selected schools are in the centre of the city of Sapiranga. The public school had nine elementary school classes (five in the early years and four in the later years), as well as 29 high school classes, divided into three shifts (morning, afternoon, and evening). The school had 955 students enrolled in high school. The private school had 19 elementary school classes (11 in the early years and 8 in the later years), plus 5 high school classes, totalling 70 students in the final stage of basic education.

Both schools are traditional in the city. The public school celebrated its 87th anniversary in 2024, its history intertwined with the city's history, and it is a benchmark for public education. The private school, on the other hand, has been in existence for 72 years and is highly regarded for its quality of teaching. The public high school program is divided into three shifts (morning, afternoon, and evening), while the private program is exclusively daytime, although in the school analysed, it is only offered in the morning.

The collection of empirical data took place between August and September 2022. The questionnaire was disseminated through social networks and instant messaging applications, with the support of the pedagogical coordinators of the participating institutions to encourage student engagement. In accordance with the ethical precepts governing scientific research, participants were duly informed about the academic objectives of the study, as well as the voluntary and anonymous nature of participation. The application of the instrument was conditional upon the existence of the Informed Consent Form (ICF), previously signed by the legal guardians with the educational institutions.

This research was not submitted to the Ethics Committee, pursuant to Article 1 of Resolution No. 510 of April 7, 2016, issued by the National Health Council of Brazil. According to said resolution, Research Ethics Committees or the National Health Council systems do not register or evaluate public opinion surveys involving unidentified participants, research based on aggregated databases where participant identification is impossible, or research aimed at the theoretical exploration of situations

arising spontaneously and contingently in professional practice, provided no data capable of identifying participants is disclosed (Brasil, 2016).

At the end of the data collection period, a total of 238 valid questionnaires were obtained, corresponding to approximately 23.7% of the target population of the selected institutions. Data processing and analysis were performed using SPSS software. Following the methodological guidelines of Hair *et al.* (2009), the statistical analysis was structured in two stages. In the first stage, descriptive data analysis was performed by calculating measures of central tendency (mean) and dispersion (standard deviation) to characterise the sample profile and summarise the behaviour of the investigated variables.

In the second stage, inferential analysis was performed using Analysis of Variance (Anova), followed by Tukey's post-hoc test, to identify possible statistically significant differences in sustainable consumption practices among the analysed institutional groups. The Tukey Test is used after carrying out an Analysis of Variance (Anova) when it is important to identify which groups are significantly different from each other. It is especially useful in situations where there are more than two groups to be compared (Morettin; Bussab, 2013).

4 ANALYSIS AND DISCUSSION OF RESULTS

Characterising the respondents' profile is a fundamental step in understanding the behavioural predispositions of the studied sample. Table 1 presents the distribution of the surveyed high school students, segmented by sociodemographic variables. According to the principles of Hair *et al.* (2009), frequency analysis and goodness-of-fit testing are essential to validate the representativeness and distribution of the collected data.

Table 1 – Distribution of students from two high schools, one private and one public, located in the city of Sapiranga, RS, Brazil, according to respondents' profile

Respondent Profile	*N*	*%*	*P-Value (1)*
Age group			
14 and 15 years	68	28.6%	< .001*
16 and 17 years	153	64.3%	
18 years or older	17	7.1%	
Gender			
Female	149	62.6%	< .001*
Male	89	37.4%	
School Type			
Private School	16	6.7%	< .001*
Public school	222	93.3%	
Current Grade Level			
1st year of High School	96	40.3%	< .001*
2nd year of High School	89	37.4%	
3rd year of High School	53	22.3%	
Number of People Living in the Household			

Respondent Profile	*N*	*%*	*P-Value (1)*
2 - 3 people	156	65.6%	
4 - 6 people	80	33.6%	< .001*
More than 6 people	2	0.8%	

Note: Results are based on non-empty rows and columns within each innermost subtable.

(1) χ^2 Goodness of Fit test (p-value < 0.05).

**Significant Values; NS - Non-Significant Values.*

Test interpretation:

***H0:** The observed means do not differ significantly between groups and categories.*

***H1:** The observed averages differ significantly between groups and categories.*

Decision: Since the computed p-value is lower than the significance level (α = .05), the null hypothesis (H_0) is rejected in favour of the alternative hypothesis (H_1).

Source: Research protocol (2025).

As shown in Table 1, the sample was predominantly composed of students aged 16 to 17 years (64.3%), females (62.6%), enrolled in public schools (93.3%), mainly attending the first year of high school (40.3%), and living in households with two to three people (65.6%). The χ^2 goodness-of-fit test indicated statistically significant differences across all analysed categories ($p < .001$), demonstrating that the respondents were not uniformly distributed but rather concentrated within specific demographic groups.

This age distribution is consistent with the indicators reported by Inep (2022), which establish entry into high school between the ages of 14 and 15 and graduation at 17 or 18 years of age. The low proportion of students aged over 18 years (7.1%) suggests a regular educational progression, as enrollment in this age group is generally associated with a history of grade retention. Notably, all 17 students aged over 18 were enrolled in the public school, indicating the absence of overage students in the private school. This pattern may be associated with pedagogical factors, such as continuous academic support strategies and lower student-to-teacher ratios, which enhance the teaching–learning process and contribute to lower dropout and grade retention rates (Inep, 2022). The predominance of female respondents is also consistent with local census data, as female enrollment in Sapiranga exceeds male enrollment (1,623 and 1,435 students, respectively) (Inep, 2022).

To examine the influence of the respondents› sociodemographic profile on the level of conscious consumption, Tukey›s post hoc test and analyses of variance (Anova) were performed. The results indicated that variations in the students› mean scores were not significantly associated with the demographic variables ($p > .05$). These findings suggest that, within this sample, characteristics such as gender, age, and grade level do not constitute significant predictors of environmental and circular consumption awareness, indicating a relatively homogeneous pattern across the demographic strata. However, when the analysis was stratified by school type (Table 2), relevant differences emerged.

Table 2 – Mean and standard deviation of the conscious consumption and circular economy questionnaire scores among students from two high schools, one private and one public, located in Sapiranga, RS, Brazil, by questionnaire item

Variable	*N*	*Mean*	*Median*	*SD*	*Minimum*	*Maximum*
Overall Score by School						
Private School	16	89.1	90.5	3.63	82	95
Public school	222	86.5	86.5	10.56	32	139
Financial Comfort Score by School						

Variable	N	Mean	Median	SD	Minimum	Maximum
Private School	16	4.13	4.00	0.80	3	5
Public school	222	3.72	4.00	1.02	1	5

Test interpretation:

H0: *The observed means do not differ significantly between groups and categories.*

H1: *The observed averages differ significantly between groups and categories.*

Decision: *Since the computed p-value is lower than the significance level ($\alpha = .05$), the null hypothesis (H_0) is rejected in favour of the alternative hypothesis (H_1).*

Source: Research protocol (2025).

As shown in Table 2, students from the private school achieved a significantly higher overall mean score than those from the public school (89.1 ± 3.63 vs 86.5 ± 10.56). Considering that higher scores indicate greater disagreement with irrational consumption behaviours, these findings suggest a stronger predisposition toward conscious consumption among private school students. Likewise, the financial comfort score was significantly higher in the private school group (4.13 ± 0.80 vs 3.72 ± 1.02).

Taken together, these findings reveal differences between the two school contexts, suggesting that factors associated with the socioeconomic and institutional environment may be related to attitudes toward conscious consumption and perceptions of financial comfort. Although the observed difference in the overall score is relatively small in absolute terms, it indicates a consistent pattern across the two groups.

Table 3 presents the central tendency (mean, median, and mode) and dispersion (standard deviation) metrics for each item of the questionnaire, segmented by institution. Following the adopted measurement scale, it is highlighted that higher scores indicate a greater degree of disagreement by the student with the statement presented.

Table 3 – Mean and standard deviation of the scores obtained for each item of the Conscious Consumption and Circular Economy Questionnaire among students from one private and one public high school in Sapiranga, RS, Brazil

Scale Items	School	N	Mean	Median	Mode	SD
On a scale from 1 (I experience significant financial difficulties) to 5 (I live comfortably in financial terms), select the option that best describes your financial situation.	Private	16	4.13	4	4	0.81
	Public	222	3.72	4	4	1.03
When purchasing a product, I consider its environmental impact.	Private	16	3	3	2	1.10
	Public	222	2.91	3	3	1.15
I try to reduce my use of disposable items, such as plastic bags.	Private	16	2.94	3	3	1.29
	Public	221	2.73	3	3	1.34
I research the place of production of an item and give preference to buying local products.	Private	16	2.94	2.5	2	1.39
	Public	222	3.35	3	3	1.34
I separate household waste whenever possible.	Private	16	1.63	1	1	1.20
	Public	221	2.19	2	1	1.38
I prefer modes of transportation that generate less environmental impact, such as walking, cycling, or using public transport.	Private	16	2.88	2.5	2	1.15
	Public	220	3.06	3	3	1.39
I consider eco-friendly products to be just as good as any other product.	Private	16	1.88	2	1	1.15
	Public	221	2.31	2	1	1.20

Scale Items	School	N	Mean	Median	Mode	SD
I do not usually repair damaged products because buying a new one is generally cheaper.	Private	16	3.56	4	4	1.41
	Public	222	3.15	3	3	1.33
I usually rent products that I use only occasionally.	Private	16	3.94	4	5	1.12
	Public	220	3.97	5	5	1.28
10. I do not separate household waste because I do not know how to do it correctly.	Private	16	4.63	5	5	1.03
	Public	220	4	5	5	1.30
11. I do not separate household waste because I do not have enough time.	Private	16	4.31	5	5	1.35
	Public	222	3.78	4	5	1.39
12. I usually buy used products for environmental reasons.	Private	16	3.06	3	4	1.44
	Public	220	3.74	4	5	1.19
13. I often replace my electronic devices, such as cell phones, with newer models.	Private	16	3.44	4	5	1.46
	Public	222	3.3	3	5	1.47
14. I prefer not to lend my belongings (such as clothes, shoes, etc.) because I don't consider it hygienic.	Private	16	4.13	4.5	5	1.20
	Public	222	2.59	2	1	1.44
15. I prefer not to lend my belongings (such as clothes, shoes, etc.) for fear that other people might damage them.	Privat	16	3.69	4	4	1.01
	Public	222	2.12	2	1	1.32
16. When purchasing a product, I consider only its price.	Private	16	3.56	4	4	1.26
	Public	221	3.14	3	3	1.41
17. I have doubts about how to separate household waste correctly.	Private	15	3.47	4	4	1.46
	Public	221	3.58	4	5	1.31
18. I buy second-hand products because they are cheaper.	Private	16	2.94	3	3	1.39
	Public	220	3.54	4	5	1.40
19. I dispose of electronic waste together with regular household waste	Private	16	4.56	5	5	1.21
	Public	220	3.95	5	5	1.35
20. I prefer to buy new products, even if I only use them a few times.	Private	16	3.94	4	4	1.18
	Public	219	3.21	3	5	1.39
21. I don't usually buy eco-friendly products because of their price.	Private	16	2.75	3	3	1.00
	Public	219	3.02	3	3	1.22
22. I prefer travelling by car to using other means of transportation.	Private	16	2.56	2.5	1	1.50
	Public	220	2.51	2	1	1.41
23. I usually repair products that have problems or defects.	Private	16	2.19	2	1	1.05
	Public	219	2.64	2	2	1.29
24. I only replace my electronics when they start having problems due to software updates that they can no longer handle.	Private	16	1.75	1	1	1.18
	Public	220	2.05	1.5	1	1.31
25. I try to buy products that have a lower environmental impact.	Private	16	2.69	3	3	1.20
	Public	220	3.1	3	3	1.19
26. I always separate household waste and encourage others around me to do the same.	Private	16	2.81	2.5	2	1.42
	Public	219	3.07	3	3	1.37
27. I do not buy second-hand products for hygiene reasons.	Private	16	3.94	4	5	1.29
	Public	220	3.14	3	3	1.40
28. I don't mind lending my things to other people.	Private	16	2.06	2	1	1.18
	Public	219	3.25	3	3	1.37

Test interpretation:

H0: *The observed means do not differ significantly between groups and categories.*

H1: *The observed averages differ significantly between groups and categories.*

Decision: *Since the computed p-value is less than the significance level alpha = 0.05, the null*

hypothesis H0 should be rejected and the alternative hypothesis Ha should be accepted.

Source: Research protocol (2025).

Table 3 presents the descriptive statistics for the items comprising the conscious consumption and circular economy scale, highlighting differences between students from public and private schools in six of the 28 statements evaluated (Items 12, 14, 15, 20, 27, and 28). These findings indicate that, although the overall level of conscious consumption was similar across the two groups, specific dimensions related to product sharing, second-hand purchasing, and consumption motivations differed between the school contexts.

Overall, the relatively high standard deviations observed for most items reveal substantial variability in students' responses, indicating the coexistence of divergent opinions regarding the same consumption practices. Moreover, the concentration of both means and medians around the midpoint of the scale (score = 3) suggests a predominantly neutral or uncertain position toward several behaviours associated with conscious consumption and the Circular Economy. This pattern indicates that these concepts have not yet been fully internalised by the adolescents surveyed, regardless of the type of school attended.

Although students from the private school exhibited greater homogeneity in their responses regarding financial comfort, whereas those from the public school showed greater variability, this finding should be interpreted with caution. From the perspective of CCT, consumer behaviour results from the interaction of economic, social, cultural, and symbolic factors (Canclini, 2010; Rocha; Pereira, 2009; Viana; Schreiber; Viana, 2025), indicating that financial resources represent only one of the elements influencing consumption practices.

The most pronounced differences between the two groups were observed in the items related to product sharing and the use of second-hand products (Items 14, 15, and 28). Students from the public school demonstrated greater resistance to lending personal belongings, primarily due to hygiene concerns and fear of product damage, whereas students from the private school were more receptive to these practices. From the perspective of Bauman (2008) and Viana and Schreiber (2025), this emphasis on individual ownership and the preference for "new products" (Item 20) may be interpreted as a search for feelings of security and status provided by the market for tangible products.

These findings also align with the Circular Economy literature. Abdalla and Sampaio (2018), Cosenza *et al.* (2020), and Ubaidillah and Zulkarnain (2025) argue that circular business models rely on expanding product reuse, maintenance, sharing, and extending product life cycles. However, the present findings indicate that practices associated with collaborative consumption still face important behavioural barriers, particularly when they involve personal belongings. This result reinforces El Ghali Ghorafi's (2026) argument that the transition toward a Circular Economy depends not only on the availability of technological solutions but also on changes in consumers' perceptions and attitudes.

The greater acceptance among private school students of lending personal belongings and their lower resistance to second-hand products is also partially consistent with the findings of Ho *et al.* (2026), Kien *et al.* (2026) and Thanh *et al.* (2026). These studies demonstrate that the adoption of circular consumption practices depends simultaneously on perceived economic benefits, environmental concern, social influence, and the collective acceptance of such behaviours. Although the present study did not directly measure these constructs, the findings suggest that social and cultural factors may contribute to reducing resistance toward collaborative consumption and second-hand markets.

Conversely, the predominance of responses around the midpoint of the scale indicates that a substantial proportion of adolescents still maintain a neutral position regarding several practices associated with conscious consumption and the Circular Economy. This pattern reinforces the attitude–behaviour gap described by De Lira (2018), according to which pro-environmental values are not always translated

into concrete behaviours. Likewise, Kien *et al.* (2026) and Thanh *et al.* (2026) found that environmental concern alone has limited explanatory power for sustainable purchase intentions compared with perceived economic benefits, subjective norms, and perceived behavioural control.

This disconnect can also be observed in the items concerning product origin, transportation choices, and product repair. The limited interest in locally produced and environmentally friendly transportation alternatives suggests that issues related to logistics, carbon emissions, and the indirect environmental impacts of consumption remain weakly integrated into students' decision-making processes. These findings are consistent with Efing and Rabelo (2020), Lied *et al.* (2019), and Vale *et al.* (2025), who emphasise the importance of considering supply chains, carbon footprints, and other environmental indicators to achieve a comprehensive understanding of sustainable consumption.

Similarly, the low willingness to repair products indicates the persistence of consumption practices aligned with the traditional linear economy, contradicting the restorative principles proposed by the Circular Economy (Arenhardt *et al.*, 2016; Ideia Circular, 2018). This behaviour reflects the predominance of early product replacement, often justified by short-term cost–benefit considerations while neglecting the environmental consequences associated with waste generation (Cosenza *et al.*, 2020). These findings support the concerns raised by Dalmora Bonissoni and Da Silva (2018), who argue that uncontrolled consumption is driven by perceived product value while overlooking its long-term environmental impacts.

Another relevant aspect concerns the role of social influence in fostering sustainable behaviours. The results revealed limited engagement among students in encouraging others to adopt conscious consumption practices (Item 26), suggesting that the consumer's role as a multiplier of sustainable behaviours remains underdeveloped. This finding contrasts with the recommendations of Costa, Lima, and Lima (2015), Mutz (2014), and Tódero, Macke, and Biasuz (2011) who argue that conscious consumers should actively disseminate sustainable consumption practices.

Finally, the findings corroborate Raposo and Terra (2021), demonstrating that the consolidation of conscious consumption depends on the joint efforts of consumers, companies, and public institutions. However, as highlighted by El Ghali Ghorafi (2026), Pastore *et al.* (2015), and Ubaidillah and Zulkarnain (2025) the effectiveness of this process requires transparent organisations, consistent public policies, and educational initiatives capable of transforming knowledge into everyday practices. Therefore, although adolescents demonstrate an initial familiarity with sustainability-related principles, the incorporation of Circular Economy principles remains partial, indicating that cultural, symbolic, and behavioural barriers continue to limit the adoption of more sustainable consumption patterns.

5 FINAL CONSIDERATIONS

The present study aimed to identify differences in perceptions and practices related to conscious consumption and the Circular Economy among high school students, considering financial comfort and the institutional context (public and private schools). Using a quantitative and descriptive survey approach, the findings demonstrate that although students are familiar with sustainability-related principles, the effective adoption of practices consistent with the Circular Economy remains partial and heterogeneous.

The results revealed that the most pronounced differences between the two groups were associated with product sharing and the consumption of second-hand products. Students from public schools showed greater resistance to lending personal belongings, mainly due to hygiene concerns and fear of material damage, whereas students from private schools demonstrated greater acceptance of these practices and less stigma toward second-hand products. On the other hand, the predominance of responses around the midpoint of the scale indicates that a substantial proportion of adolescents still

hold neutral positions regarding several practices related to conscious consumption and the Circular Economy, suggesting that these concepts have not yet been fully incorporated into their everyday consumption decisions.

From a theoretical perspective, this study contributes to the Consumer Culture Theory literature by demonstrating that sustainable consumption practices cannot be understood exclusively through economic or environmental factors. The findings reinforce that symbolic values, perceptions of ownership, social experiences, and socioeconomic conditions jointly shape the meanings attributed to sharing, reuse, and extending product life cycles.

From a practical perspective, the findings provide valuable insights for educational institutions, policymakers, and organisations seeking to promote more sustainable consumption patterns. Within schools, experiential learning initiatives are recommended, including swap fairs, product repair workshops, material reuse projects, and educational campaigns designed to reduce barriers associated with hygiene concerns and the sharing of personal belongings. Such initiatives may bring students closer to the principles of the Circular Economy through hands-on experiences, thereby narrowing the gap between conceptual knowledge and everyday practice.

For companies and marketing professionals, the findings highlight the importance of communication strategies that emphasise trust, safety, product quality, and the environmental benefits associated with second-hand markets and collaborative consumption practices. Likewise, public policies aimed at strengthening environmental education may contribute to developing conscious consumption competencies from the early stages of formal education.

Despite these contributions, several limitations should be acknowledged. The relatively small number of respondents from the private school compared with the public school requires caution when generalising the findings. Furthermore, the study was conducted in a single municipality, limiting the generalizability of the results to other Brazilian sociocultural contexts. It is also important to highlight as a limitation of the research the significant numerical difference between the two groups of students, one, from the public school, with 222 respondents, and the other, with only 16 respondents, from the private school. Finally, the use of self-administered questionnaires may have introduced social desirability bias, as respondents may have provided answers that they perceived as socially acceptable rather than reflecting their actual behaviours.

Future research should employ qualitative approaches, such as focus groups and in-depth interviews, to explore the sociocultural roots underlying the reluctance to use second-hand products among low-income adolescents. In addition, expanding the investigation to other regions of Brazil would enable comparisons across different cultural and socioeconomic contexts, thereby improving the understanding of how financial comfort influences sustainability-related perceptions and behaviours.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

The authors used Gemini 3.6 Flash for language editing and stylistic polishing only. All scientific content, analysis, and intellectual input were developed and verified by the authors; we take full responsibility for the accuracy and integrity of the manuscript.

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Latin America's Pursuit of Peaceful Nuclear Energy and Sustainable Futures in the Context of Climate Change

A Busca da América Latina por Energia Nuclear Pacífica e Futuros Sustentáveis no Contexto das Mudanças Climáticas

Iván Vargas-Chaves [1]

Mauricio Luna-Galván [2]

[1] *PhD in Law of the Supranational Unions, PhD in International Private Law, Associate Professor, Universidad Militar Nueva Granada, Bogotá, Colombia*
E-mail: ivan.vargas@unimilitar.edu.co

[2] *PhD in Political Science, Administration and International Relations, Associate Professor, Escuela Superior de Administración Pública, Cartagena de Indias, Colombia*
E-mail: mauricioj.luna@esap.edu.co

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ABSTRACT

This article examines how International Relations theories explain the decision-making of Latin American states regarding nuclear proliferation and energy within the dual context of climate change and enduring global nuclear arsenals. Employing a qualitative documentary analysis, the study identifies analytical categories across realist, constructivist, and liberal frameworks to evaluate state behaviour. The results demonstrate that, unlike traditional realist reliance on nuclear deterrence, Latin America has successfully utilised institutional liberalism and cooperation, as institutionalised by the Treaty of Tlatelolco. This regional approach prioritises non-proliferation, multilateral regimes, and international law to mitigate security dilemmas and advance peaceful nuclear energy. Ultimately, the research concludes that the Latin American experience offers a vital paradigm; it proves that states can redefine power by prioritising regional peace, legal legitimacy, and sustainable energy development over nuclear armament, thereby providing a viable model for addressing interconnected global climate and nuclear threats.

Keywords: Nuclear proliferation. Nuclear energy. Climate change. Treaty of Tlatelolco. Latin America. Energy security.

RESUMO

Este artigo examina como as teorias de Relações Internacionais explicam a tomada de decisão dos Estados latino-americanos em relação à proliferação e à energia nuclear no duplo contexto das mudanças climáticas e dos persistentes arsenais nucleares globais. Por meio de uma análise documental

qualitativa, o estudo identifica categorias analíticas nas estruturas realistas, construtivistas e liberais para avaliar o comportamento do Estado. Os resultados demonstram que, ao contrário da dependência tradicional da dissuasão nuclear, a América Latina utilizou com sucesso o liberalismo institucional e a cooperação coletiva, conforme institucionalizados pelo Tratado de Tlatelolco. Esta abordagem regional prioriza a não proliferação, os regimes multilaterais e o direito internacional para mitigar dilemas de segurança e promover a energia nuclear pacífica. Por fim, a pesquisa conclui que a experiência latino-americana oferece um paradigma vital; prova que os Estados podem redefinir o poder priorizando a paz regional, a legitimidade legal e o desenvolvimento de energia sustentável em relação ao armamento nuclear, fornecendo, assim, um modelo viável para lidar com as ameaças climáticas e nucleares globais interconectadas.

