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Conservation and land-use governance in Brazil: Domestic and international interconnectivity

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ABSTRACT

Governance strategies, involving both governmental and non-governmental entities, are instrumental in regulating land use practices and conservation, specifically in countries with high agricultural commodity production. Their interconnection is vital for advancing sustainable agriculture and forest use while simultaneously addressing greenhouse gas emissions and land use and land rights. This study examines domestic and international interconnections of Brazil's land-use-related strategies based on Social Network Analysis techniques. Our findings reveal that Brazil's governance framework is broad and comprehensive. Key policies (climate, forest, and agriculture) are well connected, thus reducing sectoral fragmentation. Regulations to curb deforestation act as key connectors. The balance between production and conservation strategies supports coherence, reinforces coordination, and contributes to Brazil's capacity to deliver sustainable outcomes. Non-state and hybrid strategies complement state-led policies but could be strengthened to further improve overall governance. International connections — mainly linked to forest and climate strategies — exist but are uneven and limited. For instance, the Brazilian Forest Policy, the most interconnected strategy, is mainly linked to a specific international forest governance cluster with little cross-sector interrelation. Our results suggest a broad and mostly well-connected domestic land use governance framework but reveal the need to improve the integration of several less-connected domestic regulations and to strengthen alignment with international policies. The findings can inform the design of policy frameworks capable of supporting national and global sustainability targets. A future focus on implementation can help bridge the gap between policy design and real-world outcomes.

1. Introduction

Balancing conservation, sustainable land use, and economic development is a key challenge for environmental governance (Cocco et al., 2023; Pörtner et al., 2023). Environmental and societal challenges need to be tackled simultaneously (Bateman et al., 2024; Beland Lindahl et al., 2023; Zurek et al., 2022), while also considering a multifaceted international land use governance framework (Kleinschmit et al., 2024). In an interconnected global context, governance strategies across countries constitute intricate networks that integrate domestic and international policies into complex policy mixes (Bouma et al., 2018). This paper examines these interlinkages, focusing on synergies within Brazil's governance framework and its alignment with global commitments.

Brazil is a major player in global commodity supply chains and environmental negotiations. The country plays a key role in meeting the world's growing demand for agricultural commodities while also working to reduce GHG emissions from land-use changes (de Sousa-Neto et al., 2018). Brazil's export commodities, such as soybeans, beef, timber, and palm oil, contribute significantly to the country's GDP. In 2023, the economic sector that grew the most was the agricultural sector (15.1 %) (Cézar et al., 2024). However, this agricultural expansion often comes at the expense of natural habitats, particularly in the Amazon rainforest, where activities are commonly associated with irregular land occupation, deforestation/degradation, illegal or degrading labor, and rural violence (Moutinho et al., 2016; Moutinho and Azevedo-Ramos, 2023; B. Reydon et al., 2022). Despite some progress, persistent

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governance challenges — including weak law enforcement, policy fragmentation, and shifting political priorities — raise concerns about Brazil's ability to translate commitments into effective, long-term sustainability outcomes. Therefore, it has been argued that Brazil must balance agricultural development and forest use while conserving its natural heritage (Reydon et al., 2020). A mix of sustainable practices, conservation efforts, and land rights is vital to harmonize these goals and ensure the prosperity of both agriculture and forest ecosystems.

This balance relies heavily on how governance arrangements shape land-use dynamics and influence enforcement capacity. The effective governance of land, forests, agriculture, and climate policies is key to achieving sustainability. From 2005–2013, a combination of measures — including command and control policies, the expansion of protected areas, restricted access to credit, and interventions in specific production chains — contributed to approximately 70 % of deforestation reduction in the Brazilian Amazon (Nepstad et al., 2014). After a period of an increasing trend due to political disturbance, deforestation dropped by 30.6 % between 2023 and 2024 as a result of similar strategies (INPE, 2024).

However, domestic progress needs to be analyzed in light of shifting international pressures, particularly those driven by trade and environmental regulations. The rising global demand for forest-risk commodities has already driven more stringent regulations and international efforts to curb the negative impacts of unsustainable trade (Bager et al., 2021; Estrada et al., 2018). Yet, the effects of foreign policies aiming at increased carbon removal and ecological restoration, like the Green Deal policy package in Europe, need to be taken into account, as they have been shown to increase the demand for agricultural commodities from countries like Brazil. In general, the translation of international land-use governance frameworks into Brazilian policies has been uneven, varying across initiatives such as forest certification, market-based mechanisms, and international funds. Power dynamics, institutional capacity, and local governance often mediate how global expectations are interpreted and implemented (Kanashiro Uehara et al., 2023). Similarly, Milhorance et al. (2022) found that efforts to mainstream climate adaptation into sectoral policies have led to a fragmented and divergent policy landscape.

One example, also part of the European Green Deal policy package, is the EU Regulation on Deforestation-Free Products (EUDR) — Regulation (EU) 2023/1115 (European Union, 2023). Set to enter into force in 2026, it is currently the subject of intense debate, as it imposes strict restrictions on the import of commodities associated with deforestation. The regulation places direct compliance obligations on Brazilian exporters, requiring them to align domestic monitoring systems and land-use practices with increasingly stringent international sustainability standards (Azevedo-Ramos and Murakami Lima, 2024).