Palavras-chave: *Proliferação nuclear. Energia nuclear. Mudanças climáticas. Tratado de Tlatelolco. América Latina. Segurança energética.*

1 INTRODUCTION

Nuclear proliferation continues to pose a significant threat to humanity and international security. Following the Cold War, nuclear powers implemented measures to reduce arsenals and ease tensions, exemplified by the 1991 Strategic Offensive Reductions Treaty (Woolf, 2010). Nevertheless, Russia and the United States still possess substantial nuclear arsenals, collectively exceeding 15,500 nuclear weapons (Scheffran, 2015). The continued existence of these stockpiles sustains a high risk of proliferation.

Latin America and the Caribbean set a precedent for regional peace and security through the Treaty of Tlatelolco, which prohibited nuclear weapons within the region. This treaty established Latin America as the first nuclear-weapon-free zone and demonstrated a regional commitment to legal and cooperative security approaches.

Emerging 21st-century threats have exacerbated the risks associated with nuclear proliferation. Research indicates that the use of 50 to 100 nuclear weapons could trigger catastrophic climate change (Scheffran, 2015, p.6). States must now consider both deterrence and environmental risks, as nuclear and climate crises threaten national and community stability (Masson-Delmotte *et al.*, 2019).

Scholars increasingly contend that nuclear and climate change threats are closely interconnected, complicating the development of effective policy responses (Pelopidas; Verschuren, 2023). Some research suggests that this interconnection could promote the global expansion of nuclear energy, potentially reducing proliferation risks while lowering carbon emissions (Claussen, 2021, p. 179; Egeland, 2025; Xia *et al.*, 2022).

This convergence prompts a central policy debate: How can national and multilateral policies leverage nuclear energy to promote non-proliferation, facilitate low-carbon transitions, and mitigate associated risks? Addressing this interdependence directly may enable policymakers and diplomats to identify effective strategies for confronting both challenges.

The emergence of illicit nuclear actors has introduced new and fragmented threats, as the exchange of nuclear materials becomes increasingly privatised. Consequently, states, governments, and unauthorised groups all participate in the formation of nuclear supply chains, further complicating non-proliferation efforts (Robayo *et al.*, 2014, p. 10).

State strategies regarding nuclear armament continue to prioritise military security, despite the emergence of new threats. Both nuclear and climate challenges originate from unsustainable development and a confrontational security paradigm that prioritises conflict over cooperation. This

underscores the tension between traditional approaches and the necessity for more comprehensive solutions.

Despite the growing recognition of the climate-nuclear nexus, current literature predominantly focuses on the deterrence strategies and great-power competition of the Global North. A significant theoretical gap remains regarding how Global South regions navigate these dual existential threats without relying on nuclear armament.

This study seeks to fill that gap by proposing a new paradigm: it demonstrates that the Latin American experience, deeply rooted in institutional liberalism and constructivist norm-building, offers a viable, alternative theoretical model. This contribution illustrates how states can redefine power through legal legitimacy and regional cooperation, moving beyond traditional realist frameworks to address interconnected global threats.

In this context, the central research question addressed in this article is: How can International Relations analysis explain the decision-making and actions of Latin American states concerning nuclear proliferation and nuclear energy, particularly in relation to climate change and persistent global nuclear arsenals?

To address this research question, this article—resulting from project INV-DER-4255, 'La protección de los conocimientos tradicionales en el marco de la implementación del Tratado de Cooperación Amazónica en Colombia,' funded by Universidad Militar Nueva Granada— employs qualitative documentary analysis to examine theoretical frameworks and identify analytical categories within the literature on nuclear weapons and energy.

The primary methodological objectives are: (1) to identify theoretical and conceptual elements from International Relations theories that explain state actions on nuclear issues; (2) to specify shared interests among Latin American states that promote cooperation and reinforce nuclear non-proliferation and peaceful nuclear energy; and (3) to highlight the challenges nuclear energy encounters as a clean energy source.

2 THEORETICAL REVIEW AND LITERATURE FRAMEWORK

To provide a theoretical basis, international relations theories explore how governments cooperate or compete on nuclear issues amid dual existential threats (Lotfian, 2007; Siddi; Silvan, 2024; Udum, 2017). These theories highlight opportunities for both regional and global cooperation to address multidimensional nuclear challenges (Kelly, 2014; Sneve; Smith, 2025).

Nuclear proliferation and non-proliferation, amid tensions and climate change, directly affect security. International Relations theories explain why states pursue nuclear power: for competition, security, national interest, peaceful use, cooperation, or soft power.

Traditional interstate concepts cannot address new threats like climate change and transnational issues. These intertwined threats require broader analysis.

Several international relations theories explain why states build nuclear arsenals: to deter rivals, pursue security, and compete for power (Agyekum *et al.*, 2025; Ali *et al.*, 2025). According to Waltz (1979), nuclear weapons fundamentally shift international power dynamics, transforming nuclear violence from an existential threat to a tool of security (Harrington, 2016, p. 92). These theories provide essential frameworks for understanding nuclear policies.

Realism shows divergent views on deterrence. Waltz (1979) argued that spreading nuclear weapons could boost stability by enhancing mutual deterrence, as new nuclear states would act cautiously. Meanwhile, current realist practice, seen in U.S. and other nuclear policies, rejects further proliferation and supports nonproliferation to prevent instability and arms races.

This author's openness to some proliferation, such as with Iran, contrasts with current policies favouring containment and disarmament. This debate reveals a core tension within realism over security in a nuclear world. Structural realism focuses on security and emphasises the "anarchy" of the international system. States act like "billiard balls," constantly in tension and conflict, regardless of regime type. All states act similarly because systemic pressures compel them to prioritise security above all else (Waltz, 1979).

In this context, Harrington (2016) argued that security is achieved by nuclear deterrence, which bolsters military capability. The distinction between violence and power clarifies nuclear strategy and unites realism with deterrence theory. This debate supports nuclear weapons as deterrence. American School IR scholars see deterrence as a realistic alternative to disarmament (Egeland, 2025).

Realists credit nuclear weapons for maintaining the Cold War's ' long peace.' They dismiss arms control initiatives such as the Nonproliferation Treaty, the Comprehensive Test Ban Treaty, and the Fissile Material Cut-Off Treaty as irrelevant (Shasko; Hurlbert, 2025).

The realist system structure defines the distribution of power. Nuclear deterrence relies on these conditions, pushing states toward self-help and leading to the Security Dilemma: states feel threatened as others gain power, driving arms races (Waltz, 1979), and reducing prospects for non-proliferation or peaceful nuclear energy.

This concept appears in Latin America, where Argentina and Brazil, each fearing the other would pursue nuclear arms, embarked on ambitious programs. Later, transparency and verification transformed mistrust into cooperative non-proliferation. Their example shows how regional security dilemmas can be solved through cooperation supporting non-proliferation.

Realists generally downplay the impact of multilateral nonproliferation efforts, doubting their effectiveness relative to nuclear deterrence. They often view the goal of nuclear disarmament as either idealistic or risky. Consequently, realists argue that actively preparing for nuclear war—by building and securing arsenals—is the most reliable way to prevent it (Harrington, 2016, p. 91-92).

Constructivists see norms and identities as central in explaining state behaviour. Preferences can shift, and nuclear perceptions evolve with institutions, values, and ideas (Maitre, 2018, p. 12). Nuclear abolitionists say nuclear weapons threaten human survival; abolition is both an ethical imperative and a norm (Harrington, 2016).

Such a moral stance has led some organisations and governments to explicitly attempt to delegitimise and stigmatise nuclear weapons and nuclear deterrence through a new and unequivocal legal instrument under the auspices of the United Nations (Ritchie, 2019, p. 1).

For constructivists, international society's change in values and ideas when existential challenges such as climate change and nuclear weapons arise requires pledges for transformative action (Pelopidas; Verschuren, 2023). However, in the political process, constructivists highlight serious dilemmas facing governments and others over energy and climate change policies that may well determine the fate of the planet (Findlay, 2010).

As a result, policy-makers and decision-makers have failed to address climate change and nuclear weapons challenges by claiming that overcoming structural obstacles and adversarial forces is

impossible, making it difficult to attain common goals in climate change and nuclear politics (Pelopidas; Verschuren, 2023, p. 3). Yet specific Latin American initiatives, such as the Treaty of Tlatelolco, the Agency for the Prohibition of Nuclear Weapons in Latin America and the Caribbean, and ongoing regional cooperation on peaceful nuclear technology, stand out as examples of agency, demonstrating how a shared commitment to non-proliferation and sustainability can overcome these barriers and offer a forward-looking pathway for other regions.

In addition, a modification of behaviour among States can derive from a change in the cost/benefit analysis of a situation, a change of preferences linked to genuine persuasion or a need to conform, the internalisation of a norm, or an attempt to identify with a group of states by adopting its behaviour (Maitre, 2018, p. 12). This analysis is cross-cutting across most perspectives in international relations, though with alternative preferences and outcomes (Udum, 2017).

A third theory, institutional liberalism, focuses on how international institutions, such as regimes, organisations, or treaties, alter state behaviour (Kelly, 2014). Faced with conflicts arising from anarchy in the international system, institutionalists believe that cooperation is both possible and rational, reaching agreements through international law to reduce the costs of using force. States use multiple tools, including monetary, social, and cultural ones, not just military ones (Keohane, 1984).

Due to such characteristics, liberals lean towards a non-proliferation stance as they would rather use multiple tools through collective mechanisms instead of the use of force and nuclear armament, which ultimately destroy global economic, social, and political stability (Jun; Cho; Lee, 2024; Lotfian, 2007; Mills *et al.*, 2014).

As a result of states or a group's preferences on non-proliferation, such mechanisms can be achieved through nuclear diplomacy as a key tool, which can find recognition as a contributor to global peace and boost its international standing, leading to these states improvement in their moral authority by promoting arms control and disarmament in the international forum, common elements of both institutional liberalism and constructivism.

Additionally, diplomatic efforts in nonproliferation crises demonstrate an international stance as negotiators, mediators, or facilitators when nonproliferation mechanisms aim to improve security and address serious security threats worldwide, testifying to a state's commitment to energy security and the global environment (Maitre, 2018, p. 12).

Both realist and liberal theories, when facing complex problems, hold that politics must assume 'responsibility'; their mechanisms and tools differ, with realists emphasising military strength, rearmament, and military intervention (SWP; GMF 2013). However, for liberals, "the underlying conflict management must give priority to civilian instruments; civilian and military means must remain more clearly separated."

For realists, there is a wide range of possible conflicts associated with the effects of climate change on rainfall and water scarcity; land use and food security; migration and refugee movements; extreme weather events and natural disasters; and vegetation and biodiversity, which can become conflict factors individually or in combination. They may trigger societal tipping points, leading to societal unrest, riots, violence, crime, and armed conflict (Udum, 2017).

Finally, tackling climate change also have different views among these theories, however, liberal, realist and constructivist agree that climate change may become a risk multiplier and cross-cuts complex crises, for instance ''climate change and human insecurity; vulnerable infrastructures and networks; economic and financial crises; social and political instability; environmental migration; climate change and violent conflict'' (Scheffran *et al.*, 2016, p. 11).

3 METHODOLOGY

This study employs qualitative documentary analysis to address the central research question. It examines how International Relations frameworks account for Latin American decision-making and actions concerning nuclear proliferation and energy, particularly within the context of climate change and persistent global nuclear arsenals. The methodology reviews relevant theories and delineates analytical categories present in the literature on nuclear weapons and energy.

The methodological design adopts a dialectical hermeneutic approach. This interpretive method moves beyond literal readings of official documents and academic texts to achieve a deeper understanding of underlying structural contexts, shifting power dynamics, and evolving normative intentions of states.

Through this hermeneutic lens, the research examines how traditional confrontational security paradigms, which emphasise military security, are challenged and redefined. The analysis highlights the need for broader solutions and cooperation in response to contemporary dual existential threats. Data collection was conducted through a systematic literature review utilising major academic databases, including Scopus, Web of Science, and Google Scholar.

To retrieve sources comprehensively and efficiently, the search strategy employed Boolean operators such as AND, OR, and NOT to combine, expand, and filter relevant concepts.

This search used keywords in both English and Spanish. It aimed to capture the full spectrum of global discourse and specific regional nuances. The main English keywords were “nuclear proliferation,” “nuclear energy,” “climate change,” “Treaty of Tlatelolco,” and “Latin America.” Their Spanish equivalents included “proliferación nuclear,” “energía nuclear,” “cambio climático,” “Tratado de Tlatelolco,” and “América Latina.” The strategy built search equations like (“nuclear energy” OR “energía nuclear”) AND (“climate change” OR “cambio climático”). This mapped the intersection of environmental challenges and security policies. The NOT operator excluded strictly technical engineering literature unrelated to political analysis.

To ensure analytical validity and robustness, the study employed theoretical and documentary triangulation. This process involved cross-referencing the foundational principles of structural realism, constructivism, and institutional liberalism with concrete regional frameworks, such as the Treaty of Tlatelolco, and with contemporary literature. By triangulating these theoretical perspectives with empirical realities, the methodology identifies shared interests among Latin American states. This approach promotes cooperation and reinforces nuclear non-proliferation and peaceful nuclear energy, while also highlighting the challenges nuclear energy faces as a clean energy source.

To ensure a rigorous analytical protocol, specific document selection criteria were established. The inclusion criteria focused on peer-reviewed articles, official treaty texts, and institutional reports published between 2010 and 2025 that explicitly address International Relations theories applied to the Latin American nuclear sector and climate change. The exclusion criteria discarded purely technical or engineering literature lacking political or theoretical analysis.

A total of 58 documents were ultimately selected for the final review. The analytical protocol involved a systematic coding procedure, in which the literature was categorised into three predefined theoretical analytical nodes: realist deterrence, institutional liberal cooperation, and constructivist norm-building. This structured coding allowed for an objective theoretical triangulation of state behaviour.

4 RESULTS

4.1 ANALYSING NUCLEAR WEAPONS VS NUCLEAR ENERGY THROUGH THE INTERNATIONAL RELATIONS LENS

The dynamics, actors, and processes through which nuclear issues are better analysed and understood in terms of politics and policy. However, complex issues can be better understood by applying concepts and categories from international relations theory (Van Buuren *et al.*, 2025). First, security as policy, politics, and means is a wide, cross-cutting concept that stems from a sense of threat arising from different sources (Çelik; Selçuklu, 2025). The nuclear issue is examined from different angles and captures the complicated realities, security concerns, and power dynamics of nuclear politics at the global level (Findlay, 2010, p. 3; Robayo *et al.*, 2014, p. 47; Sadekin *et al.*, 2019).

Based on our documentary analysis, the findings demonstrate a stark contrast between traditional realist paradigms and Latin American strategic behaviour. While the analysed realist literature heavily emphasises 'anarchy' and security dilemmas that drive arms races, our coding of regional treaties and policy documents reveals that Latin American states actively reject this self-help reliance. Instead, the analysis identifies a consistent regional preference for collective security frameworks over individual nuclear deterrence.

In such a context, states aim for ''preserving the survival of the nation, lacking the financial, technical or political possibility to acquire nuclear weapons on their own, to rely on extended deterrence'' (Maitre, 2018, p. 10). That led to the notion that nuclear weapons are a necessary and cheap tool to strengthen security, which has been the argument for the US nuclear modernisation as a deterrence strategy (Egeland, 2025).

Building a nuclear infrastructure for states within the dynamics of the international system depends on specific scenarios, conditions, and capabilities. One of them is whether a state's policy choices are based on territorial threats or an ongoing war, on the presence of allies that provide the state's security, and on whether the state is increasing in relative power (Bell, 2019). Another incentive to develop a nuclear arsenal, or to abstain from it, arises when states tend to equate nuclear military power with enhanced authority and stature on the international stage. Today, these same arguments tend to convince states to decide against nuclearisation'' (Maitre, 2018, p. 11).

Despite the risks of nuclearization, nuclear deterrence strategy emerges in a changing and complicated scenario in which nuclear weapons are used as the main defense tool for nuclear states when military responses take place, including missile defense, counter-proliferation, and nuclear weapons, thus fueling the arms race and undermining the political stability necessary for the controlled maintenance of nuclear weapons (Scheffran *et al.*, 2016, p. 7).

The importance of nuclear security in Latin America and the Caribbean is unquestionable, even with risks associated with operating nuclear plants and storing radioactive materials. Furthermore, in a region with permeable borders and subject to political challenges, international cooperation and effective coordination between countries are crucial to guarantee nuclear security (Alfaro; Rentería; Araújo, 2025).

Non-proliferation initiatives are concerned with preventing additional states from acquiring nuclear weapons. Mechanisms are built through 'global nuclear governance', which is referred to as the network of international treaties (Findlay, 2012, p. 2). The function of international organisations and non-nuclear states in non-proliferation efforts, such as arms control and disarmament initiatives, is also consistent with their pursuit of security interests (Pizarro; Macfarlane, 2026).

Thereby, states are compelled to protect their territory and their population from the use or the threat of use of nuclear weapons, and non-proliferation actions and mechanisms aim to lower risks by checking arsenals for non-state actors from accessing nuclear or radiological material that could potentially be used in a terrorist attack (Maitre, 2018, p. 10).

However, recent events such as the conflict between Ukraine, a non-nuclear country, and Russia, a nuclear power, have made nuclear weapons a tool claiming prominence in Russian and NATO defence doctrines. Thus, implying more "risks of nuclear war caused by accident, miscalculation or intent remain significant" (Scheffran *et al.*, 2016, p. 7).

The aforementioned scenarios and ''the fear of an apocalyptic nuclear attack" are the same arguments that advocates of nuclear deterrence use to justify maintaining a nuclear arsenal as essential to U.S. national security. (Harrington, 2016, p. 107). Precisely, the US plays a key role when establishing hegemony to control nuclear weapons and energy complexes based on Cox's description, and this is characterised by a ''set of identities, interests, understandings, and practices in the global politics of nuclear weapons whilst dismissing or sidelining others'' (Ritchie, 2019, p. 19).

The hegemonic dynamics of superpowers, driven by national security and power, in the international arena, on the other hand, lead to collective security arrangements by international institutions and less powerful states to preserve national sovereignty (Maitre, 2018, p. 11). Furthermore, national security is also pursued through collective action and cooperation among non-nuclear states and middle-range nuclear countries, as is the case with Latin American countries through the Agency for the Prohibition of Nuclear Weapons in Latin America and the Caribbean.

From above, different mechanisms and conceptions on national security have led to a paradox when studying the aims of nuclear weapons, in which we find ''two responses, first a complete logic of pursuing national security through violence. On the other hand, they leave all nation states more vulnerable than ever before'' (Harrington, 2016, p. 106).

International cooperation as a response has built a framework of nuclear weapons on a Ban Treaty, highlighting concerns with nuclear injustice and inequality, and also the central role played by the United States in nuclear ordering (Ritchie, 2019, p. 3).

However, the hegemonic control the United States exercises in setting the terms of global nuclear governance also shapes the trajectory of climate outcomes, as nuclear policy directly influences energy pathways, emissions, and international regulatory priorities. By controlling the global nuclear order, the US has had significant sway over which nations can access nuclear energy technologies, under what conditions, and with what safeguards, which, in turn, affects not just proliferation risk but also the scale and distribution of low-carbon nuclear energy deployment.

This linkage implies that debates about nuclear hegemony are inseparable from global emissions debates, as decisions over who governs nuclear technology access and norms ultimately help determine which regions can decarbonise their energy systems through nuclear power (Quiroga-Barriga *et al.*, 2025). Such a perspective enhances the article's interdisciplinary contribution by foregrounding how the structure of nuclear order may enable or constrain collective responses to climate change. Non-nuclear countries undertake such a position; however, middle powers focus the debate on security not only around deterrence, but also on the massive consequences of nuclear explosions in terms of health and the environment, which is a security threat in itself. (Maître, 2018, p. 10).

In such scenarios, the discussion on the constraints that states face when deciding to halt or not their nuclear projects, according to Robayo et al (2014), requires a combination of different factors related to transformations in three distinct areas:

First, a state's external security situation improves considerably or substitutes to nuclear weapons emerge which render them unnecessary; second, there is a change in the national political regime in which the market economy replaces central planning; third, there is a change in the national political regime in which the market economy replaces central planning; and fourth, new regulations emerge, both domestically and internationally, that diminish the appeal of nuclear weapons (Robayo *et al.*, 2014, p. 16)

Such factors are interconnected with emerging security threats in the 21st century, which opens a theoretical discussion, as major international organisations, for example, NATO and the UN, have identified climate change as a considerable source of insecurity, which substantially amplifies and multiplies existing threats (Egeland, 2025).

As new sources of insecurity emerge, nuclear security concerns prevent attacks on or illicit access to nuclear facilities and materials (Findlay, 2010, p. 2). Given these dynamics, cooperation plays a key role in addressing nuclear issues, whether for economic, security, or geopolitical purposes. The nuclear approach requires a critical analysis of the power relations that constitute nuclear order and to which the Ban Treaty poses a major challenge. There are important reasons for doing this, according to Ritchie (2019):

First, to understand contemporary global nuclear order and nuclear ordering anxiety; second, to understand the significance and limits of the Ban Treaty in the context of ideas of nuclear order; and third, to understand responses to both. The absence of serious engagement with hegemony in global nuclear politics is particularly surprising given its stratified nature (p. 2).

In power relations, nuclear and climate issues are ‘‘embedded in complex socio-economic structures, and both present onerous collective action problems’’ (Jayabal, 2025; Xiao *et al.*, 2025). A connection between nuclear politics and climate change concerns the prospects for climate cooperation in a world of nuclearised great power competition. (Quiroga-Barriga *et al.*, 2025). The power competition makes it more difficult to effectively implement cooperation mechanisms among nuclear superpowers and between non-nuclear countries for non-proliferation.

Such debate raises the question of whether “peaceful” and “military” nuclear capacities are somewhat tenuous; there is significant overlap between the infrastructure required for civilian nuclear energy production and for nuclear weapons acquisition (Jayabal, 2025). Especially as energy programs increase visibility of the country in the political and economic realms (Miller, 2017)

The variable energy security concerns national security and, in some cases, power competition, leading a country to adopt an active position in the international debate on the control of nuclear technologies and materials. For natural resource-deprived nations, access to nuclear energy is a key option for achieving energy security (Maitre, 2018, p. 10).

Different states use nuclear weapons to facilitate different foreign policy behaviours, such as aggression, expansion, steadfastness, independence, bolstering, and compromise (Bell, 2019, p. 24). The responses and behaviours based on national security and collective actions around a complex and dynamic nuclear order are part of the interaction of issues related to national interests and power politics, which are subject to modifications due to changes in their security, geopolitical, social, and economic conditions, and lead to various scenarios correlated to power competition and to deterrence strategies. On the other hand, the nuclear energy approach aligns more closely with the State's limited capabilities, energy security interests, and cooperation mechanisms.

4.2 COMMON INTERESTS AND FACTORS TO IMPROVE COOPERATION IN LATIN AMERICA TOWARDS NUCLEAR ENERGY

The most relevant instrument of international cooperation achieved by Latin American states is the Tlatelolco Treaty, aimed at denuclearising military zones through complete disarmament at a later stage and further developing peaceful nuclear programs, promoting cooperation in research, security, and nuclear regulation (Alfaro; Rentería; Araujo, 2025; Rodriguez, 2017). The only international organisation dedicated to nuclear non-proliferation and nuclear disarmament in Latin America and the Caribbean, the Agency for the Prohibition of Nuclear Weapons in Latin America and the Caribbean, was established as a control system and political instrument that coordinates demands at the international level of nuclear non-proliferation (Rodriguez, 2017).

The success of the Tlatelolco Treaty is important for creating mechanisms for verification, dispute resolution, and regional dialogue. The Treaty shows how persistent diplomacy and a focus on shared interests can overcome external pressures and internal mistrust. As such, Tlatelolco provides a policy template that illustrates the critical role of multilateral commitment, adaptation to regional contexts, and institution-building in the durable success of nuclear disarmament efforts beyond Latin America.

Its relevance is explained first as a mechanism that articulates a new foreign policy vision that collaboratively integrates the agendas of disarmament and sustainability. Secondly, the intrinsic ambiguity of the Nonproliferation Treaty and its interpretations has complicated how nuclear programs are approached among developed countries. This consists of a blurry line between acquiring technology for the development of atomic energy for peaceful purposes and nuclear proliferation (Robayo; Sahid; Villareal, 2014, p. 34). Consequently, it led to the Treaty's recognition of nuclear weapons by the international community (Rodriguez, 2017, p. 176).

Such purposes are articulated with the preservation of peace and security in the region for all signatory states of the Treaty. Specifically, when Latin American and Caribbean countries were operating amid widespread mistrust and military regimes, particularly in Argentina, Brazil, Chile, and Perú, this created a difficult context for negotiating a legal instrument related to the region's security (Rodriguez, 2017).

Precisely, Argentina and Brazil made the most progress in scientific research and technology acquisition. Other countries, such as Colombia and Peru, built some reactors for research purposes only, but never developed a nuclear industry (Robayo; Sahid; Villareal, 2014, p. 12). More specifically, 18 research reactors are located in seven countries in Latin America and the Caribbean: six in Argentina, four in Brazil, three in Mexico, two in Peru, one in Chile, one in Colombia, and one in Jamaica (Argüello, 2010).

Furthermore, Argentina and Brazil were seen by the international community as a victory for international law over the prevalence of military power as the main criterion of power on the international stage. This is ''why alarm bells rang when a large number of South American governments, known for their readiness to challenge the power of the United States in the region, leaned toward seeking greater nuclear participation in the international arena'' (Robayo; Sahid; Villareal, 2014, p. 20).

However, the United States policy is based on nuclear deterrence, which ultimately locks in a degree of hostility that obstructs cooperation'' (Egeland, 2025, p. 7). Furthermore, its influence determines the conditions under which other countries could develop their nuclear power capabilities by linking the purchase of reactors to regulations on safeguards procedures and spent nuclear fuel management. Latin American countries faced US opposition when defining transit and the zone of application of a ban on the Tlatelolco Treaty (Rodríguez; Mendenhall, 2022).

However, they limited maritime nuclear transit under the Treaty and established ocean governance rules in the 1970s. More than acceding to concessions in Tlatelolco, they reached consensus and took

strategic decisions that helped them promote their governance preferences (Rodríguez; Mendenhall, 2022).

To achieve a comprehensive prohibition of such weapons, the contracting parties committed to the use of nuclear material and facilities under their jurisdiction for peaceful purposes, and to negotiate multilateral or bilateral agreements with the International Atomic Energy Agency (Rodriguez, 2017, p. 175, 179).

Nuclear diplomacy surges as a key tool through the interaction among and between international actors to tackle strategic issues such as energy (Maitre, 2018, p. 8). Approaching such issues spans both realist and liberal perspectives, especially the latter, which focuses on nuclear norms and coordination rather than the use of force, on multilateralism rather than unilateralism, on interdependence, on shared responsibility for solving global problems such as conflict, and on energy production and distribution.

The concept of nuclear safety is closer to the liberal perspective, highlighting the potential of regional cooperation, in which the regulatory framework, industrial standards, and supply chain need to be considered, given the high degree of interaction and feedback among states (Alfaro; Rentería; Araújo, 2025). For instance, in efforts to tackle climate change, governments and decision-makers adopted legally binding international agreements, such as the 1992 United Nations Framework Convention on Climate Change and, subsequently, the Paris Agreement in 2015 (Pelopidas; Verschuren, 2023, p. 3).

Additionally, international cooperation within the nuclear nonproliferation framework must also address transnational threats posed by organised crime. Terrorist groups might gain the means through nuclear weapon capability through smuggling nuclear weapons or nuclear weapons material (Bunn, 2019).

Scheffran et al (2016) further describe the linkages between climate change and nuclear weapons, posing critical security risks. First, the chance of a nuclear weapon being used could create more fertile breeding grounds for nuclear terrorism, and could feed the ambitions among some states to acquire nuclear arms. Secondly, extreme weather events, environmental degradation, and major seismic events can directly impact the safety and security of nuclear installations.

On the other hand, the complex relationship between nuclear weapons development and energy, along with other catastrophic environmental risk factors, such as climate-induced nuclear vulnerabilities, requires identifying adaptation measures (Egeland, 2025, p. 11). Increasing environmental risks are leading to conflict factors such as food insecurity, poverty, and natural disasters. Hence, as resources become scarcer, wars loom over ‘‘raw materials, water, and fertile land, which is the case in the regions in the global South most affected by climate disasters. Conflicts fueled by the climate catastrophe thus also prevent possible adjustment strategies to this very crisis’’ (Claussen, 2019, p. 179).

In fact, the Centre for Climate and Security concluded in 2017 that climate insecurity could make nuclear war more likely: “Regions or countries destabilised by the effects of climate change, combining with other security threats, could make nuclear escalation and misperception risks even more likely’’ (Egeland, 2025).

Claussen (2021) also highlights that climate change not only intensifies existing conflicts, but wars and armed interventions are, at the same time, extremely harmful to the climate. Disarmament can therefore not merely reduce emissions from arms production, but also free up financial resources for climate protection, loss of biodiversity, and overexploitation of our livelihoods that have massive consequences on health and human security (Claussen, 2019).

Such challenges require global prevention and collective action; for example, the Paris Climate Agreement of 2015 is a historic example of joint action (Claussen, 2019). As for Latin America, Tlatelolco was a

worldwide pioneer in establishing a nuclear–weapon–free zone, making it possible for Latin American countries to work collectively for nuclear energy through peaceful means and security in the region. Those aims, such as peace and energy security, are mainly achieved through cooperation mechanisms and multilateralism, which are more closely aligned with the institutional liberal perspective.

One common element in the Latin American region is the high potential for renewable energy production, which is twice the global average, thanks to hydropower. On the other hand, the region's oil share is 10% higher than the global average. In terms of installed capacity, the Latin American system is characterised by a high share of hydroelectricity and several electrical interconnections that facilitate electricity exchange between countries (Alfaro, Rentería, Araújo, 2025).

Empirical data further supports this successful cooperative model through strong institutional performance. Notably, the Agency for the Prohibition of Nuclear Weapons in Latin America and the Caribbean has maintained strict compliance among all its 33 member states, ensuring over five decades of regional governance without a single proliferation breach.

Furthermore, comparative indicators reveal that countries like Brazil and Argentina have successfully developed civilian nuclear programs underpinned by rigorous bilateral verification mechanisms, specifically the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC). This robust policy implementation provides concrete evidence that regional integration and transparent governance can successfully decouple nuclear energy development from military proliferation.

4.3 CHALLENGES AND PROSPECTS FACING NUCLEAR ENERGY AS A RENEWABLE SOURCE OF ENERGY FOR COUNTRIES

Our analysis reveals that the transition toward nuclear energy in Latin America is not merely a technical shift, but a strategic policy decision deeply embedded in climate adaptation and energy security goals. Unlike traditional great-power approaches that often entangle civilian and military nuclear infrastructure, the evaluated documents indicate that Latin American countries systematically approach nuclear energy as a strictly peaceful tool for economic resilience and decarbonization, establishing a clear boundary maintained by regional governance.

The current consumption rate of fossil fuels is expected to decline sharply by 2100; thus, considering renewables and nuclear energy is part of the solution (Robayo *et al.*, 2014). The latter is distinguished not only for its high energy density and dependability but also for its ability to complement renewable energy sources, thus helping in the global progress towards a renewable energy future and to achieve net-zero greenhouse gas emissions, addressing the associated challenges (Jun; Cho; Lee, 2024).

As part of the solution, nuclear energy plays a key role in tackling climate change, as it aligns with the Paris Agreement and other climate goals. Furthermore, the International Atomic Energy Agency published a report on a wide range of aspects of nuclear power as a climate-mitigation technology (Muellner *et al.*, 2021).

The aforementioned is the starting point to make the case for nuclear energy, deemed as a ''low-carbon energy, which contributes on a large scale to a low-carbon economy and a green energy grid'' (Mathew, 2022). Second, nuclear-produced electricity, although under debate (Mez, 2012), is the path to choose to preserve the environment and avoid global warming; it is the second largest source of clean electricity, and third, it generates a high amount of electrical energy in one single plant (Sadekin *et al.*, 2019).

Compared to other power sources, there are safety and security risks for the environment from nuclear energy development, ''whether from nuclear reactors, nuclear materials in situ or in transit''

(Findlay, 2010, p. 2). However, nuclear energy continues to evolve, offering safer and more efficient power plants. Low greenhouse gas (GHG) emissions are among the factors countries that use or are introducing nuclear energy take into account. Security of fuel supply and competitive generation costs'' (Robayo *et al.*, 2014, p. 40).

The development of nuclear energy requires various factors, conditions, and elements to achieve a clean, sustainable energy supply. Such demands meet challenges and constraints: "first is that nuclear energy is too costly and stands in the way of increased renewable energy, and increased energy efficiency". This partially explains the apparent ''slowdown of or withdrawal from nuclear power in industrialised countries and their diminished interest in a further build-up'' (Scheffran *et al.*, 2016, p. 17).

In addition to mostly technical challenges in the prospect of nuclear energy, there are some political constraints, as nuclear energy faces scrutiny under the Nonproliferation Treaty framework and supplier requirements. That means nuclear fuel and other materials are heavily controlled, and countries with energy programs face higher costs associated with sanctions (Miller, 2017).

Distrust is politically instrumentalised; Bunn (2019) therefore stresses that nuclear energy may not be able to grow on the scale required unless governments and publics are confident that it will not contribute to the spread of nuclear weapons. Thus, managing the proliferation and disarmament implications of nuclear energy is necessary. This is further debated if there are non-state actors, such as terrorist groups, that could also cause a large reactor accident, for example, by destroying power and cooling systems or draining water from a spent fuel pool (Bunn, 2019, p. 6).

Therefore, the need for a ''regulatory framework, industrial standards, and supply chains integrated into an efficient structure capable of feedback" is crucial to achieving competitiveness (Alfaro; Rentería; Araújo, 2025, p. 22). Another constraint facing nuclear energy at that scale would place unprecedented demands on global systems for verification, control, and security for weapons-usable nuclear materials (Bunn, 2019).

The above is particularly problematic, as many countries do not have the trained personnel, regulatory structures, or other elements required to safely launch a nuclear energy program today, due to regulatory delays or inclusion in evolving grids (Bunn, 2019, p. 7). Even though nuclear power has the potential to be a low-carbon technology, cost reduction is seen as the main obstacle. Similarly, it is noted that nuclear expansion strategies are not practicable due to resource limitations (Muellner *et al.*, 2021, p. 9).

In economic terms, if nuclear power aims for success, which means growing on a large scale, it requires being economically competitive compared with other energy sources. This includes fulfilling criteria such as low-cost, government-backed financing for state-owned nuclear companies, stable nuclear electricity prices, and a market with little competition from cheap natural gas. However, in many markets, new nuclear plants are uncompetitive today, and additional incident risks ultimately lead to safety issues (Bunn, 2019).

Despite many constraints and risks, there is a growing energy demand to sustain economic development. Therefore, in early 2008, it publicly launched the new national strategic plan, striving to increase nuclear power generation capacity and ensure self-sufficiency in nuclear fuel production, providing 100% of domestic demand (Robayo *et al.*, 2014, p. 19).

The interest of States and economic stakeholders wishing to develop nuclear energy in their countries is followed by a ''strong incentive to influence the international norms ruling how they can access, develop, and sell equipment and technologies. In specific cases, they hope to secure assistance and

foreign cooperation and resort, therefore, to diplomatic tools to defend their interests'' (Maitre, 2018, p. 11).

This works under the non-proliferation logic, as Miller (2017) claims the relationship between nuclear energy and proliferation programs is ''overstated. Thus, more reasons why pursuing energy programs would actually limit the odds of proliferation. First, by engaging in any nuclear program, you increase interest and visibility of your country, which makes it more likely that weapons programs will be discovered. Second, this attracts sanctions, increasing the cost of your program.

5. DISCUSSION

Our findings confirm that a unique synthesis of energy security and climate mitigation goals drives the Latin American transition toward peaceful nuclear energy. By implementing robust public policies and regional compliance mechanisms, these states effectively utilise nuclear power to diminish environmental damage while shielding their energy matrices from geopolitical volatility. This distinctly separates the Latin American approach from regions locked in traditional deterrence-based paradigms, proving that economic development and non-proliferation can be mutually reinforcing.

As a result, several nuclear countries have decided to expand their installed capacity, and new countries are evaluating nuclear power for electricity production. In Latin America, as shown in a recent report from the International Atomic Energy Agency, ten countries Bolivia, Chile, the Dominican Republic, Ecuador, El Salvador, Haiti, Jamaica, Peru, Uruguay, and Venezuela- have requested the agency's support to initiate nuclear activities aimed at future electricity generation (Robayo; Sahid; Villareal, 2014, p. 18).

Besides energy security, economic development is a key aspect of national interest. Wang *et al.* (2023) explored whether nuclear energy can promote economic growth without increasing carbon emissions by examining the impacts of coal, oil, natural gas, and renewable energy (Sadekin *et al.*, 2019). Both nuclear energy and renewable energy can curb carbon emissions. For instance, in Canada, Finland, Russia, Slovenia, South Korea, and the United Kingdom, nuclear energy reduces carbon emissions more significantly than renewable energy. This means that nuclear and renewable energy could boost economic growth, offering nuclear-power countries an option to pursue economic growth without increasing carbon emissions.

Nuclear power developments in Latin America feature two countries with a central position in nuclear technology: Argentina and Brazil, which have the most advanced nuclear programs and have helped countries in the region develop their own. Mexico is also at an advanced stage of development. Chile, Colombia, Peru, Uruguay, and, historically, Cuba are at an intermediate level of nuclear development. There are 15 research reactors in operation in the region, and 7 have been decommissioned or are in the process of being decommissioned, or are in temporary, extended, or permanent shutdown (Alfaro; Rentería; Araújo, 2025, p. 3).

The future of nuclear energy depends on political, economic, and environmental factors. Politically, nuclear energy may not be able to grow on the scale required for it to be an important contributor to reducing climate change unless governments and the public are confident that such growth will not contribute to the spread of nuclear weapons (Bunn, 2019, p. 3).

For countries to invest in nuclear plants, attractive subsidies, loan guarantees, tax exemptions, and other incentives are required (Robayo *et al.*, 2014, p. 55). Furthermore, in the context of Latin America, it is worth considering domestic technological capacities as well as the potential for importing technology. Thus, the growth of nuclear energy globally will ultimately depend on the confluence of decisions by governments, electricity utilities, the nuclear industry, private and institutional investors, and

international organisations (Findlay, 2010, p. 1). This ultimately leads to arguments over the relative merits of competitive versus clean energy sources, in which nuclear power is weighed against political, economic, or environmental risks.

6. CONCLUSIONS

The complex debate around the use of nuclear weapons for military purposes and nuclear energy for peaceful means requires identifying elements and factors that add to a deeper understanding of the behaviour of states, as the main driver actors in the international system, facing the dilemma in the use of nuclear power as growing and multidimensional security threats arise.

Looking ahead, a key challenge for scholars and policymakers is to consider what forms of international cooperation or institutional innovation could extend the Tlatelolco model to other regions facing nuclear and climate risks. Addressing this question may lay the groundwork for new approaches that combine non-proliferation, energy security, and global climate action, further magnifying the influence and relevance of the Latin American experience.

Decision-making and actions in international politics take into account various elements and categories provided mainly by realist and liberal theories of international relations, offering a more complete grasp.

The non-proliferation debate between nuclear weapons and nuclear energy in the case of the Treaty of Tlatelolco confirms that state decisions on nuclear matters cannot be understood in isolation from levels of power, the definition of national interest, the security environment, and the structure of the international system.

From a realist perspective, the state acts as a rational actor focused on its national security, survival, and position in the international system. In this sense, developing nuclear arms is closely linked to its position in the international system. It appears as a strategy associated with perceptions of threat and the power equilibrium, pursued through nuclear deterrence. Under this logic, nuclear weapons serve as instruments of strategic power and geostrategic affirmation, notably in environments of high rivalry or structural asymmetries; thus, the incentive to proliferate is strengthened.

However, the Latin American case study shows that power is not expressed exclusively in military terms. The Latin American experience reveals an alternative approach to security, grounded in the institutionalisation of nuclear non-proliferation as a collective mechanism for regional peace. The Treaty of Tlatelolco not only limited proliferation in the region but also redefined the exercise of power through collective action aligned with the principles of institutional liberalism. In this vision, international cooperation, international law, and the construction

In this vision, international cooperation, international law, and the construction of multilateral regimes enable the mitigation of security dilemmas and the building of mutual trust in national security based not on nuclear deterrence but on regional integration, stability, and international legitimacy to build a zone of peace, which ultimately relies on political conditions as well.

This decision is associated with conceptual elements of liberalism, such as normative factors, including observance of international law and commitment to non-proliferation, and organisational factors of the regional system, due to the absence of high-intensity interstate rivalries and restrictions in economic and technological power to sustain nuclear weapons programs. As a result, the region has focused its capabilities on nuclear energy programs for power generation, scientific research, and technological development to strengthen energy security and respond to the growing demand for clean energy.

From the Latin American case, the non-proliferation framework indicates that interdependence and institutions shape states' preferences. The Treaty of Tlatelolco serves as a paradigm for how international law can redefine strategic incentives, reduce the likelihood of nuclear proliferation, and promote technical cooperation in nuclear energy. In this context, international legitimacy and the prestige derived from regulatory compliance also become forms of power.

To summarise, the debate over nuclear weapons and nuclear energy in Latin America confirms that the orientation of nuclear programs depends on a combination of structural and normative variables: economic power, scientific and technological capacity, the definition of national interest, perceptions of threats, and geopolitical integration. Thus, Latin American countries are much less likely to resort to nuclear proliferation for power and security aims; liberal theory illuminates the viability of cooperation, institutionalisation, and regional peace.

The case of the Treaty of Tlatelolco shows that, under certain historical and regional conditions, states can revise their conception of power, prioritising cooperation and energy development over nuclear deterrence. Latin America thus constitutes a normative process in which nuclear non-proliferation does not represent strategic weakness. Rather, it is an alternative for exercising influence and prestige in the international system, grounded in legal legitimacy, regional cooperation, and a commitment to peace and sustainable energy security.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

IV: Conceptualisation, Methodology, Data Curation - Writing - Original draft preparation, Visualisation, Investigation, Data curation. ML: Data curation - Writing - Reviewing and Editing.

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STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

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The Andean chakra as a socioecological system of Buen Vivir for food sovereignty

A Chakra Andina como sistema socioecológico do Bem Viver para a soberania alimentar

Charles Cachipuendo [1]

Erika Churuchumbi [2]

Sergio Pilataxi [3]

[1] *Doctorate of Science in Agricultural Systems Engineering, Professor and Researcher, Environmental Science Research Group, Universidad Politécnica Salesiana, Quito, Pichincha, Ecuador*
E-mail: ccachipuendo@ups.edu.ec

[2] *Master's Degree in Water Resources, Environmental Science Research Group, Universidad Politécnica Salesiana, Quito, Pichincha, Ecuador*
E-mail: churuchumbi@ups.edu.ec

[3] *Agricultural Engineer, Universidad Central del Ecuador, Quito, Pichincha, Ecuador*
E-mail: zherghio@hotmail.es

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ABSTRACT

Agricultural production systems developed by Indigenous peoples in the Andes respond to mountain ecosystems characterised by high climatic, edaphic, biological and cultural diversity. This study analyses the agronomic and sociocultural practices of the Andean chakra in communities of the Ecuadorian highlands that produce food under the paradigm of *Sumak Kawsay* and the symbolism of the Chakana. The research adopted a mixed-methods approach across three phases: territorial characterisation through GIS georeferencing, fieldwork comprising 24 surveys, 16 semi-structured interviews and 3 focus groups in six provinces of the north-central highlands, and data analysis using NVivo 14 and SPSS 30. The results show that the chakra constitutes a family-based agricultural and livestock system underpinned by resilient ancestral knowledge and technologies, with an average of 25 cultivated species per productive unit. Among the main practices identified are crop association, conservation of native seeds, organic soil management, efficient water use and the application of phytomedicine. These practices strengthen biodiversity and reciprocity between society and nature through the communal work known as the minka. Likewise, the great majority of the chakras studied are managed mainly by women, who ensure food sovereignty, the transmission of knowledge and the conservation of agrobiodiversity. It is concluded that the Andean chakra is a current and adaptive strategy of sustainable agriculture, whose preservation requires intercultural public policies, recognition of women's work, and longitudinal and comparative lines of research across the Andes.

Keywords: Agrobiodiversity. Indigenous food systems. Ancestral knowledge. Community-based agriculture. Socioecological resilience. Andean cosmovision.

RESUMO

Os sistemas de produção agropecuária desenvolvidos pelos povos originários dos Andes respondem a ecossistemas montanhosos caracterizados por elevada diversidade climática, edáfica, biológica e cultural. Este estudo analisa as práticas agronômicas e socioculturais da "chakra" andina em comunidades da serra equatoriana que produzem alimentos sob o paradigma do "Sumak Kawsay" e sob o simbolismo da "Chakana". A pesquisa adotou uma abordagem mista em três fases: caracterização territorial por meio de georreferenciamento no SIG, trabalho de campo com 24 questionários, 16 entrevistas semiestruturadas e 3 grupos focais em seis províncias da serra centro-norte, e análise de dados com NVivo 14 e SPSS 30. Os resultados evidenciam que a "chakra" constitui um sistema agropecuário familiar sustentado em saberes e tecnologias ancestrais resilientes, com uma média de 25 espécies cultivadas por unidade produtiva. Entre as principais práticas identificam-se a associação de cultivos, a conservação de sementes nativas, o manejo orgânico do solo, o uso eficiente da água e a aplicação de fitomedicina. Essas práticas fortalecem a biodiversidade e a reciprocidade entre a sociedade e a natureza por meio do trabalho comunitário da "minka". Da mesma forma, a maioria das "chakras" estudadas é gerida principalmente por mulheres, que garantem a soberania alimentar, a transmissão de conhecimentos e a conservação da agrobiodiversidade. Conclui-se que a "chakra" andina é uma estratégia vigente e adaptativa de agricultura sustentável, cuja preservação requer políticas públicas interculturais, reconhecimento do trabalho feminino e linhas de pesquisa longitudinais e comparativas nos Andes.

Palavras-chave: *Agrobiodiversidade. Sistemas alimentares indígenas. Saberes ancestrais. Agricultura comunitária. Resiliência socioecológica. Cosmovisão andina.*

1 INTRODUCTION

The contemporary capitalist model of development has proven to be environmentally and socially unsustainable, as expressed in climate change, environmental pollution, water scarcity, food insecurity and the rise of global consumerism (Fernández; Gutiérrez, 2013; García, 2021; Whitmee *et al.*, 2015). In the agricultural sector, this crisis is expressed in the expansion of monocultures and the intensive use of agrochemicals and fossil fuels, practices that degrade soils, reduce biodiversity and deteriorate ecosystem services (Altieri; Nicholls, 2020; Brunet; Böcker, 2015), generating a growing debate about the need to move towards more resilient, diversified and socially just production models.

Conventional agriculture has been oriented towards maximising productivity through synthetic fertilisers, pesticides and modified seeds, with negative impacts on human health, ecosystems and food resilience (Ceccon, 2008; Fletcher, 2015). In response, international organisations promote sustainable systems based on the conservation of biodiversity and organic soil management (FAO, 2015; Rizo *et al.*, 2017). Agroecology proposes a break by conceiving the agricultural system as a social construction that integrates peasant knowledge (Altieri; Nicholls, 2020; Gliessman, 2015), while the Andean cosmovision incorporates reciprocity with the Pachamama (Escobar, 2014; Gudynas, 2011), which is absent from the conventional model. There remains a risk that technical solutions may render invisible the knowledge and practices of Indigenous peoples, with no consensus yet on how to reconcile productive efficiency with ancestral epistemologies.

In this context, agroecology integrates scientific knowledge and traditional knowledge to design sustainable agricultural systems, understanding traditional systems as reservoirs of ecological knowledge that enable environmental adaptation, conservation of agrobiodiversity and food sovereignty.

In Ecuador, these discussions gain relevance with the constitutional recognition of Buen Vivir or Sumak Kawsay, which proposes a harmonious relationship between human beings and nature and respect for the rights of the Pachamama (Cruz, 2018), based on reciprocity, complementarity and balance.

Among these practices, the Andean chakra stands out as an ancestral agricultural system that combines biological diversity, community organisation and Indigenous cosmovision in food production. Beyond its productive function, it reproduces the family unit and articulates ecological, community and spiritual knowledge in the management of agricultural biodiversity (Cachipuendo *et al.*, 2025; Confederación del Pueblo Kayambi, 2021; Herrán, 2017; Tamayo; Alegre, 2022).

Thus, in the face of the global socio-environmental crisis, studying the Andean chakra makes it possible to explore how the agronomic, cultural and spiritual practices of Indigenous communities contribute to the construction of more sustainable and resilient agricultural models (Altieri; Nicholls, 2020; Gliessman, 2015). This study analyses these practices in the production of healthy food, with the aim of understanding their contribution as a sustainable agriculture strategy for rural communities in the centre and north of the Ecuadorian Andes, considering the following theoretical framework.

Buen Vivir in food production

From the Andean cosmovision, producing food does not mean dominating the land, but rather being part of it in order to "nurture life" in reciprocity with the Pachamama (Acosta, 2015; Hidalgo *et al.*, 2014). Agriculture is conceived as a comprehensive practice that articulates political, spiritual, social and ecological dimensions oriented towards collective wellbeing. The Andean chakra expresses this paradigm by integrating biodiversity, family cooperation, organic soil management and gender equity (Confederación del Pueblo Kayambi, 2021; Herrán, 2017), revaluing the solidarity economy (Cachipuendo *et al.*, 2025).

Andean cosmovision and the alli mikuy

In the Andean cosmovision, the territory is a living system. The Chakana, or Andean cross, symbolises this structure of interrelationships and guides territorial organisation through ancestral knowledge (Campohermoso *et al.*, 2015; Confederación del Pueblo Kayambi, 2021). The chakra is configured as a biosystem oriented towards the nurturing of life, characterised by the diversified association of crops, the conservation of native seeds and the avoidance of agrochemicals (Herrán, 2017; Tamayo; Alegre, 2022), incorporating rituals linked to the alli mikuy, the collective right to healthy food. The family is the organisational core, driving practices such as the minka (Cachipuendo *et al.*, 2025).

Interculturality and the dialogue of knowledges

Contemporary Andean agriculture integrates ancestral and scientific knowledge in soil management, seed selection and agricultural calendars, without losing Indigenous cultural identity (De Sousa Santos, 2009; Escobar, 2014). In the chakra, knowledge is transmitted through communal experience, orality and spirituality (Churuchumbi, 2020), strengthening peasant autonomy and the decolonisation of agricultural knowledge (Salinas, 2019), in pursuit of complementarity between science and local wisdom (De Sousa Santos, 2009; Dubey *et al.*, 2026; Roos, 2025).

The chakra and the production of healthy food

The chakra is a comprehensive system of annual provisioning and intergenerational transmission of knowledge, understood as a living school of communal learning (Almeida *et al.*, 2021). It contributes to the family economy through bartering or agroecological fairs (bioferias) (Conejo, 2020; Monteros, 2020;

Requelme *et al.*, 2019). Its crop diversity optimises the use of soil, water and solar energy (Zambrano *et al.*, 2018), integrating food, medicinal and ornamental plants that strengthen food sovereignty (Confederación del Pueblo Kayambi, 2021; Herrán, 2017).

Socioecological resilience and adaptation to climate change

The chakra is a socioecological system that is resilient to environmental, health and economic crises (Altieri; Nicholls, 2020; Cachipuendo *et al.*, 2025). Its structure is related to the levels of Hanan Pacha, Kay Pacha and Uku Pacha, an expression of Andean ecological complementarity (Tamayo; Alegre, 2022). At each level, species adapted to different climatic conditions are cultivated, conserving seeds and water essential for food sovereignty (Altieri; Nicholls, 2020; Koohafkan; Altieri, 2011), which strengthens climate resilience and soil fertility. The land is understood as a living subject in a relationship of reciprocity (Toledo; Barrera-Bassols, 2008), such that the chakra articulates ecological knowledge, community organisation and biocultural diversity in favour of the continuity of life (Escobar, 2014; Gliessman, 2015).

2 METHODOLOGY

2.1 STUDY AREA

The research was carried out in rural communities in the provinces of Chimborazo, Tungurahua, Cotopaxi, Pichincha, Imbabura and Carchi, in the Andean region of Ecuador (Figure 1). These provinces are home to Kichwa Indigenous peoples such as the Karanki, Otavalo, Kayambi, Chibuleo, Puruwá and Panzaleo, whose productive practices maintain traditional agricultural systems based on the Andean chakra.

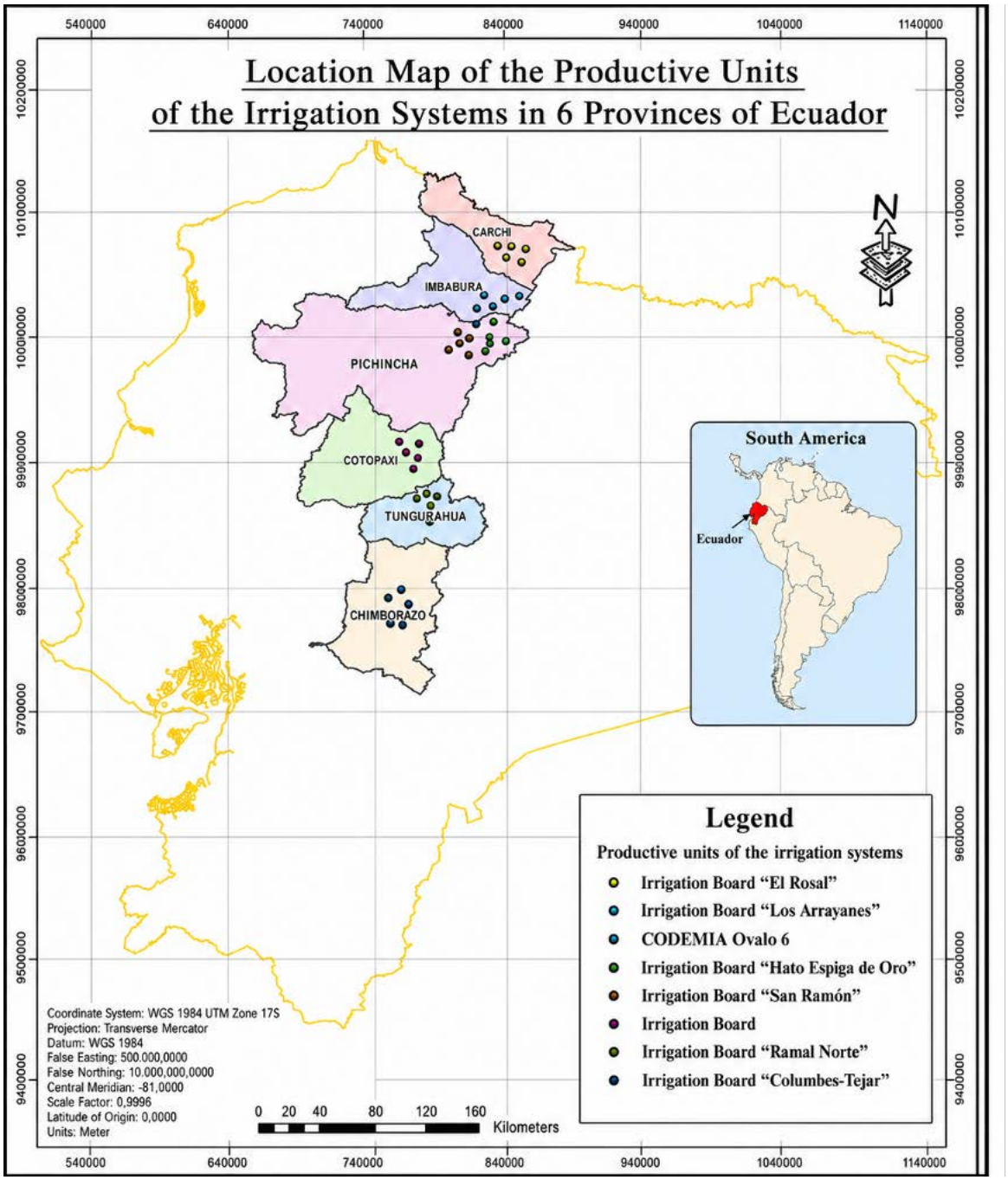

Figure 1 – Study area and location of the Andean chakras studied

Source: The authors (2026).

The study areas are located between 2,100 and 3,500 m.a.s.l., with a cool temperate climate (9°C to 16°C) and average annual rainfall of between 1,721 mm and 2,877 mm, giving rise to mountain ecosystems with high ecological diversity and agrobiodiversity (Climate, 2022). These conditions have favoured diversified agroecological systems based on ancestral knowledge of soil management, seed conservation and efficient water use.

2.2 METHODOLOGICAL DESIGN AND PROCEDURE

The research was carried out using an empirical, descriptive, analytical and participatory approach, combining qualitative and quantitative methods with leaders, producers and families who are guardians of chakras. Fieldwork was conducted between 2022 and 2024, in three phases.

First phase: contextual diagnosis

A documentary review was carried out of agroecological projects, rural development programmes and previous studies on Indigenous production systems in the north-central highlands. In addition, nine semi-structured interviews were conducted with key informants (NGO technicians, local government representatives, community leaders and academics), which made it possible to identify previous experiences and organisational processes related to chakra management.

Second phase: participatory fieldwork

24 surveys were administered to producers with active chakras, selected through purposive convenience sampling, and 16 semi-structured interviews were conducted with community leaders, women farmers and seed guardians, taking into account gender, generational and territorial diversity.

The questionnaire was organised into four sections: socioeconomic characteristics of the household; agronomic management of the chakra; cultural and spiritual practices; and marketing and food sovereignty. The instruments were validated through a pilot test with four producers not included in the sample and reviewed by a panel of three specialists in agroecology and Andean ethnobotany.

Fieldwork was complemented by three focus groups (northern highlands, central highlands and the transition zone), each with 8 to 12 members, with gender representation (at least 50% women), generational diversity and different community roles. The sessions were recorded with consent and transcribed for analysis. In addition, community discussions and participant observation were carried out during agricultural workdays, mingas and agroecological fairs, recorded in a structured field diary with predefined categories and free-form notes.

Third phase: systematisation and analysis

The chakras were georeferenced using GIS, employing QGIS 3.28 and ArcGIS 10.8, in order to identify their territorial distribution and the agroecological characteristics of the landscape. Qualitative data were processed through thematic content analysis using NVivo 14, and quantitative data using SPSS 30, by means of descriptive statistics, absolute frequencies and Spearman correlations between key ordinal variables (adoption of ancestral practices, crop diversity, use of compost and participation in exchange networks). Given the sample size, the results are presented as descriptive frequencies and trends, without statistical generalisation. Triangulation between sources, methods and analytical techniques strengthened the validity and reliability of the results.

2.3 ETHICAL CONSIDERATIONS

The study followed the ethical principles of the Declaration of Helsinki and ILO Convention 169 on Indigenous and Tribal Peoples. The Universidad Politécnica Salesiana does not have an institutional Ethics Committee; however, the study was endorsed by the representative organisations of the participating peoples, including the Confederation of Pueblo Kayambi, within the framework of the Free, Prior and Informed Consent (FPIC) protocol. Participants were informed of the objectives, methods and scope, and gave voluntary consent. Data were anonymised using alphanumeric codes, and the results were

shared with the communities through assemblies prior to publication. The authors declare that the research involved no risk to participants and no clinical data, minors or sensitive information.

3 RESULTS AND DISCUSSION

This section presents the results on the Andean chakra as a system for the production of healthy food: agronomic practices and biodiversity management; community dynamics, highlighting the minka and the role of women; and its contribution to food sovereignty and Andean socioecological resilience.

Given the small sample size, the quantitative data are presented as descriptive frequencies and trends, without statistical representativeness. Qualitative data from 16 interviews and 3 focus groups complement the findings, cited with anonymised codes.

3.1 BUEN VIVIR AGRICULTURE AND THE CHAKRA AS A SOCIOECOLOGICAL SYSTEM

The results show that agricultural production in the Indigenous communities of the north-central highlands of Ecuador is organised around the paradigm of Buen Vivir (Sumak Kawsay), in which the chakra constitutes the central family productive unit. This system integrates crop diversity, organic soil management and relationships of reciprocity between the family, the community and nature.

In the territories studied, the coexistence of different agricultural approaches is observed. On the one hand, productive systems based on ancestral knowledge and the Andean cosmovision are maintained; on the other, contemporary approaches such as agroecology, biodynamic agriculture and regenerative agriculture are incorporated (Table 1).

Table 1 – Unit of study of Buen Vivir and sustainable agriculture approaches

Criteria/ Approaches	*Andean Chakra Agriculture*	*Agroecology*	*Biodynamic Agriculture*	*Regenerative Agriculture*
Knowledge base	Ancestral knowledge and Andean cosmovision (cosmovivencial)	Integration of local and scientific knowledge; systemic and ecological approach	Anthroposophy, agricultural spirituality and lunar cycles	Ecological science, adaptive management and innovative practices
System structure	Geo-biodiverse systems: chakras, ajás, terraces, gardens; integrated into the landscape	Diversified and integrated systems: gardens, farms, mixed holdings	Self-sufficient farms with cyclical, closed-loop design	Systems in ecological transition with a regenerative approach to soil and ecosystem
Relationship with the environment	Sacred territory: connection with family, community and the cosmos	Ecological approach at multiple scales: plot, farm, watershed	Astral rhythms, lunar calendars, respect for subtle energies	Restoration of degraded landscapes, ecological efficiency
Productive objectives	Family food, reciprocity, food sovereignty	Food security and sovereignty, resilience, fair trade	Energetic balance, health of the agricultural ecosystem	Soil regeneration, carbon sequestration, adaptation to climate change
Approach to soil	Soil as a living being linked to the Pacha Mama	Natural fertility, compost, green manures, ecological management	Dynamisation of the soil with biodynamic preparations and ritualised compost	Active soil regeneration: vegetation cover, soil biology, erosion control

Criteria/ Approaches	Andean Chakra Agriculture	Agroecology	Biodynamic Agriculture	Regenerative Agriculture
Scale and context	Local and communal, adapted to the territory and cosmovision	Local to regional, adaptable to multiple scales	Medium scale with specific technical and ritual requirements	Variable scale, adaptable to the ecological and economic context

Source: Altieri and Nicholls (2020), Herrera-Sánchez (2023) and Requelme et al. (2019).

The field analysis also made it possible to identify two main types of chakra: the traditional chakra, based on ancestral knowledge and oriented mainly towards subsistence production, and the modern chakra, which incorporates contemporary technologies and crops oriented towards the local or regional market (Table 2).

Table 2 – Characterisation and evolution of the Andean chakras

Criterion	Traditional Chakra	Modern Chakra
Knowledge base	Ancestral knowledge, orally transmitted across generations.	Integration of traditional knowledge with technology and contemporary agroecological approaches.
Crop diversity	High biodiversity with native and medicinal species.	Maintains diversity, but incorporates commercial species (e.g. roses, fruit trees, vegetables).
Destination of production	Mainly subsistence and communal bartering.	Mixed: subsistence and production for local markets or agro-export.
Use of technology	Manual tools and traditional techniques adapted to the environment.	Implementation of modern technologies: technified irrigation, solar energy, genetic improvement.
Relationship with nature	Based on reciprocity with the Pacha Mama and respect for natural cycles.	Focus on efficiency and optimisation of natural resources (soil, water, energy).
Organisation of space	Adaptation to the natural landscape following symbolic, spiritual and ecological logic.	Technical-productive design adapted to the space, with functional efficiency.
Climate resilience	Based on biological diversity and local ecological knowledge.	Strengthened through adaptation technologies and resource management.
Cosmovision	Strongly linked to Andean spirituality and Buen Vivir.	Still present but combined with market approaches and agricultural modernisation.

Source: The authors (2026).

Thus, the Andean chakra can be interpreted as a complex socioecological system, in which ecological, cultural and economic dimensions interact in food production. Unlike other contemporary agricultural approaches, its productive logic is not focused solely on productive efficiency, but on nurturing life in reciprocity with nature, a fundamental principle of Buen Vivir (Altieri; Nicholls, 2020; Cachipuendo; Pilataxi, 2025; Gudynas, 2011).

This finding is consistent with studies indicating that traditional agricultural systems constitute reservoirs of local ecological knowledge and can contribute significantly to territorial sustainability (Toledo; Barrera-Bassols, 2008).

The empirical data obtained in this study confirm and extend the propositions of Altieri and Nicholls (2020) on agroecological resilience: the average of 25 species per productive unit and the crop-livestock

integration observed in the chakras studied are consistent with the functional diversity attributes that these authors identify as determinants of resilience in Andean agroecosystems. However, the findings also reveal a dimension that conventional agroecology, as framed by Gliessman (2015), does not fully integrate: the chakra is not only an ecological management system, but a space for nurturing life articulated to the Andean cosmovision, in which the spiritual dimension —rituals, the agro-festive calendar, the relationship with the Pachamama— is not a cultural complement but a constitutive part of the productive system. This finding engages with the epistemology of the South proposed by De Sousa Santos (2009): the ancestral knowledge of the chakra is not a lesser form of knowledge to be validated by Western science, but a system of knowledge with its own logic that produces tangible agroecological results. The presence of these practices in every province studied, even under pressure from agricultural modernisation, suggests that the epistemological complementarity proposed by De Sousa Santos is not merely a normative horizon, but a reality already operating in Andean territories.

Recognising the chakra as a socioecological system can contribute to the design of rural development policies with an intercultural approach, capable of integrating ancestral knowledge and agroecological practices into strategies for food security, biodiversity conservation and adaptation to climate change in Andean territories.

The coexistence of traditional and modern chakras identified in this study (Table 2) nonetheless raises critical questions that go beyond typological description. The transition towards the modern chakra is not a neutral process: it involves trade-offs between productive efficiency and cultural continuity that deserve more in-depth discussion. The incorporation of roses, technified irrigation, and market crops—defining features of the modern chakra—generates monetary income, but may erode the logic of subsistence and reciprocity that underpin the system. The loss of the principle of alli mikuy (the collective right to healthy, culturally appropriate food) and the substitution of the minka by paid individual labour are dimensions of this transition that do not appear in the quantitative data, but which emerge as latent risks. In terms of Toledo and Barrera-Bassols (2008), the modernisation of the chakra may represent a form of extinction of biocultural memory, in which the loss is not only of species or varieties, but of the relationships, meanings and practices that articulate the system.

In this productive process, all family members participate actively: boys, girls, young people, women, men and older adults, who are regarded as living sources of ancestral wisdom (Figure 2).



Figure 2 – Distribution scheme of the Andean chakra

Source: Cachipuendo et al. (2025).

The **traditional chakra** is a system for producing healthy food, aligned with the paradigm of Buen Vivir and aimed at strengthening the socioecological resilience of Andean communities. This system maintains a high diversity of crops such as maize, beans, broad beans, potatoes, lupins (chochos), quinoa, squash (zambo), among others (Confederación del Pueblo Kayambi, 2021). Planting techniques are usually organised linearly in rows or in quadrants divided into sections that group different species in a diversified manner (see Figure 3), which ensures ecological balance by favouring crop rotation and association (Zambrano *et al.*, 2018).

Depending on the size of the land and the territorial context, this system is related to similar practices known in other regions of Latin America, such as the milpa in Mexico, which is likewise based on agricultural diversity and the rational use of soil (Gortaire, 2015).

In addition to crop production, the traditional chakra integrates the raising of small animals such as poultry, guinea pigs (cuyes), sheep and, in some cases, larger animals such as cattle, which reinforces food sovereignty and the peasant family economy (Figure 3).



Figure 3 – Traditional chakra with a polycultural arrangement in rows and quadrants, north-central highlands of Ecuador

Source: Cachipuendo et al. (2025.).

The **modern chakra** constitutes an agro-productive system that retains elements of traditional crop diversity while also integrating medicinal plant species and complementary subsystems such as milk, vegetable and fruit production. The latter are oriented mainly towards the local or regional market, albeit under an agroecological approach that respects certain principles of sustainability and ecological balance.

However, in response to new demands from the economic context, non-traditional species such as roses have been incorporated, along with contemporary technologies focused on optimising available natural resources, such as soil, water and solar energy. These innovations are adapted to the space, the landscape and the natural elements present in the environment (Figure 4), thereby strengthening the resilience of the productive system in the face of the effects of climate change.



Figure 4 – Modern chakra with diversified crops and irrigation technology and greenhouse construction in the Ecuadorian highlands

Source: Cachipuendo et al. (2025).

3.2 ANCESTRAL KNOWLEDGE AND INTERGENERATIONAL TRANSMISSION OF KNOWLEDGE

The study shows that more than 70% of producers in Chimborazo, Tungurahua, Cotopaxi, Pichincha and Imbabura maintain ancestral knowledge associated with the Andean chakra, transmitted mainly within the family.

Among the forms of knowledge identified are practices such as alli muyu (seed selection), alli tarpuy (appropriate planting times), communal work through the minka, solidarity exchange (ranti ranti), and the organisation of agricultural activities through the agro-festive calendar. These practices form part of the agricultural knowledge passed down between generations.

This intergenerational character was highlighted by the participants themselves. A farmer from Imbabura (EF-02) noted:

> For the Otavalo people, the chakra constitutes a space of family life, in which children, young people, parents and grandparents take part in production tasks. Here, we pass on values, principles and knowledge about the importance of producing in the chakra, mainly for family subsistence. However, in recent years, productive activities aimed at market sales have also developed, generating income for families (EF-02, farmer, Otavalo people, Imbabura, 2023).

Likewise, in the various focus groups, particularly with representatives of the Kayambi, Cotacachi, Otavalo and Panzaleo peoples, it was stated that:

> For us, the chakra is a space where we share knowledge, principles, communal practices and our way of seeing life. We also take the agro-festive calendars into account, because they guide us on the times for sowing, tending, harvesting and celebration, and they have cultural, spiritual and productive value for each people. Furthermore, the chakra strengthens the minka, first within the family, where we all

> take part in production, and then in the community, where neighbours and community members collaborate collectively in agricultural work. (FG-01, representatives of the Kayambi, Cotacachi, Otavalo and Panzaleo peoples, 2023)

In contrast, in the province of Carchi, a lower presence of this knowledge is observed: only 1 of the producers surveyed in that province reported having general knowledge of the chakra (Figure 5).

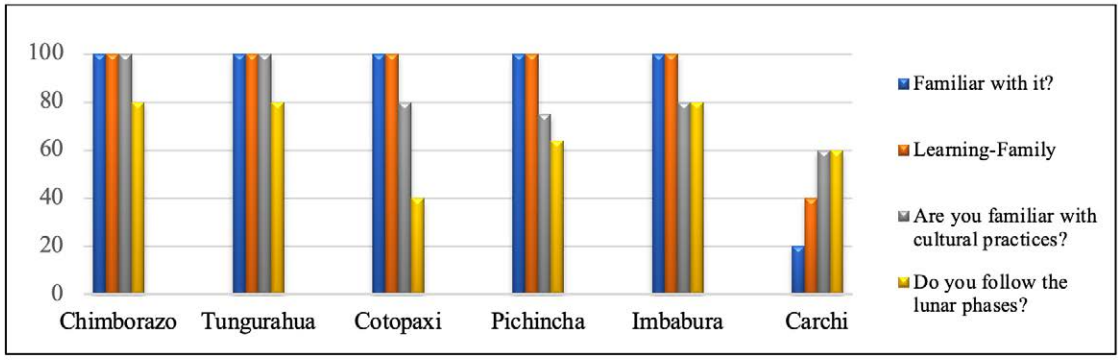

Figure 5 – Notion of knowledge and wisdom of the *chakra* by province

Source: The authors (2026).

The intergenerational transmission of knowledge is a fundamental element for the continuity of traditional agricultural systems. This knowledge not only guides agricultural practices, but also structures the relationship between communities and their territory, shaping systems of local ecological knowledge that have enabled rural peoples to adapt to different environmental conditions over time (Berkes, 2012; Toledo; Barrera-Bassols, 2008).

However, the decline of this knowledge in certain territories reflects processes of transformation associated with the expansion of agricultural models based on the Green Revolution, which have promoted production systems oriented towards maximising productivity through the intensive use of external inputs, mechanisation and the homogenisation of agricultural practices (Crespo; Vila, 2014). These processes have contributed to the devaluation of peasant knowledge and the progressive loss of traditional knowledge associated with the management of agricultural biodiversity and the sustainable management of the territory.

In the Ecuadorian case, this process has a specific history: the Green Revolution reached the highlands from the 1960s onwards, driven by state programmes for agrarian modernisation that promoted the use of improved seeds, synthetic fertilisers and pesticides as a condition for access to agricultural credit (Crespo; Vila, 2014). In provinces such as Carchi—where this study records the greatest loss of chakra knowledge and the exclusive use of tractors—the adoption of the conventional model was particularly early and intense, associated with the expansion of potato cultivation using improved varieties and agrochemicals (Crespo; Vila, 2014). This territorial contrast found in the study is no coincidence: it confirms that the erosion of chakra knowledge follows the historical geography of the Green Revolution's penetration into the country (Brassel *et al.*, 2008), and reinforces the urgency of differentiated policies to protect systems of ancestral knowledge where they still persist.

The preservation of this knowledge has important implications for the sustainability of rural food systems. Incorporating ancestral knowledge into agricultural education programmes, participatory research and rural extension could strengthen communities' resilience to climate change and to transformations in

food systems, favouring the development of more sustainable and culturally appropriate agricultural models (Altieri; Nicholls, 2017; FAO, 2022).

3.3 AGROECOLOGICAL MANAGEMENT OF THE ANDEAN CHAKRA

Agronomic management of the chakras varies between provinces. In Imbabura, most respondents (approximately 4 out of 5) use minimum tillage, while 1 uses a tractor. In Pichincha, around 3 out of 5 respondents apply minimum tillage, and 2 use a tractor. In Cotopaxi and Tungurahua, use is distributed similarly between both practices. In Carchi, respondents reported exclusive use of the tractor. Given that the n per province ranges between 3 and 5 cases, these figures reflect descriptive trends in the context studied and do not allow for statistical generalisation.

Regarding the use of compost, all respondents in Imbabura, Tungurahua and Chimborazo reported using it, while in Carchi only 1 respondent did so. With respect to seed origin, in Tungurahua, Cotopaxi and Imbabura almost all the farmers surveyed reuse their own seeds, whereas in Chimborazo the use of commercial seeds predominated among the cases recorded (Figure 6).

This orientation towards organic practices was confirmed qualitatively: a producer from Tungurahua (EF-07) stated:

> In our chakra we try to avoid the use of external products, such as agrochemicals and synthetic fertilisers. That is why we keep our own seeds for the next planting, we use crop stubble to nourish the soil, and we use manure from our animals, together with kitchen waste, to make compost. Some of us also produce vermicompost (worm humus). With these practices, we look after the soil, strengthen our autonomy and keep agroecological and ancestral production alive. (EF-07, producer, Tungurahua, 2023).

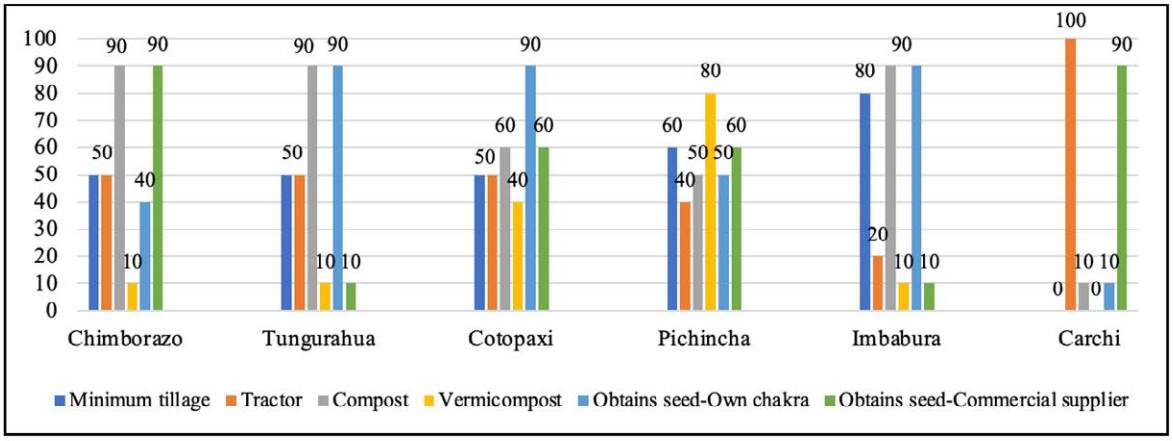

Figure 6 – Agroecological management practices in the Andean chakra, Ecuadorian highlands

Source: The authors (2026).

The practices observed reflect different levels of integration between traditional knowledge and modern agricultural technologies. The use of compost, minimum tillage and the conservation of local seeds contribute to improving soil fertility, favouring biological activity and strengthening the resilience of agroecosystems in the face of environmental and climatic disturbances (Gliessman, 2015; Pretty, 2008). Likewise, the conservation of local seeds is a key element in maintaining the genetic diversity of crops and the productive autonomy of peasant communities, by preserving varieties adapted to the

ecological conditions of the territory and to environmental change (Jarvis *et al.*, 2011; Toledo; Barrera-Bassols, 2008).

Promoting these agroecological practices through family farming support programmes, community seed banks and farmer-to-farmer training processes could help to reduce dependence on external inputs and strengthen the sustainability of rural production systems. Various studies have shown that participatory approaches to agricultural innovation and horizontal knowledge exchange between farmers favour the adoption of sustainable practices and strengthen the resilience of local agricultural systems (FAO, 2023; Rosset; Martínez-Torres, 2012).

3.4 AGRICULTURAL PRODUCTION AND CROP DIVERSITY

The chakras display significant productive diversity. In Chimborazo, Tungurahua and Cotopaxi, most of the cases recorded correspond to vegetables as the predominant crop, followed by roots and tubers, cereals and legumes. In Pichincha and Imbabura, a more balanced distribution is observed among different crop groups, while in Carchi production is concentrated mainly on vegetables and fruit trees (Figure 7). This crop diversity reflects the capacity of the chakras to adapt to different agroecological conditions and to integrate traditional food species with introduced crops, giving rise to multifunctional agricultural systems adapted to the territory.

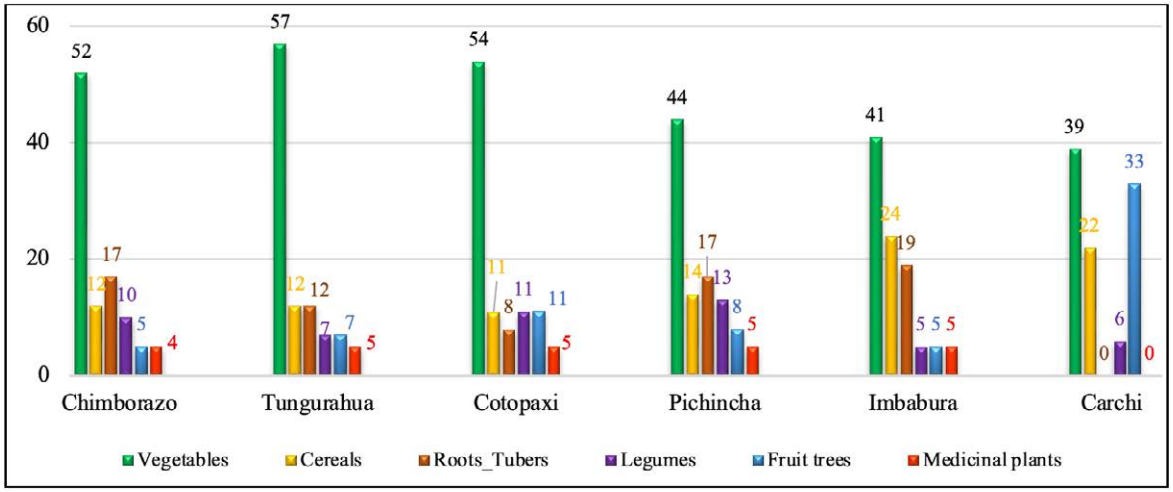

Figure 7 – Crop diversity in Andean chakras by province, north-central highlands of Ecuador

Source: The authors (2026).

The agricultural diversification observed in the chakras confirms their multifunctional character as agricultural systems oriented towards both family subsistence and local marketing. Various studies have shown that diversified agricultural systems help improve the resilience of agroecosystems by reducing production risks, increasing yield stability and strengthening food security in rural communities (Gliessman, 2015; Perfecto; Vandermeer, 2010; Pretty, 2008). Likewise, crop diversity is a key element for the conservation of agrobiodiversity and the maintenance of agricultural varieties adapted to local ecological conditions, which favours the adaptation of production systems to climatic and environmental variability (Jarvis *et al.*, 2011; Toledo; Barrera-Bassols, 2008; Zimmerer, 2014).

Strengthening diversified agricultural systems based on the chakra could help improve food security in rural Andean territories and promote short marketing circuits that strengthen the peasant economy. In this regard, traditional agricultural systems have been recognised as relevant strategies for addressing the current challenges facing food systems, including biodiversity loss, ecosystem degradation and the

effects of climate change on agricultural production (Altieri; Nicholls, 2020; FAO, 2023; Koohafkan; Altieri, 2011).

3.5 LIVESTOCK PRODUCTION AND ECOLOGICAL CYCLES IN THE CHAKRA

Livestock production is an integral part of the chakra. In absolute terms, 14 of the 24 households surveyed raise guinea pigs (cuyes), while between 3 and 6 raise laying hens, depending on the province. Organic waste from animal rearing is reused as natural fertiliser for crops (Figure 8). This practice makes it possible to recycle nutrients within the production system and maintain soil fertility through the use of organic manures generated within the productive unit itself. This integration between agriculture and animal rearing was clearly described by one of the focus group participants:

> For us, the chakra is an integral productive unit, where we combine plants that serve for family food with the raising of animals such as guinea pigs, sheep, chickens, rabbits, pigs, cows and horses. These animals complement our diet and, when there is a surplus, they also help generate income through sale at market. In addition, their waste serves as manure for the crops, while plant residues feed the animals. In this way, we maintain a supportive relationship between plants and animals, strengthening biodiversity and the care of the chakra. (FG-02, producer, north-central highlands of Ecuador, 2023).

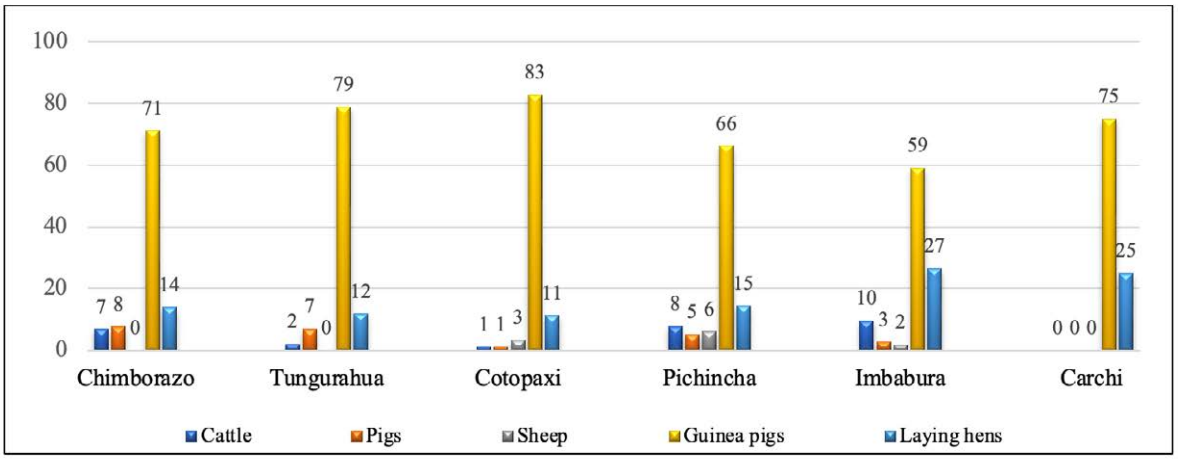

Figure 8 – Animal species in Andean chakras by province, north-central highlands of Ecuador

Source: The authors (2026).

The integration of agriculture and livestock farming makes it possible to close nutrient cycles within the production system and reduce dependence on chemical fertilisers. These integrated systems have been recognised as effective strategies for improving the sustainability of agroecosystems by favouring nutrient recycling, resource-use efficiency and the ecological balance of production systems (Gliessman, 2015; Herrero *et al.*, 2010; Pretty, 2008). Likewise, diversified agricultural systems that integrate crops and animals help strengthen the resilience of productive units in the face of environmental and economic disturbances by increasing nutrient-use efficiency, diversifying sources of income and reducing the risks associated with climate variability (Dumont *et al.*, 2013; FAO, 2023; Thornton; Herrero, 2015).

In this context, promoting integrated crop-livestock production systems could strengthen the sustainability of family farming and generate complementary sources of income for rural communities. In addition, these practices help to improve soil fertility, optimise the use of local resources and

strengthen the productive autonomy of peasant families, fundamental aspects for the development of more resilient and sustainable agricultural systems (Altieri; Nicholls, 2020; Wezel *et al.*, 2020).

3.6 AGROBIODIVERSITY AND FAMILY MANAGEMENT OF THE CHAKRA

The chakras analysed have an average of 25 cultivated species per productive unit, evidencing a high level of agrobiodiversity (Figure 9). This agricultural diversity includes food, medicinal and ornamental species adapted to different ecological conditions. The simultaneous presence of multiple crops within the same productive space constitutes a traditional strategy of territorial management that optimises the use of natural resources such as soil, water and solar energy, in addition to reducing production risks associated with climate variability (Altieri; Nicholls, 2020; Toledo; Barrera-Bassols, 2008).

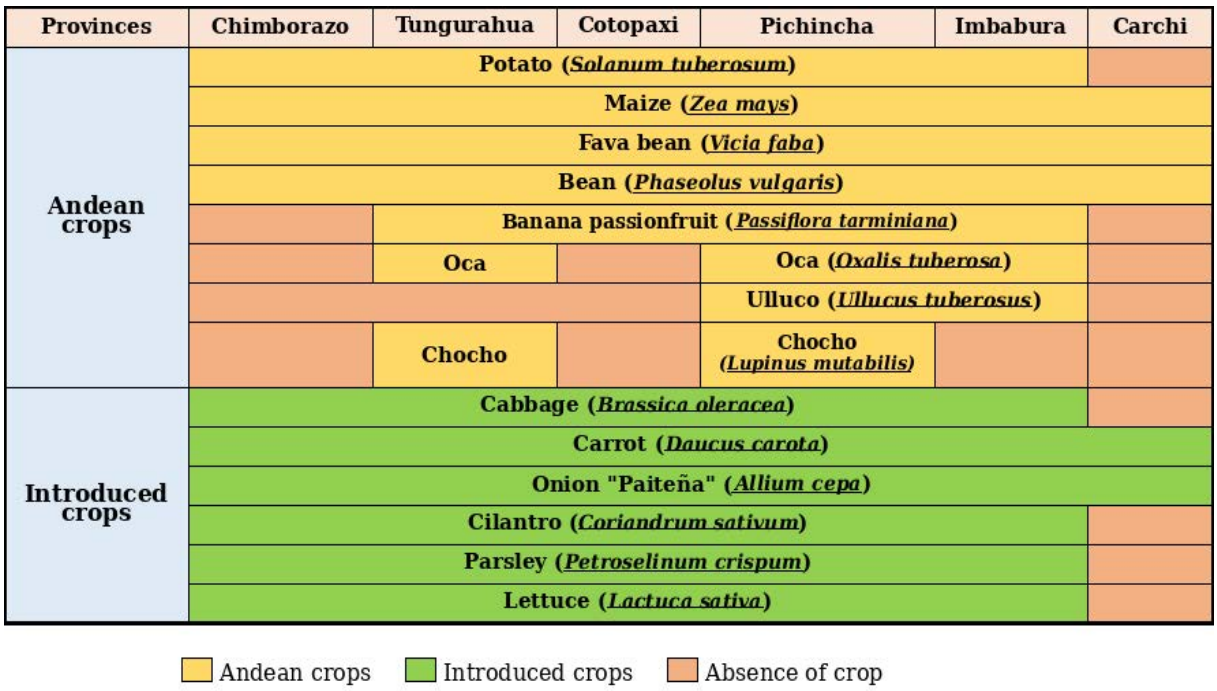

Figure 9 – Species cultivated in Andean chakras in the north-central highlands of Ecuador

Source: The authors (2026).

The crop diversity present in the chakras confirms their importance as reservoirs of agrobiodiversity and as agricultural systems fundamental to the food security of rural communities. Various studies have noted that traditional agricultural systems maintain a wide genetic diversity of crops adapted to local ecological conditions, which contributes to the productive stability and food sovereignty of peasant communities (FAO, 2013; Koohafkan; Altieri, 2011).

Likewise, the conservation of these traditional agricultural systems could help preserve agricultural genetic resources and strengthen the resilience of food systems to climate change, since species and varietal diversity allows for greater adaptive capacity in the face of environmental change and extreme climatic events (Altieri, 2017; FAO, 2022). In this respect, Andean chakras can be considered key spaces for the in situ conservation of agrobiodiversity and for the maintenance of the biocultural heritage of the Indigenous peoples of the Andes.

3.7 THE ROLE OF WOMEN IN CHAKRA MANAGEMENT

The study shows that in the great majority of the chakras visited (between 18 and 19 of the 24 units surveyed), management falls mainly to rural women. These women play a central role in seed selection, soil management, the organisation of agricultural production and the intergenerational transmission of knowledge. Through these practices, women contribute to maintaining crop diversity, caring for the territory and reproducing family food systems based on ancestral knowledge. Various studies on family farming indicate that women tend to be the main custodians of seed conservation, the management of diversified gardens and the transmission of agricultural knowledge within the domestic and community sphere (Agarwal, 2018; Howard, 2003). This central role was expressed by the women themselves during the interviews. A seed guardian from Pichincha (EF-11) stated*:*

> Since ancient times, we women have been responsible for caring for the family's food and for the chakra as a source of life. One of our main roles has been to look after the seed, because the next harvests are born from it; for us, the seed is like our wawas [children]: we care for it, protect it and watch it grow. We are also the ones who encourage the family to take part in the chakra, especially at weekends, when we gather to work, share knowledge and keep our ancestral practices alive. (EF-11, seed guardian, Kayambi people, Pichincha, 2023)

The prominent role of women in chakra management confirms their key part in the sustainability of peasant food systems and in the conservation of agrobiodiversity. Research on traditional agricultural systems has highlighted that rural women play a fundamental role in the management of agricultural biodiversity, particularly in the conservation of native seeds, the management of family gardens and the transmission of agricultural and food-related knowledge (FAO, 2023; Zimmerer, 2014). Likewise, agroecological approaches recognise the importance of women's work in producing food for subsistence and in organising communal exchange networks, which helps strengthen food sovereignty and the resilience of local agricultural systems (Altieri; Nicholls, 2020; Bezner Kerr *et al.*, 2021).

Furthermore, the knowledge of rural women has been recognised as a fundamental component of climate change adaptation strategies in peasant and Indigenous territories, owing to their knowledge of crop diversity, water management and agroecological practices adapted to local conditions (FAO, 2023; Nelson; Stathers; Martin, 2016). In this regard, their participation in chakra management has implications that are not only productive but also cultural, ecological and territorial, as it contributes to the conservation of biocultural heritage and to strengthening the socioecological resilience of rural communities.

Thus, the role of women in production, leadership, marketing and feeding their families is fundamental, as expressed in the focus groups:

> Those of us who work in the production of healthy food from the chakra recognise that women carry a large part of the organisation and leadership. For this reason, we play a fundamental role in keeping this form of production alive. For us, the chakra is not only a place to sow and harvest, but also a place where we share knowledge, values, respect for the land and love for nature. We experience all this work as a minka, in which we all collaborate with our labour, knowledge, exchange of produce and sales at agroecological fairs (bioferias). In this way, we strengthen the chakra through family unity, community organisation and spiritual respect for life, the land and the community. (FG-03, women participants, Kayambi, Cotacachi, Otavalo and Panzaleo peoples, 2023)

Recognising the role of women in chakra management has important implications for the design of rural development policies with a gender approach. Strengthening their participation in training

programmes, agricultural financing and territorial decision-making could help improve the sustainability of production systems, the conservation of agrobiodiversity and resilience to climate change in Andean rural communities.

However, women's prominent role in the chakra involves a tension: women are the main guardians of the system, but this role is frequently exercised without economic recognition, without equitable access to land or credit, and under conditions of a double workday. Research among Ecuadorian Kichwa communities has documented that women's empowerment in agroecological systems can coexist with structures that restrict women's autonomy in territorial decision-making (Churuchumbi, 2020; Conejo, 2020). The chakra can simultaneously be a space of agency and identity and a space of unpaid work overload, a tension that future studies will need to address with specific instruments.

3.8 STUDY LIMITATIONS

The results should be interpreted taking into account four limitations. First, the sample size (n=24 across six provinces, ~4 cases per province) limits inter-provincial statistical generalisation. Second, purposive sampling of families who are guardians of active chakras under-represents those who have abandoned the system, whose trajectories are equally relevant. Third, the cross-sectional design (2022-2024) captures a single moment in the system without accounting for its historical evolution; longitudinal studies would be necessary to understand its long-term trajectory. Consequently, the findings are specific to the Ecuadorian north-central highlands, and their transposition to other Andean contexts—Bolivia, Peru, Colombia—requires caution, as each territory expresses a particular configuration of cosmovision, agrarian history, and ecological conditions.

4 CONCLUSIONS

In the communities studied in the north-central highlands of Ecuador, the chakra retains its relevance as a production system based on crop association, the conservation of native seeds and the raising of small animals, sustained by the intergenerational transmission of knowledge —alli muyu, alli tarpuy, minka— and by the prominent role of women as the main guardians of the system. The coexistence of traditional and modern chakras shows that this relevance is not static but adaptive.

However, the expansion of conventional agricultural models is eroding knowledge in some territories, and women's prominent role coexists with structures that limit women's access to land, credit and territorial decision-making. These tensions indicate that the resilience of the chakra is not guaranteed and depends on institutional, cultural and economic conditions that this study cannot resolve on its own.

The findings support the incorporation of the chakra into intercultural territorial planning instruments, the strengthening of community banks for native seeds, and the economic recognition of the women's work that sustains the system. These measures require the involvement of local governments, research institutions and Indigenous organisations.

The Andean chakra represents an active response to present-day socio-environmental challenges under the paradigm of Sumak Kawsay. Preserving it means preserving a way of relating to the territory that the global crisis makes increasingly necessary, and a longitudinal and comparative research agenda across the Andes is essential to consolidate the evidence needed to guide this task.

DECLARATION ON THE USE OF ARTIFICIAL INTELLIGENCE

The authors used ChatGPT, developed by OpenAI, exclusively for linguistic revision and stylistic refinement. All scientific content, analysis and intellectual contribution were developed and verified by the authors, who assume full responsibility for the accuracy and integrity of the manuscript.

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La chakra andina como sistema socioecológico del Buen Vivir para la soberanía alimentaria

The Andean chakra as a socioecological system of Buen Vivir for food sovereignty

Charles Cachipuendo [1]

Erika Churuchumbi [2]

Sergio Pilataxi [3]

[1] Doctorado en Ciencias en Ingeniería de Sistemas Agrícolas, Profesor e Investigador, Grupo de Investigación en Ciencias Ambientales, Universidad Politécnica Salesiana, Quito, Pichincha, Ecuador
E-mail: ccachipuendo@ups.edu.ec

[2] Maestría en Recursos Hídricos, Grupo de Investigación en Ciencias Ambientales, Universidad Politécnica Salesiana, Quito, Pichincha, Ecuador
E-mail: churuchumbi@ups.edu.ec

[3] Ingeniero Agrónomo, Universidad Central del Ecuador, Quito, Pichincha, Ecuador
E-mail: zherghio@hotmail.es

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ARTICLE- VARIA

RESUMEN

Los sistemas de producción agropecuaria desarrollados por pueblos originarios en los Andes responden a ecosistemas montañosos caracterizados por alta diversidad climática, edáfica, biológica y cultural. Este estudio analiza las prácticas agronómicas y socioculturales de la chakra andina en comunidades de la sierra ecuatoriana que producen alimentos bajo el paradigma del *Sumak Kawsay* y el simbolismo de la Chakana. La investigación adoptó un enfoque mixto en tres fases: caracterización territorial mediante georreferenciación SIG, trabajo de campo con 24 encuestas, 16 entrevistas semiestructuradas y 3 grupos focales en seis provincias de la sierra centro-norte, y análisis de datos con NVivo 14 y SPSS 30. Los resultados evidencian que la chakra constituye un sistema agropecuario familiar sustentado en saberes y tecnologías ancestrales resilientes, con un promedio de 25 especies cultivadas por unidad productiva. Entre las principales prácticas se identifican la asociación de cultivos, conservación de semillas nativas, manejo orgánico del suelo, uso eficiente del agua y aplicación de fitomedicina. Estas prácticas fortalecen la biodiversidad y la reciprocidad entre sociedad y naturaleza mediante el trabajo comunitario de la minka. Asimismo, la gran mayoría de las chakras estudiadas son gestionadas principalmente por mujeres, quienes garantizan la soberanía alimentaria, la transmisión de conocimientos y la conservación de agrobiodiversidad. Se concluye que la chakra andina es una estrategia vigente y adaptativa de agricultura sustentable, cuya preservación requiere políticas públicas interculturales, reconocimiento del trabajo femenino y líneas de investigación longitudinales y comparativas en los Andes.

Palabras-clave: Agrobiodiversidad. Sistemas alimentarios indígenas. Saberes ancestrales. Agricultura comunitaria. Resiliencia socioecológica. Cosmovisión andina.

ABSTRACT

Agricultural production systems developed by Indigenous peoples in the Andes respond to mountain ecosystems characterised by high climatic, edaphic, biological and cultural diversity. This study analyses the agronomic and sociocultural practices of the Andean chakra in communities of the Ecuadorian highlands that produce food under the paradigm of "Sumak Kawsay" and the symbolism of the "Chakana". The research adopted a mixed-methods approach across three phases: territorial characterisation through GIS georeferencing, fieldwork comprising 24 surveys, 16 semi-structured interviews and 3 focus groups in six provinces of the north-central highlands, and data analysis using NVivo 14 and SPSS 30. The results show that the "chakra" constitutes a family-based agricultural and livestock system underpinned by resilient ancestral knowledge and technologies, averaging 25 cultivated species per productive unit. Among the main practices identified are crop association, conservation of native seeds, organic soil management, efficient water use and the application of phytomedicine. These practices strengthen biodiversity and reciprocity between society and nature through the communal work known as the "minka". Likewise, the great majority of the "chakras" studied are managed mainly by women, who ensure food sovereignty, the transmission of knowledge and the conservation of agrobiodiversity. It is concluded that the Andean "chakra" is a current and adaptive strategy of sustainable agriculture, whose preservation requires intercultural public policies, recognition of women's work, and longitudinal and comparative lines of research across the Andes.

Keywords: *Agrobiodiversity. Indigenous food systems. Ancestral knowledge. Community-based agriculture. Socioecological resilience. Andean cosmovision.*

1 INTRODUCCIÓN

El modelo de desarrollo capitalista contemporáneo ha demostrado ser ambiental y socialmente insostenible, expresado en el cambio climático, la contaminación ambiental, la escasez de agua, la inseguridad alimentaria y el aumento del consumismo global (Fernández; Gutiérrez, 2013; García, 2021; Whitmee *et al.*, 2015). En el ámbito agropecuario, esta crisis se expresa en la expansión de monocultivos y en el uso intensivo de agroquímicos y combustibles fósiles, prácticas que degradan los suelos, reducen la biodiversidad y deterioran los servicios ecosistémicos (Altieri; Nicholls, 2020; Brunet; Böcker, 2015), generando un debate creciente sobre la necesidad de transitar hacia modelos de producción más resilientes, diversificados y socialmente justos.

La agricultura convencional se ha orientado a maximizar la productividad mediante fertilizantes sintéticos, pesticidas y semillas modificadas, con impactos negativos sobre la salud humana, los ecosistemas y la resiliencia alimentaria (Ceccon, 2008; Fletcher, 2015). Frente a ello, organismos internacionales promueven sistemas sostenibles basados en la conservación de la biodiversidad y el manejo orgánico del suelo (FAO, 2015; Rizo *et al.*, 2017). La agroecología plantea una ruptura al concebir el sistema agrícola como una construcción social que integra saberes campesinos (Altieri; Nicholls, 2020; Gliessman, 2015), mientras la cosmovivencia andina incorpora la reciprocidad con la Pachamama (Escobar, 2014; Gudynas, 2011), ausente en el modelo convencional. Persiste el riesgo de que las soluciones técnicas invisibilicen los conocimientos y prácticas de los pueblos indígenas, sin consenso aún sobre cómo articular eficiencia productiva y epistemologías ancestrales.

En este contexto, la agroecología integra conocimientos científicos y saberes tradicionales para diseñar sistemas agrícolas sostenibles, entendiendo los sistemas tradicionales como reservorios de conocimiento ecológico que permiten adaptación ambiental, conservación de la agrobiodiversidad y soberanía alimentaria.

En Ecuador, estas discusiones adquieren relevancia con el reconocimiento constitucional del Buen Vivir o Sumak Kawsay, que propone una relación armónica entre el ser humano y la naturaleza y el respeto a los derechos de la Pachamama (Cruz, 2018), basada en reciprocidad, complementariedad y equilibrio.

Entre estas prácticas destaca la chakra andina, sistema agrícola ancestral que combina diversidad biológica, organización comunitaria y cosmovisión indígena en la producción de alimentos. Más allá de su función productiva, reproduce la unidad familiar y articula saberes ecológicos, comunitarios y espirituales en el manejo de la biodiversidad agrícola (Cachipuendo *et al.*, 2025; Confederación del Pueblo Kayambi, 2021; Herrán, 2017; Tamayo; Alegre, 2022).

Así, ante la crisis socioambiental global, estudiar la chakra andina permite explorar cómo las prácticas agronómicas, culturales y espirituales de las comunidades indígenas aportan a la construcción de modelos agrícolas más sostenibles y resilientes (Altieri; Nicholls, 2020; Gliessman, 2015). El presente estudio analiza dichas prácticas en la producción de alimentos saludables, con el objetivo de comprender su contribución como estrategia de agricultura sustentable para comunidades rurales del centro y norte de los Andes ecuatorianos, considerando la siguiente fundamentación teórica.

Buen Vivir en la producción de alimentos

Desde la cosmovisión andina, producir alimentos no implica dominar la tierra, sino formar parte de ella para “criar vida” en reciprocidad con la Pachamama (Acosta, 2015; Hidalgo *et al.*, 2014). La agricultura se concibe como una práctica integral que articula dimensiones políticas, espirituales, sociales y ecológicas orientadas al bienestar colectivo. La chakra andina expresa este paradigma al integrar biodiversidad, cooperación familiar, manejo orgánico del suelo y equidad de género (Confederación del Pueblo Kayambi, 2021; Herrán, 2017), revalorizando la economía solidaria (Cachipuendo *et al.*, 2025).

Cosmovisión andina y el allí mikuy

En la cosmovisión andina, el territorio es un sistema vivo. La Chakana o cruz andina simboliza esta estructura de interrelaciones y guía la organización territorial mediante saberes ancestrales (Campohermoso *et al.*, 2015; Confederación del Pueblo Kayambi, 2021). La chakra se configura como un biosistema orientado a la crianza de vida, caracterizado por la asociación diversificada de cultivos, la conservación de semillas nativas y la evitación de agroquímicos (Herrán, 2017; Tamayo; Alegre, 2022), incorporando rituales vinculados al allí mikuy, el derecho colectivo a una alimentación sana. La familia es el núcleo organizativo, dinamizando prácticas como la minka (Cachipuendo *et al.*, 2025).

Interculturalidad y diálogo de saberes

La agricultura andina contemporánea integra conocimientos ancestrales y científicos en el manejo del suelo, la selección de semillas y los calendarios agrícolas, sin perder la identidad cultural indígena (De Sousa Santos, 2009; Escobar, 2014). En la chakra, el conocimiento se transmite mediante la experiencia comunitaria, la oralidad y la espiritualidad (Churuchumbi, 2020), fortaleciendo la autonomía campesina y la descolonización del conocimiento agrícola (Salinas, 2019), en busca de complementariedad entre ciencia y sabiduría local (De Sousa Santos, 2009; Dubey *et al.*, 2026; Roos, 2025).

La chakra y la producción de alimentos saludables

La chakra es un sistema integral de abastecimiento anual y de transmisión intergeneracional de conocimientos, comprendida como una escuela viva de aprendizaje comunitario (Almeida *et al.*, 2021).

Contribuye a la economía familiar mediante el trueque o las bioferias (Conejo, 2020; Monteros, 2020; Requelme *et al.*, 2019). Su diversidad de cultivos optimiza el uso del suelo, el agua y la energía solar (Zambrano *et al.*, 2018), integrando plantas alimenticias, medicinales y ornamentales que fortalecen la soberanía alimentaria (Confederación del Pueblo Kayambi, 2021; Herrán, 2017).

Resiliencia socioecológica y adaptación al cambio climático

La chakra es un sistema socioecológico resiliente frente a crisis ambientales, sanitarias y económicas (Altieri; Nicholls, 2020; Cachipuendo *et al.*, 2025). Su estructura se relaciona con los niveles de Hanan Pacha, Kay Pacha y Uku Pacha, expresión de la complementariedad ecológica andina (Tamayo; Alegre, 2022). En cada nivel se cultivan especies adaptadas a distintas condiciones climáticas, conservando semillas y agua esenciales para la soberanía alimentaria (Altieri; Nicholls, 2020; Koohafkan; Altieri, 2011), lo que fortalece la resiliencia climática y la fertilidad del suelo. La tierra es entendida como sujeto de vida en relación de reciprocidad (Toledo; Barrera-Bassols, 2008), de modo que la chakra articula conocimientos ecológicos, organización comunitaria y diversidad biocultural en favor de la continuidad de la vida (Escobar, 2014; Gliessman, 2015).

2 METODOLOGÍA

2.1 ÁREA DE ESTUDIO

La investigación se llevó a cabo en comunidades rurales de las provincias de Chimborazo, Tungurahua, Cotopaxi, Pichincha, Imbabura y Carchi, en la región andina del Ecuador (Figura 1). En estas provincias habitan pueblos indígenas kichwa como Karanki, Otavalo, Kayambi, Chibuleo, Puruwá y Panzaleo, cuyas prácticas productivas mantienen sistemas agrícolas tradicionales basados en la chakra andina.

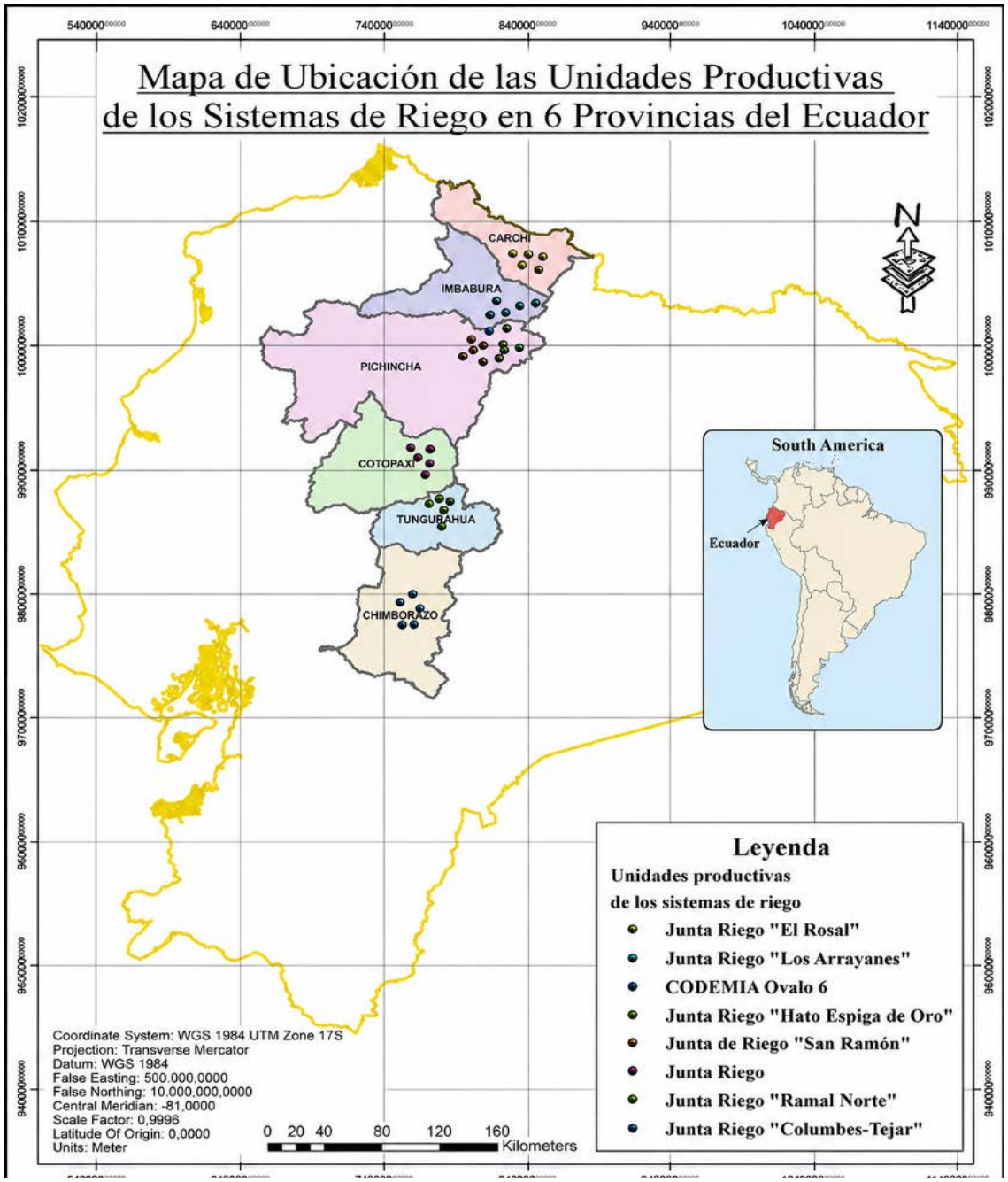

Figura 1 – Área de estudio y localización de chakras andinas en estudio

Fuente: los autores (2026).

Las zonas de estudio se localizan entre 2 100 y 3 500 msnm, con clima templado frío (9 °C a 16 °C) y precipitación media anual entre 1 721 mm y 2 877 mm, configurando ecosistemas montañosos de alta diversidad ecológica y agrobiodiversidad (Climate, 2022). Estas condiciones han favorecido sistemas agroecológicos diversificados basados en conocimientos ancestrales de manejo del suelo, conservación de semillas y uso eficiente del agua.

2.2 DISEÑO METODOLÓGICO Y PROCEDIMIENTO

La investigación se desarrolló bajo un enfoque empírico, descriptivo, analítico y participativo, combinando métodos cualitativos y cuantitativos con dirigentes, productores y familias guardianas de chakras. El trabajo de campo se realizó entre 2022 y 2024, en tres fases.

Primera fase: diagnóstico contextual

Se realizó una revisión documental de proyectos agroecológicos, programas de desarrollo rural y estudios previos sobre sistemas productivos indígenas en la sierra centro-norte. Además, se aplicaron nueve entrevistas semiestructuradas a informantes clave (técnicos de ONG, representantes de gobiernos locales, líderes comunitarios y académicos), que permitieron identificar experiencias previas y procesos organizativos relacionados con la gestión de chakras.

Segunda fase: trabajo de campo participativo

Se aplicaron 24 encuestas a productores con chakras activas, seleccionadas mediante muestreo intencionado por conveniencia, y 16 entrevistas semiestructuradas a líderes comunitarios, mujeres agricultoras y guardianes de semillas, considerando diversidad de género, generacional y territorial.

El cuestionario se organizó en cuatro secciones: características socioeconómicas del hogar; manejo agronómico de la chakra; prácticas culturales y espirituales; y comercialización y soberanía alimentaria. Los instrumentos fueron validados mediante prueba piloto con cuatro productores no incluidos en la muestra y revisados por un panel de tres especialistas en agroecología y etnobotánica andina.

El trabajo de campo se complementó con tres grupos focales (sierra norte, sierra centro y zona de transición), de 8 a 12 integrantes cada uno, con representación de género (al menos 50 % mujeres), diversidad generacional y distintos roles comunitarios. Las sesiones fueron grabadas con consentimiento y transcritas para su análisis. Asimismo, se realizaron conversatorios comunitarios y observación participante durante jornadas agrícolas, mingas y ferias agroecológicas, registrados en un diario de campo estructurado con categorías predefinidas y notas libres.

Tercera fase: sistematización y análisis

Las chakras fueron georreferenciadas mediante SIG utilizando QGIS 3.28 y ArcGIS 10.8, para identificar su distribución territorial y características agroecológicas del paisaje. Los datos cualitativos se procesaron mediante análisis de contenido temático con NVivo 14, y los cuantitativos con SPSS 30, mediante estadística descriptiva, frecuencias absolutas y correlaciones de Spearman entre variables ordinales clave (adopción de prácticas ancestrales, diversidad de cultivos, uso de compost y participación en redes de intercambio). Dado el tamaño muestral, los resultados se presentan como frecuencias y tendencias descriptivas, sin generalización estadística. La triangulación entre fuentes, métodos y técnicas de análisis fortaleció la validez y confiabilidad de los resultados.

2.3 CONSIDERACIONES ÉTICAS

El estudio siguió los principios éticos de la Declaración de Helsinki y el Convenio 169 de la OIT sobre Pueblos Indígenas y Tribales. La Universidad Politécnica Salesiana no dispone de un Comité de Ética institucional; no obstante, el estudio fue avalado por las organizaciones representativas de los pueblos participantes, incluyendo la Confederación del Pueblo Kayambi, en el marco del protocolo de Consentimiento Libre, Previo e Informado (CLPI). Los participantes fueron informados sobre objetivos,

métodos y alcances, y otorgaron consentimiento voluntario. Los datos fueron anonimizados mediante códigos alfanuméricos y los resultados fueron devueltos a las comunidades mediante asambleas previas a la publicación. Los autores declaran que la investigación no implicó riesgo para los participantes ni datos clínicos, menores de edad o información sensible.

3 RESULTADOS Y DISCUSIÓN

Esta sección presenta los resultados sobre la chakra andina como sistema de producción de alimentos saludables: prácticas agronómicas y manejo de biodiversidad; dinámicas comunitarias, destacando la minka y el rol de las mujeres; y su aporte a la soberanía alimentaria y la resiliencia socioecológica andina.

Dado el tamaño muestral reducido, los datos cuantitativos se presentan como frecuencias y tendencias descriptivas, sin representatividad estadística. Los datos cualitativos de 16 entrevistas y 3 grupos focales complementan los hallazgos, citados con códigos anonimizados.

3.1 AGRICULTURA DEL BUEN VIVIR Y LA CHAKRA COMO SISTEMA SOCIOECOLÓGICO

Los resultados evidencian que la producción agrícola en las comunidades indígenas de la Sierra centro-norte del Ecuador se organiza en torno al paradigma del Buen Vivir (Sumak Kawsay), donde la chakra constituye la unidad productiva familiar central. Este sistema integra diversidad de cultivos, manejo orgánico del suelo y relaciones de reciprocidad entre la familia, la comunidad y la naturaleza.

En los territorios estudiados se observa la coexistencia de diferentes enfoques agrícolas. Por un lado, se mantienen sistemas productivos basados en saberes ancestrales y cosmovisión andina; por otro, se incorporan enfoques contemporáneos como la agroecología, la agricultura biodinámica y la agricultura regenerativa (Tabla 1).

Tabla 1 – Unidad de estudio de enfoques de agricultura del Buen Vivir y Sustentable

Criterios/Enfoques	*Agricultura de la Chakra andina*	*Agroecología*	*Agricultura Biodinámica*	*Agricultura Regenerativa*
Base de conocimientos	Saberes ancestrales y cosmovisión andina (*cosmovivenciales*)	Integración de saberes locales y científicos; enfoque sistémico y ecológico	Antroposofía, espiritualidad agrícola y ciclos lunares	Ciencia ecológica, manejo adaptativo y prácticas innovadoras
Estructura del sistema	Sistemas geobiodiversos: *chakras*, *ajás*, terrazas, huertas; integrados al paisaje	Sistemas diversificados e integrales: huertas, fincas, granjas mixtas	Fincas autosuficientes con diseño cíclico y cerrado	Sistemas en transición ecológica con enfoque regenerativo del suelo y ecosistema
Relación con el entorno	Territorio sagrado: conexión con la familia, comunidad y el cosmos	Enfoque ecológico en múltiples escalas: parcela, finca, cuenca	Ritmos astrales, calendarios lunares, respeto a energías sutiles	Restauración de paisajes degradados, eficiencia ecológica
Objetivos productivos	Alimentación familiar, reciprocidad, soberanía alimentaria	Seguridad y soberanía alimentaria, resiliencia, comercio justo	Equilibrio energético, salud del ecosistema agrícola	Regeneración de suelo, secuestro de carbono, adaptación al cambio climático

Criterios/Enfoques	*Agricultura de la Chakra andina*	*Agroecología*	*Agricultura Biodinámica*	*Agricultura Regenerativa*
Enfoque del suelo	Suelo como ser vivo vinculado a la Pacha Mama	Fertilidad natural, compost, abonos verdes, manejo ecológico	Dinamización del suelo con preparados biodinámicos y compost ritualizado	Regeneración activa del suelo: cobertura vegetal, biología del suelo, control de erosión
Escala y contexto	Local y comunitario, adaptado al territorio y cosmovisión	Local a regional, adaptable a múltiples escalas	Escala media con requerimientos técnicos y rituales específicos	Escala variable, adaptable al contexto ecológico y económico

Fuente: Altieri and Nicholls (2020), Herrera-Sánchez (2023) and Requelme et al. (2019).

Asimismo, el análisis de campo permitió identificar dos tipologías principales de chakras: la chakra tradicional, basada en conocimientos ancestrales y orientada principalmente a la producción de autoconsumo, y la chakra moderna, que incorpora tecnologías contemporáneas y cultivos orientados al mercado local o regional (Tabla 2).

Tabla 2 – Caracterización y su evolución de las chakras andinas

Criterio	*Chakra Tradicional*	*Chakra Moderna*
Base de conocimientos	Saberes ancestrales, transmitidos oralmente por generaciones.	Integración de conocimientos tradicionales con tecnología y enfoques agroecológicos contemporáneos.
Diversidad de cultivos	Alta biodiversidad con especies nativas y medicinales.	Mantiene diversidad, pero incorpora especies comerciales (ej. rosas, frutales, hortalizas).
Destino de la producción	Principalmente autoconsumo y trueque comunitario.	Mixto: autoconsumo y producción para mercados locales o agroexportación.
Uso de tecnología	Herramientas manuales y técnicas tradicionales adaptadas al entorno.	Implementación de tecnologías modernas: riego tecnificado, energía solar, mejoramiento genético.
Relación con la naturaleza	Basada en la reciprocidad con la Pacha Mama y respeto a los ciclos naturales.	Enfoque de eficiencia y optimización de recursos naturales (suelo, agua, energía).
Organización del espacio	Adaptación al paisaje natural con lógica simbólica, espiritual y ecológica.	Diseño técnico-productivo adaptado al espacio, con eficiencia funcional.
Resiliencia climática	Basada en la diversidad biológica y el conocimiento ecológico local.	Fortalecida mediante tecnologías de adaptación y gestión de recursos.
Cosmovisión	Fuertemente vinculada a la espiritualidad andina y al Buen Vivir.	Aún presente, pero combinada con enfoques de mercado y modernización agrícola.

Fuente: los autores (2026).

Así, la chakra andina puede interpretarse como un sistema socioecológico complejo, donde interactúan dimensiones ecológicas, culturales y económicas en la producción de alimentos. A diferencia de otros enfoques agrícolas contemporáneos, su lógica productiva no se centra únicamente en la eficiencia productiva, sino en la crianza de vida en reciprocidad con la naturaleza, principio fundamental del Buen Vivir (Altieri; Nicholls, 2020; Cachipuendo; Pilataxi, 2025; Gudynas, 2011).

Esta característica coincide con estudios que señalan que los sistemas agrícolas tradicionales constituyen reservorios de conocimiento ecológico local y pueden contribuir significativamente a la sostenibilidad territorial (Toledo; Barrera-Bassols, 2008).

Los datos empíricos obtenidos en este estudio confirman y amplían los planteamientos de Altieri y Nicholls (2020) sobre resiliencia agroecológica: el promedio de 25 especies por unidad productiva y la integración agricultura-ganadería observados en las chakras estudiadas son consistentes con los atributos de diversidad funcional que estos autores identifican como determinantes de la resiliencia en agroecosistemas andinos. Sin embargo, los hallazgos también revelan una dimensión que la agroecología convencional de Gliessman (2015) no integra plenamente: la chakra no es solo un sistema de manejo ecológico, sino un espacio de crianza de vida articulado a la cosmovisión andina, donde la dimensión espiritual — rituales, calendario agrofestivo, relación con la Pachamama — no es un complemento cultural sino parte constitutiva del sistema productivo. Esta constatación dialoga con la epistemología del sur propuesta por De Sousa Santos (2009): los saberes ancestrales de la chakra no son saberes menores a validar desde la ciencia occidental, sino sistemas de conocimiento con lógica propia que producen resultados agroecológicos tangibles. La presencia de estas prácticas en todas las provincias estudiadas, incluso bajo presión de la modernización agrícola, sugiere que la complementariedad epistemológica que De Sousa Santos propone no es solo un horizonte normativo, sino una realidad ya operante en los territorios andinos.

Reconocer la chakra como un sistema socioecológico puede contribuir al diseño de políticas de desarrollo rural con enfoque intercultural, capaces de integrar conocimientos ancestrales y prácticas agroecológicas en estrategias de seguridad alimentaria, conservación de biodiversidad y adaptación al cambio climático en territorios andinos.

La coexistencia de chakras tradicionales y modernas identificada en este estudio (Tabla 2) plantea, sin embargo, interrogantes críticos que van más allá de la descripción tipológica. La transición hacia la chakra moderna no es un proceso neutro: implica disyuntivas entre eficiencia productiva y continuidad cultural que merecen discutirse con mayor profundidad. La incorporación de rosas, riego tecnificado y cultivos de mercado —rasgos definitorios de la chakra moderna— genera ingresos monetarios, pero puede erosionar la lógica del autoconsumo y la reciprocidad que fundamentan el sistema. La pérdida del principio de alli mikuy (derecho colectivo a una alimentación sana y culturalmente pertinente) y la sustitución de la minka por trabajo individual remunerado son dimensiones de esta transición que no aparecen en los datos cuantitativos, pero que emergen como riesgos latentes. En términos de Toledo y Barrera-Bassols (2008), la modernización de la chakra puede representar una forma de extinción de la memoria biocultural, donde la pérdida no es solo de especies o variedades, sino de las relaciones, significados y prácticas que articulan el sistema.

En este proceso de producción, todos los miembros de la familia participan activamente: niños, niñas, jóvenes, mujeres, hombres y adultos mayores, quienes son considerados como fuentes vivas de sabiduría ancestral (Figura 2).



Figura 2 – Esquema de distribución de la chakra andina

Fuente: Cachipuendo et al. (2025).

La **chakra tradicional** es un sistema de producción de alimentos saludables, alineado al paradigma del Buen Vivir y orientado a fortalecer la resiliencia socioecológica de las comunidades andinas. Este sistema mantiene una alta diversidad de cultivos como maíz, fréjol, habas, papas, chochos, quinua, zambo, entre otros (Confederación del Pueblo Kayambi, 2021). Las técnicas de siembra suelen organizarse de forma lineal por hileras, o en cuadrantes divididos por secciones que agrupan distintas especies de manera diversificada (ver Figura 3), lo que garantiza un equilibrio ecológico al favorecer la rotación y asociación de cultivos (Zambrano *et al.*, 2018).

Dependiendo de la extensión del terreno y el contexto territorial, este sistema se relaciona con prácticas similares conocidas en otras regiones de América Latina, como la milpa en México, que también se basa en la diversidad agrícola y el uso racional del suelo (Gortaire, 2015).

Además de la producción agrícola, la chakra tradicional integra la crianza de animales menores como aves, cuyes (cobayos), ovinos y, en algunos casos, animales mayores como vacunos, lo que refuerza la soberanía alimentaria y la economía familiar campesina (Figura 3).



Figura 3 – Chakra tradicional con disposición policultural en hileras y cuadrantes, sierra centro-norte del Ecuador

Fuente: Cachipuendo et al. (2025).

La **chakra moderna** constituye un sistema agroproductivo que conserva elementos de la diversidad de cultivos tradicionales, integrando además especies de plantas medicinales y subsistemas complementarios como la producción de leche, hortalizas y frutales. Estos últimos están orientados principalmente al mercado local o regional, aunque bajo un enfoque agroecológico que respeta ciertos principios de sostenibilidad y equilibrio ecológico.

No obstante, en respuesta a las nuevas demandas del contexto económico, se han incorporado especies no tradicionales como las rosas, así, como tecnologías contemporáneas enfocadas en la optimización de los recursos naturales disponibles, tales como el suelo, el agua y la energía solar. Estas innovaciones se adaptan al espacio, al paisaje y a los elementos naturales presentes en el entorno (Figura 4), fortaleciendo así la resiliencia del sistema productivo frente a los efectos del cambio climático.



Figura 4 – Chakra moderna con cultivos diversificados y tecnología de riego y construcción de invernaderos en la sierra ecuatoriana

Fuente: Cachipuendo et al. (2025).

3.2 SABERES ANCESTRALES Y TRANSMISIÓN INTERGENERACIONAL DEL CONOCIMIENTO

El estudio muestra que más del 70 % de los productores en Chimborazo, Tungurahua, Cotopaxi, Pichincha e Imbabura mantienen saberes ancestrales asociados a la chakra andina, transmitidos principalmente en el ámbito familiar.

Entre los conocimientos identificados destacan prácticas como alli muyu (selección de semillas), alli tarpuy (tiempos adecuados de siembra), el trabajo comunitario mediante minka, el intercambio solidario ranti ranti, y la organización de las actividades agrícolas mediante el calendario agrofestivo. Estas prácticas forman parte del conocimiento agrícola transmitido entre generaciones.

Este carácter intergeneracional fue destacado por los propios participantes. Una agricultora de Imbabura (EF-02) señaló:

> Para el pueblo Otavalo la chakra constituye un espacio de convivencia familiar, en el cual participan niños, jóvenes, padres y abuelos en las labores de producción. Aquí, transmitimos valores, principios y conocimientos sobre la importancia de producir en la chakra, principalmente para el autoconsumo familiar. Sin embargo, en los últimos años también se han desarrollado actividades productivas orientadas a la venta en el mercado que nos generan ingresos económicos para las familias (EF-02, agricultora, omuni Otavalo, Imbabura, 2023).

De la misma manera, en los diferentes grupos focales, principalmente con representantes de los pueblos Kayambi, Cotacachi, Otavalo y Panzaleo, manifiestan que:

> Para nosotros, la chakra es em espacio donde compartimos saberes, omunidade, prácticas omunidade y nuestra forma de ver la vida. También tomamos em cuenta los omunidade agrofestivos, porque nos orientan em los omuni de siembra, cuidado, cosecha y celebración, y tienen em valor cultural, espiritual y productivo para cada omuni. Además, la chakra fortalece la minka, primero em la omunid, donde todos participamos em la producción, y luego em la omunidade, donde vecinos y comuneros colaboramos colectivamente em los trabajos agrícolas. (GF-01, representantes de los pueblos Kayambi, Cotacachi, Otavalo y Panzaleo, 2023)

En contraste, en la provincia del Carchi se observa una menor presencia de estos conocimientos: apenas 1 de los productores encuestados en esa provincia manifestó tener conocimiento general sobre la chakra (Figura 5).

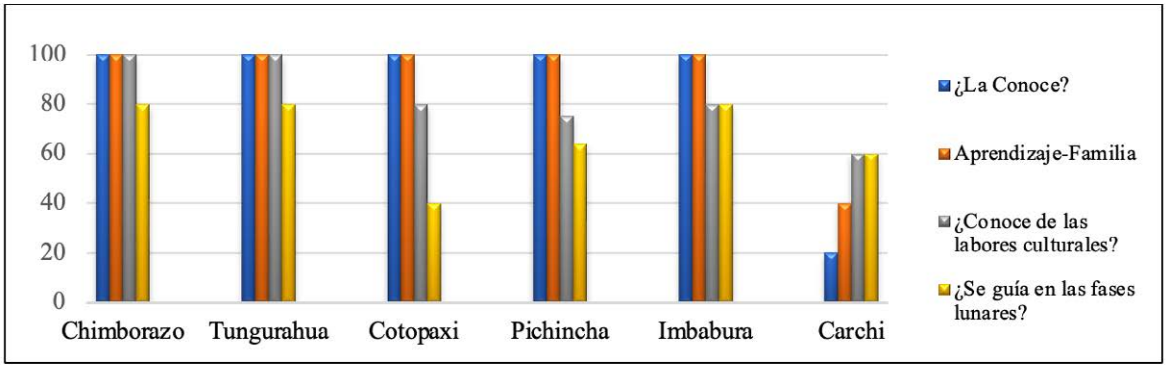

Figura 5 – Noción de saberes y sabidurías de la chakra andina por provincia

Fuente: los autores (2026).

La transmisión intergeneracional de conocimientos constituye un elemento fundamental para la continuidad de los sistemas agrícolas tradicionales. Estos saberes no solo orientan las prácticas agrícolas, sino que también estructuran la relación entre las comunidades y su territorio, configurando sistemas de conocimiento ecológico local que han permitido la adaptación de los pueblos rurales a diferentes condiciones ambientales a lo largo del tiempo (Berkes, 2012; Toledo; Barrera-Bassols, 2008).

Sin embargo, la reducción de estos conocimientos en ciertos territorios refleja procesos de transformación asociados a la expansión de modelos agrícolas basados en la Revolución Verde, los cuales han promovido sistemas productivos orientados a la maximización de la productividad mediante el uso intensivo de insumos externos, la mecanización y la homogeneización de las prácticas agrícolas (Crespo; Vila, 2014). Estos procesos han contribuido a la desvalorización de los saberes campesinos y a

la pérdida progresiva de conocimientos tradicionales asociados al manejo de la biodiversidad agrícola y a la gestión sostenible del territorio.

En el caso ecuatoriano, este proceso tiene una historia específica: la Revolución Verde penetró en la sierra a partir de la década de 1960, impulsada por programas estatales de modernización agraria que promovieron el uso de semillas mejoradas, fertilizantes sintéticos y pesticidas como condición para el acceso a crédito agrícola (Crespo; Vila, 2014). En provincias como Carchi —donde este estudio registra la mayor pérdida de saberes chakra y el uso exclusivo del tractor— la adopción del modelo convencional fue particularmente temprana e intensa, asociada a la expansión del cultivo de papa con variedades mejoradas y agroquímicos (Crespo; Vila, 2014). Este contraste territorial hallado en el estudio no es casual: confirma que la erosión del conocimiento chakra sigue la geografía histórica de penetración de la Revolución Verde en el país, (Brassel *et al.*, 2008), y refuerza la urgencia de políticas diferenciadas que protejan los sistemas de conocimiento ancestral donde aún persisten.

La preservación de estos saberes tiene implicaciones importantes para la sostenibilidad de los sistemas alimentarios rurales. Incorporar conocimientos ancestrales en programas de educación agrícola, investigación participativa y extensión rural podría fortalecer la resiliencia de las comunidades frente al cambio climático y a las transformaciones de los sistemas alimentarios, favoreciendo el desarrollo de modelos agrícolas más sostenibles y culturalmente pertinentes (Altieri; Nicholls, 2017; FAO, 2022).

3.3 MANEJO AGROECOLÓGICO DE LA CHAKRA ANDINA

El manejo agronómico de las chakras presenta variaciones entre provincias. En Imbabura, la mayoría de los encuestados (aproximadamente 4 de 5) utiliza labranza mínima, mientras que 1 emplea un tractor. En Pichincha, alrededor de 3 de 5 encuestados aplican labranza mínima y 2 emplean un tractor. En Cotopaxi y Tungurahua el uso se distribuye de forma similar entre ambas prácticas. En Carchi, los encuestados reportaron uso exclusivo del tractor. Dado que el n por provincia oscila entre 3 y 5 casos, estas cifras reflejan tendencias descriptivas del contexto estudiado y no permiten generalización estadística.

En cuanto al uso de compost, esta práctica en la totalidad de los encuestados en Imbabura, Tungurahua y Chimborazo reportó utilizarlo, mientras que en Carchi solo 1 de los encuestados lo hacía. Respecto a la procedencia de las semillas, en Tungurahua, Cotopaxi e Imbabura casi todos los agricultores encuestados reutilizan semillas propias, mientras que en Chimborazo predominó el uso de semillas comerciales entre los casos registrados (Figura 6).

Esta orientación hacia prácticas orgánicas fue confirmada cualitativamente: una productora de Tungurahua (EF-07) expresó*:*

> En nuestra chakra buscamos evitar el uso de productos externos, como agroquímicos y fertilizantes sintéticos. Por eso, guardamos nuestras propias semillas para las próximas siembras, aprovechamos el rastrojo para alimentar la tierra y usamos los abonos de nuestros animales, junto con los desperdicios de la cocina, para hacer compost. Algunas compañeras también producimos humus de lombriz. Con estas prácticas cuidamos el suelo, fortalecemos nuestra autonomía y mantenemos viva la producción agroecológica y ancestral. (EF-07, productora, Tungurahua, 2023)

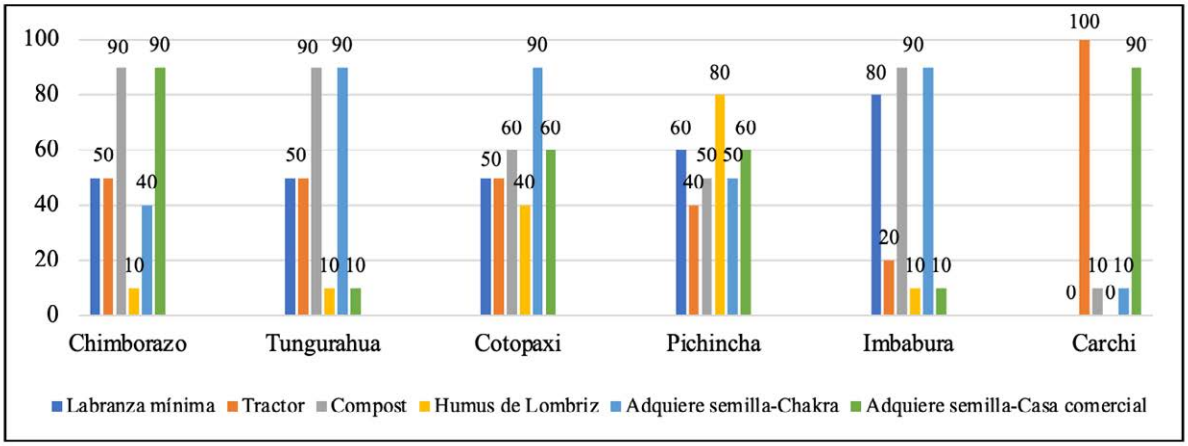

Figura 6 – Prácticas de manejo agroecológico en la chakra andina, sierra ecuatoriana

Fuente: los autores (2026).

Las prácticas observadas reflejan distintos niveles de integración entre conocimientos tradicionales y tecnologías agrícolas modernas. El uso de compost, la labranza mínima y la conservación de semillas locales contribuyen a mejorar la fertilidad del suelo, favorecer la actividad biológica y fortalecer la resiliencia de los agroecosistemas frente a perturbaciones ambientales y climáticas (Gliessman, 2015; Pretty, 2008). Asimismo, la conservación de semillas locales constituye un elemento clave para mantener la diversidad genética de los cultivos y la autonomía productiva de las comunidades campesinas, al preservar variedades adaptadas a las condiciones ecológicas del territorio y a los cambios ambientales (Jarvis *et al.*, 2011; Toledo; Barrera-Bassols, 2008).

Promover estas prácticas agroecológicas mediante programas de apoyo a la agricultura familiar, bancos comunitarios de semillas y procesos de capacitación campesino-a-campesino podría contribuir a reducir la dependencia de insumos externos y fortalecer la sostenibilidad de los sistemas productivos rurales. Diversos estudios han demostrado que los enfoques participativos de innovación agrícola y el intercambio horizontal de conocimientos entre agricultores favorecen la adopción de prácticas sostenibles y fortalecen la resiliencia de los sistemas agrícolas locales (FAO, 2023; Rosset; Martínez-Torres, 2012).

3.4 PRODUCCIÓN AGRÍCOLA Y DIVERSIDAD DE CULTIVOS

Las chakras presentan una importante diversidad productiva. En Chimborazo, Tungurahua y Cotopaxi la mayor parte de los casos registrados corresponde a hortalizas como cultivo predominante, seguidas por raíces y tubérculos, cereales y legumbres. En Pichincha e Imbabura se observa una distribución más equilibrada entre diferentes grupos de cultivos, mientras que en Carchi la producción se concentra principalmente en hortalizas y frutales (Figura 7). Esta diversidad de cultivos refleja la capacidad de las chakras para adaptarse a diferentes condiciones agroecológicas y para integrar especies alimenticias tradicionales con cultivos introducidos, configurando sistemas agrícolas multifuncionales adaptados al territorio.

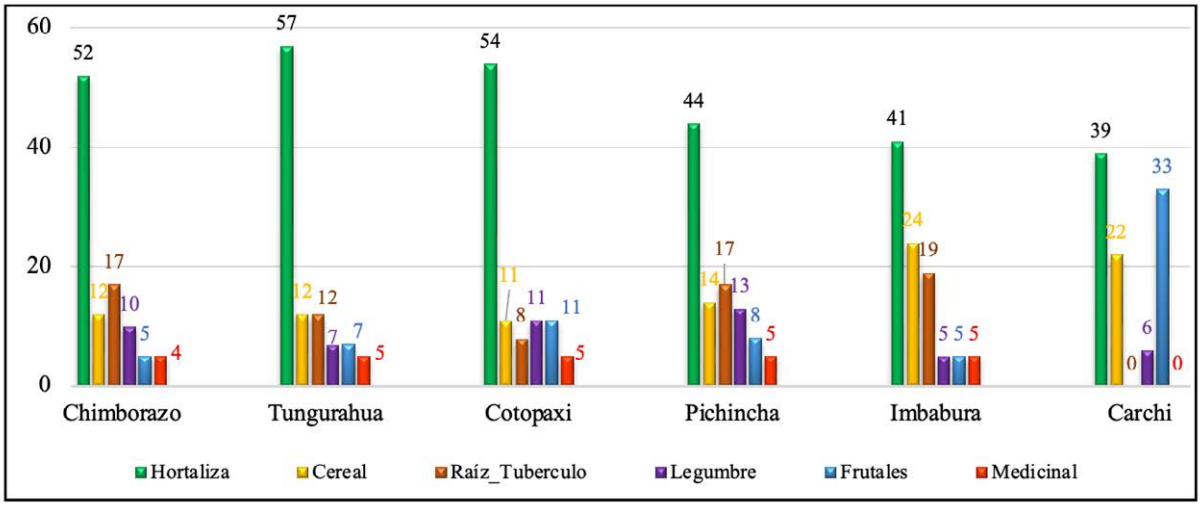

Figura 7 – Diversidad de cultivos en chakras andinas por provincia, sierra centro-norte del Ecuador

Fuente: los autores (2026).

La diversificación agrícola observada en las chakras confirma su carácter multifuncional como sistemas agrícolas orientados tanto al autoconsumo familiar como a la comercialización local. Diversos estudios han demostrado que los sistemas agrícolas diversificados contribuyen a mejorar la resiliencia de los agroecosistemas al reducir los riesgos productivos, aumentar la estabilidad de los rendimientos y fortalecer la seguridad alimentaria de las comunidades rurales (Gliessman, 2015; Perfecto; Vandermeer, 2010; Pretty, 2008). Asimismo, la diversidad de cultivos constituye un elemento clave para la conservación de la agrobiodiversidad y el mantenimiento de variedades agrícolas adaptadas a condiciones ecológicas locales, lo que favorece la adaptación de los sistemas productivos frente a la variabilidad climática y ambiental (Jarvis *et al.*, 2011; Toledo; Barrera-Bassols, 2008; Zimmerer, 2014).

El fortalecimiento de sistemas agrícolas diversificados basados en la chakra podría contribuir a mejorar la seguridad alimentaria en territorios rurales andinos y promover circuitos cortos de comercialización que fortalezcan la economía campesina. En este sentido, los sistemas agrícolas tradicionales han sido reconocidos como estrategias relevantes para enfrentar los desafíos actuales de los sistemas alimentarios, incluyendo la pérdida de biodiversidad, la degradación de los ecosistemas y los efectos del cambio climático sobre la producción agrícola (Altieri; Nicholls, 2020; FAO, 2023; Koohafkan; Altieri, 2011).

3.5 PRODUCCIÓN PECUARIA Y CICLOS ECOLÓGICOS EN LA CHAKRA

La producción pecuaria forma parte integral de la chakra. En términos absolutos, 14 de los 24 hogares encuestados realizan la crianza de cuyes, mientras que entre 3 y 6 producen gallinas ponedoras según la provincia. Los residuos orgánicos derivados de la crianza animal se reutilizan como fertilizantes naturales en los cultivos (Figura 8). Esta práctica permite reciclar nutrientes dentro del sistema productivo y mantener la fertilidad del suelo mediante el uso de abonos orgánicos generados en la propia unidad productiva. Esta integración entre agricultura y crianza fue descrita con claridad por uno de los participantes de los grupos focales:

> Para nosotros, la chakra es una unidad productiva integral, donde combinamos plantas que sirven para la alimentación familiar con la crianza de animales como cuyes, borregos, gallinas, conejos, chanchos, vacas y caballos. Estos animales complementan nuestra alimentación y, cuando hay excedentes, también ayudan a generar ingresos con la venta en el mercado. Además, sus desechos sirven como abono para los cultivos, mientras que los residuos de las plantas alimentan

a los animales. Así mantenemos una relación de apoyo entre plantas y animales, fortaleciendo la biodiversidad y el cuidado de la chakra. (GF-02, productor, sierra centro-norte del Ecuador, 2023).

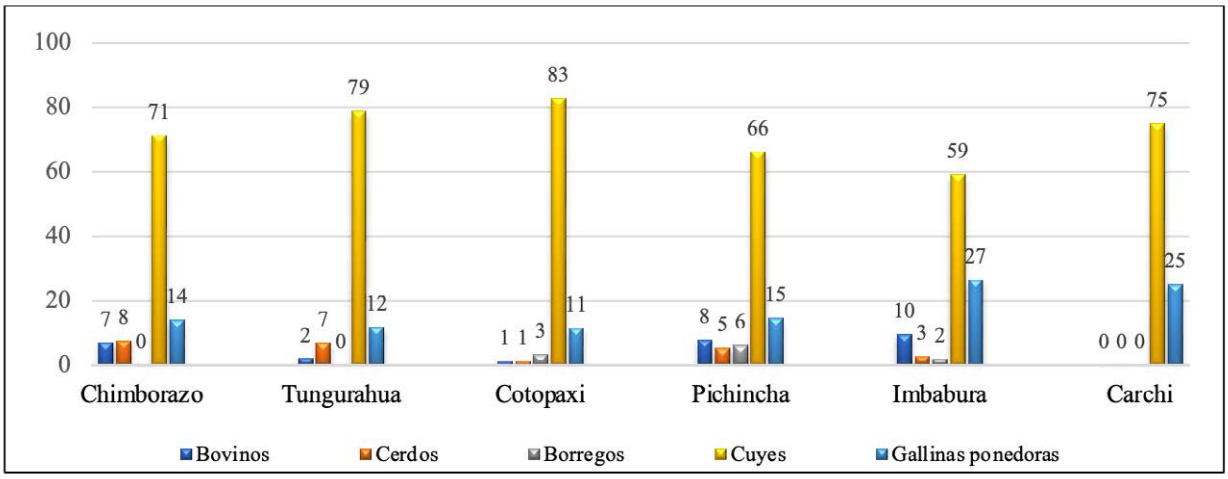

Figura 8 – Especies animales en chakras andinas por provincia, sierra centro-norte del Ecuador

Fuente: los autores (2026).

La integración entre agricultura y ganadería permite cerrar ciclos de nutrientes dentro del sistema productivo y reducir la dependencia de fertilizantes químicos. Estos sistemas integrados han sido reconocidos como estrategias eficaces para mejorar la sostenibilidad de los agroecosistemas, al favorecer el reciclaje de nutrientes, la eficiencia en el uso de recursos y el equilibrio ecológico de los sistemas productivos (Gliessman, 2015; Herrero *et al.*, 2010; Pretty, 2008). Asimismo, los sistemas agrícolas diversificados que integran cultivos y animales contribuyen a fortalecer la resiliencia de las unidades productivas frente a perturbaciones ambientales y económicas, al incrementar la eficiencia del uso de nutrientes, diversificar las fuentes de ingreso y reducir los riesgos asociados a la variabilidad climática (Dumont *et al.*, 2013; FAO, 2023; Thornton; Herrero, 2015).

En este contexto, promover sistemas integrados de producción agrícola y pecuaria podría fortalecer la sostenibilidad de la agricultura familiar y generar fuentes complementarias de ingresos para las comunidades rurales. Además, estas prácticas contribuyen a mejorar la fertilidad del suelo, optimizar el uso de recursos locales y fortalecer la autonomía productiva de las familias campesinas, aspectos fundamentales para el desarrollo de sistemas agrícolas más resilientes y sostenibles (Altieri; Nicholls, 2020; Wezel *et al.*, 2020).

3.6 AGROBIODIVERSIDAD Y GESTIÓN FAMILIAR DE LA CHAKRA

Las chakras analizadas presentan en promedio 25 especies cultivadas por unidad productiva, lo que evidencia un alto nivel de agrobiodiversidad (Figura 9). Esta diversidad agrícola incluye especies alimenticias, medicinales y ornamentales adaptadas a diferentes condiciones ecológicas. La presencia simultánea de múltiples cultivos en un mismo espacio productivo constituye una estrategia tradicional de manejo del territorio que permite optimizar el uso de recursos naturales como el suelo, el agua y la energía solar, además de reducir los riesgos productivos asociados a la variabilidad climática (Altieri; Nicholls, 2020; Toledo; Barrera-Bassols, 2008).

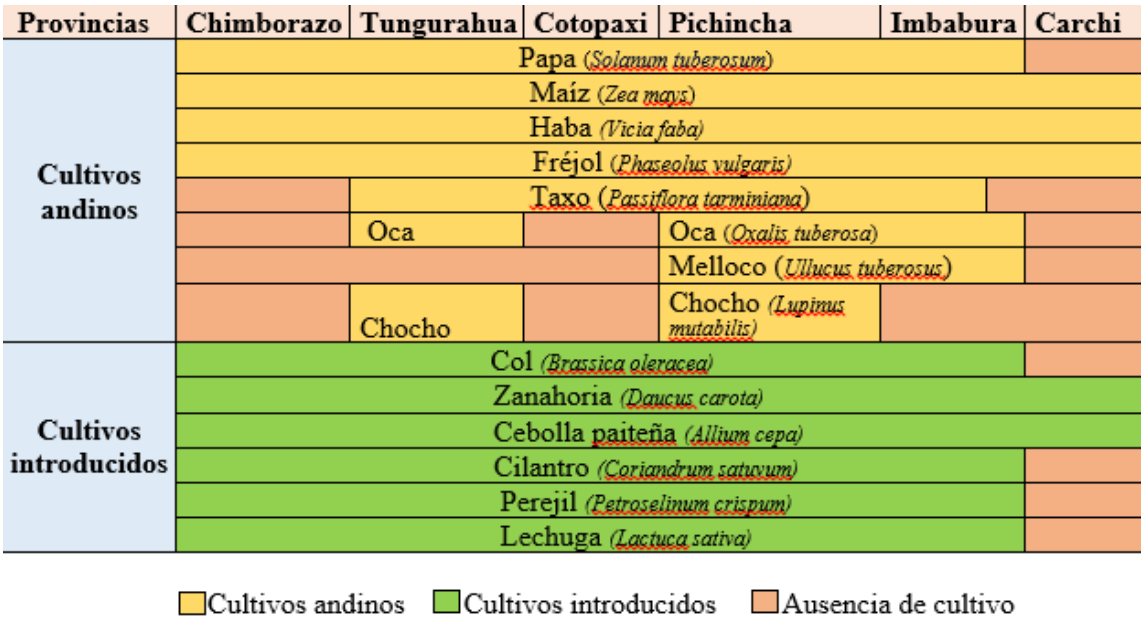

Figura 9 – Especies cultivadas en chakras andinas de la sierra centro-norte del Ecuador

Fuente: los autores (2026).

La diversidad de cultivos presente en las chakras confirma su importancia como reservorios de agrobiodiversidad y como sistemas agrícolas fundamentales para la seguridad alimentaria de las comunidades rurales. Diversos estudios han señalado que los sistemas agrícolas tradicionales mantienen una amplia diversidad genética de cultivos adaptados a condiciones ecológicas locales, lo que contribuye a la estabilidad productiva y a la soberanía alimentaria de las comunidades campesinas (FAO, 2013; Koohafkan; Altieri, 2011).

Asimismo, la conservación de estos sistemas agrícolas tradicionales podría contribuir a preservar recursos genéticos agrícolas y a fortalecer la resiliencia de los sistemas alimentarios frente al cambio climático, ya que la diversidad de especies y variedades permite una mayor capacidad de adaptación frente a cambios ambientales y eventos climáticos extremos (FAO, 2022; Altieri, 2017). En este sentido, las chakras andinas pueden ser consideradas espacios clave para la conservación in situ de la agrobiodiversidad y para el mantenimiento del patrimonio biocultural de los pueblos indígenas de los Andes.

3.7 ROL DE LAS MUJERES EN LA GESTIÓN DE LAS CHAKRAS

El estudio muestra que en la gran mayoría de las chakras visitadas (entre 18 y 19 de las 24 unidades encuestadas) la gestión recae principalmente en mujeres rurales. Estas desempeñan un papel central en la selección de semillas, el manejo del suelo, la organización de la producción agrícola y la transmisión intergeneracional de conocimientos. A través de estas prácticas, las mujeres contribuyen al mantenimiento de la diversidad de cultivos, al cuidado del territorio y a la reproducción de los sistemas alimentarios familiares basados en saberes ancestrales. Diversos estudios sobre agricultura familiar señalan que las mujeres suelen ser las principales responsables de la conservación de semillas, la gestión de huertas diversificadas y la transmisión de conocimientos agrícolas dentro del ámbito doméstico y comunitario (Agarwal, 2018; Howard, 2003). Este protagonismo fue expresado por las propias mujeres durante las entrevistas. Una guardiana de semillas de Pichincha (EF-11) afirmó:

> Desde tiempos antiguos, nosotras, las mujeres, hemos estado al cuidado de la alimentación de la familia y de la chakra como fuente de vida. Uno de nuestros principales roles ha sido cuidar la semilla, porque de ella nacen las próximas cosechas; para nosotras, la semilla es como nuestras wawas: la cuidamos, la protegemos y la vemos crecer. También somos quienes animamos a la familia a participar en la chakra, especialmente los fines de semana, cuando nos reunimos para trabajar, compartir conocimientos y mantener vivas nuestras prácticas ancestrales. (EF-11, guardiana de semillas, pueblo Kayambi, Pichincha, 2023)

El protagonismo de las mujeres en la gestión de las chakras confirma su papel clave en la sostenibilidad de los sistemas alimentarios campesinos y en la conservación de la agrobiodiversidad. Investigaciones sobre sistemas agrícolas tradicionales han destacado que las mujeres rurales desempeñan un rol fundamental en la gestión de la biodiversidad agrícola, particularmente en la conservación de semillas nativas, el manejo de huertas familiares y la transmisión de conocimientos agrícolas y alimentarios (FAO, 2023; Zimmerer, 2014). Asimismo, los enfoques agroecológicos reconocen la importancia del trabajo de las mujeres en la producción de alimentos para el autoconsumo y en la organización de redes de intercambio comunitario, lo que contribuye a fortalecer la soberanía alimentaria y la resiliencia de los sistemas agrícolas locales (Altieri; Nicholls, 2020; Bezner Kerr *et al.*, 2021).

Además, los saberes de las mujeres rurales han sido reconocidos como un componente fundamental en las estrategias de adaptación al cambio climático en territorios campesinos e indígenas, debido a su conocimiento sobre diversidad de cultivos, manejo del agua y prácticas agroecológicas adaptadas a las condiciones locales (FAO, 2023; Nelson; Stathers; Martin, 2016). En este sentido, su participación en la gestión de las chakras no solo tiene implicaciones productivas, sino también culturales, ecológicas y territoriales, ya que contribuye a la conservación del patrimonio biocultural y al fortalecimiento de la resiliencia socioecológica de las comunidades rurales.

Así, el rol de las mujeres en los procesos de producción, liderazgo, comercialización y alimentación de sus familias es fundamental, tal como se manifestó en los grupos focales:

> Quienes trabajamos en la producción de alimentos saludables desde la chakra reconocemos que las mujeres llevamos gran parte de la organización y el liderazgo. Por ello, cumplimos un papel fundamental para mantener viva esta forma de producción. Para nosotros, la chakra no es solo un espacio para sembrar y cosechar, sino también un lugar donde compartimos conocimientos, valores, respeto a la tierra y amor por la naturaleza. Todo este trabajo lo vivimos como una minka, donde todas y todos colaboramos con nuestro trabajo, saberes, intercambio de productos y venta en las bioferias. Así, fortalecemos la chakra desde la unión familiar, la organización comunitaria y el respeto espiritual hacia la vida, la tierra y la comunidad. (GF-03, participantes mujeres, pueblos Kayambi, Cotacachi, Otavalo y Panzaleo, 2023)

Reconocer el papel de las mujeres en la gestión de las chakras tiene implicaciones importantes para el diseño de políticas de desarrollo rural con enfoque de género. Fortalecer su participación en programas de capacitación, financiamiento agrícola y toma de decisiones territoriales podría contribuir a mejorar la sostenibilidad de los sistemas productivos, la conservación de la agrobiodiversidad y la resiliencia frente al cambio climático en las comunidades rurales andinas.

No obstante, el protagonismo femenino en la chakra encierra una tensión: las mujeres son las principales guardianas del sistema, pero este rol se ejerce frecuentemente sin reconocimiento económico, sin acceso equitativo a la tierra ni al crédito, y en condiciones de doble jornada. Investigaciones con comunidades kichwa ecuatorianas han documentado que el empoderamiento femenino en sistemas agroecológicos puede coexistir con estructuras que restringen la autonomía de las mujeres en la toma de decisiones territoriales (Churuchumbi, 2020; Conejo, 2020). La chakra puede ser simultáneamente

un espacio de agencia e identidad y un espacio de sobrecarga de trabajo no remunerado, tensión que futuros estudios deberán abordar con instrumentos específicos.

3.8 LIMITACIONES DEL ESTUDIO

Los resultados deben interpretarse considerando cuatro limitaciones. Primero, el tamaño muestral (n=24 en seis provincias, ~4 casos por provincia) restringe la generalización estadística interprovincial. Segundo, el muestreo intencional hacia familias guardianas de chakras activas subrepresenta a quienes han abandonado el sistema, cuyas trayectorias son igualmente relevantes. Tercero, el diseño transversal (2022-2024) captura un momento del sistema sin dar cuenta de su evolución histórica; estudios longitudinales serían necesarios para comprender su trayectoria de largo plazo. Entonces, los hallazgos son específicos de la sierra centro-norte ecuatoriana y su transposición a otros contextos andinos —Bolivia, Perú, Colombia— requiere precaución, pues cada territorio expresa una configuración particular de cosmovisión, historia agraria y condiciones ecológicas.

4 CONCLUSIONES

En las comunidades estudiadas de la sierra centro-norte del Ecuador, la chakra mantiene su vigencia como sistema productivo basado en la asociación de cultivos, la conservación de semillas nativas y la crianza de animales menores, sostenido por la transmisión intergeneracional de saberes —alli muyu, alli tarpuy, minka— y por el protagonismo de las mujeres como principales guardianas del sistema. La coexistencia de chakras tradicionales y modernas evidencia que esta vigencia no es estática sino adaptativa.

Sin embargo, la expansión de modelos agrícolas convencionales erosiona los saberes en algunos territorios, y el protagonismo femenino coexiste con estructuras que limitan el acceso de las mujeres a tierra, crédito y decisiones territoriales. Estas tensiones señalan que la resiliencia de la chakra no está garantizada y depende de condiciones institucionales, culturales y económicas que el estudio no puede resolver por sí solo.

Los hallazgos respaldan la incorporación de la chakra en los instrumentos de planificación territorial intercultural, el fortalecimiento de bancos comunitarios de semillas nativas y el reconocimiento económico del trabajo femenino que sostiene el sistema. Estas medidas requieren el concurso de gobiernos locales, instituciones de investigación y organizaciones indígenas.

La chakra andina representa una respuesta activa a los desafíos socioambientales del presente bajo el paradigma del Sumak Kawsay. Preservarla es preservar una forma de relacionarse con el territorio que la crisis global hace cada vez más necesaria, y una agenda de investigación longitudinal y comparativa en los Andes es indispensable para consolidar la evidencia que oriente esa tarea

DECLARACIÓN SOBRE EL USO DE INTELIGENCIA ARTIFICIAL

Los autores utilizaron ChatGPT, desarrolhado por OpenAI, exclusivamente para la revisión lingüística y el perfeccionamiento estilístico. Todo el contenido científico, el análisis y la contribución intelectual fueron desarrollados y verificados por los autores, quienes asumen plena responsabilidad por la precisión e integridad del manuscrito.

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In this edition of August 2026, governance and the gap between scientific knowledge and political decision-making are recurring themes. Jesus and Wernke examine coastal conservation units in Amapá against licensing of the FZA-M-59 block in the Equatorial Margin, finding environmental justice only partially incorporated, and Leal *et al.* apply an SDG-adherence index to municipal solid waste plans in 34 Goiás municipalities, finding the highest scores driven by declarative elements rather than implementation. Costa *et al.* map the State and Federal District Water Resources Councils, finding public-sector representation dominant and functioning uneven across the federation. The science-policy interface is examined by Araújo *et al.*, comparing two Brazilian climate-governance arenas between 1999 and 2009. Institutional gaps and their socio-environmental costs are explored by Oliveira *et al.*, tracking soil quality in the Jacaré Curituba Settlement, Sergipe; by Silva and Guerrieri, assessing distributed photovoltaic generation among low-consumption households and proposing an exemption from the availability cost for systems up to 1.5 kW; and by Borille *et al.*, studying perceptions of meat consumption and Amazon deforestation. Vecchietti *et al.* address conscious consumption and circularity among secondary-school students. Finally, Vargas-Chaves and Luna-Galván examine institutional cooperation in Latin America through the Treaty of Tlatelolco, and Cachipuendo *et al.* analyse the Andean chakra as a socioecological system of Sumak Kawsay.

Nesta edição de agosto de 2026, governança e a distância entre o conhecimento científico e a decisão política são temas recorrentes. Jesus e Wernke examinam unidades de conservação costeiras no Amapá diante do licenciamento do bloco FZA-M-59, na Margem Equatorial, constatando que a justiça ambiental permanece apenas parcialmente incorporada, e Leal et al. aplicam um índice de aderência aos ODS aos planos municipais de resíduos sólidos de 34 municípios de Goiás, verificando que as pontuações mais altas são sustentadas por elementos declarativos, não por implementação. Costa et al. mapeiam os Conselhos Estaduais e Distrital de Recursos Hídricos, identificando preponderância do poder público e funcionamento desigual entre as unidades da federação. A interface entre ciência e política é examinada por Araújo et al., que comparam duas arenas de governança climática brasileira entre 1999 e 2009. Lacunas institucionais e seus custos socioambientais são explorados por Oliveira et al., que acompanham a qualidade do solo no Assentamento Jacaré Curituba, em Sergipe; por Silva e Guerrieri, que avaliam a geração distribuída fotovoltaica entre consumidores de baixo consumo e propõem isenção do custo de disponibilidade para sistemas de até 1,5 kW; e por Borille et al., que estudam a percepção sobre consumo de carne e desmatamento na Amazônia. Vecchietti et al. abordam o consumo consciente e a circularidade entre estudantes do ensino médio. Por fim, Vargas-Chaves e Luna-Galván examinam a cooperação institucional na América Latina por meio do Tratado de Tlatelolco, e Cachipuendo et al. analisam a chakra andina como sistema socioecológico do Sumak Kawsay.

Execution

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