As sustainability expectations increase, nations must adapt their governance strategies to avoid the leakage-effect of environmental risks from such stricter regulations elsewhere and to comply with stricter global regulations in general (Azevedo-Ramos and Murakami Lima, 2024; Shen et al., 2024). Understanding how governance strategies function and interact — particularly in developing nations — is essential for clarifying land rights, reducing environmental impact, and ensuring equitable resource use. A comprehensive analysis of governance mechanisms can also help policymakers identify gaps and develop stronger regulatory frameworks to support sustainable land management through integrated policy mixes and participatory decision-making. Such policy mixes (Bouma et al., 2018) are also essential to ensure that increased international demands do not result in an expansion of unsustainable land use practices, leading to pressure on natural resources.

To advance the scientific understanding of how governance strategies respond to these pressures, it is crucial to analyze how internal and external forces interact. Both domestic and systemic factors (e.g., external influences) are essential for understanding the economic and environmental dynamics of international politics (Chaudoin et al., 2015; Frieden and Martin, 2003; Shen et al., 2024). However, the intricate interaction between international and domestic politics challenges the establishment of clear causal relationships in the development of national or international policies, partly due to indirect or independent outcomes (Chaudoin et al., 2015). While international sustainability initiatives may influence domestic policies in producing countries, their effectiveness depends on how they interact with pre-existing national strategies, which may have been established prior to external demands (Bernstein and Cashore, 2012). This interaction is essential because the structure and articulation of domestic policy frameworks, as well as their national implementation, may be crucial for global impacts. Global frameworks are not effective without national implementation (Torre et al., 2021). Moreover, the long-term validity of initiatives is intrinsically linked to how they are operationalized in practice by domestic institutions and to the interpretations attributed by the social actors involved in their implementation (Sessin-Dilascio et al., 2024). While domestic institutions act as mediators, balancing external pressures with national interests (Chaudoin et al., 2015; Frieden and Martin, 2003), coalitions of actors shape how international policies are (or are not) implemented domestically (Sotirov et al., 2021).

While prior studies have advanced our understanding of individual policy implications (e.g., Boyd, 2008; Butler and Laurance, 2008; Tacconi et al., 2019), there is limited research on the systemic interactions within Brazil's domestic governance strategies, and between them and international sustainability frameworks. Some authors have assessed how specific international frameworks — such as global conventions and goals — influence particular Brazilian policies, including those on forestry (Faggin and Behagel, 2017) and agriculture (Siegel and Bastos Lima, 2020, Oliveira et al., 2024). Also, the degree of alignment between domestic governance strategies and global frameworks, particularly in reconciling economic development goals with progressively stringent environmental regulations, remains uncertain.

This study analyzes the following research questions: To what extent do Brazil's existing governance strategies meet domestic and international expectations, particularly in climate change mitigation, conservation, and sustainable commodity production? To address this question, the research approach examines the interconnection of synergistic goals within Brazil's governance framework related to climate change, land use/rights, agriculture, and forests, including production practices adopted to strengthen sustainable commodity trade. We also assess the interconnections between Brazil's domestic policies and their alignment with international governance frameworks, particularly in efforts to reduce deforestation/degradation, GHG emissions, and impacts associated with international forest-risk commodity trade. The assumption is that the greater the integration between intersectoral/transnational strategies, the greater the chances of achieving common environmental objectives (Lafferty, 2007; Lafferty and Hovden, 2002). The discussion presents reflections on the gaps between policy design (de jure) and implementation (de facto) while assessing interconnections among governance strategies. This study also provides a novel approach to evaluating Brazilian policy interconnectivity by applying Social Network Analysis (SNA) (Aurenhammer, 2015).

1.1. Theoretical approach

Given the complex interplay between Brazil's domestic and international governance strategies, a policy mix approach allows for a more nuanced analysis of complementary regulations, sectoral interactions, and multi-level governance dynamics. This approach is particularly relevant in contexts where policy effectiveness depends on cross-sectoral coordination and transnational cooperation. Governance strategies often rely on policy mixes, which combine political strategies (objectives and plans) with instruments that interact through political processes. Policy mixes are generally more effective than isolated strategies in achieving long-term strategic goals (Quitzow, 2015; Bouma et al., 2018). An effective policy mix must also be consistent, coherent, credible, comprehensive, and adaptable (Rogge and Reichardt, 2013). Additional factors — including multi-level governance, policy sequencing, and integration across strategies or countries (Cejudo and Michel, 2021; Howlett, 2019) — challenge the assessment of policy-mix effectiveness. In addition to state-led efforts, non-state initiatives such as coalitions, voluntary agreements, and independent monitoring systems, play a complementary role in optimizing land use and minimizing environmental harm (Reydon et al., 2020). This set of different relevant variables and layers of analysis in the assessment of governance strategies makes the task very complex.

Policy interaction is a central feature of policy mixes, especially in the horizontal dimension of analyses, as it refers to the way in which different policies complement, contradict, or influence each other, affecting their outcomes (Rogge and Reichardt, 2016). In countries of production, where large-scale agricultural, livestock farming, and unsustainable logging activities often have significant environmental impacts, governance strategies serve as crucial tools for steering land use towards sustainability. Aligning governance strategies across sectors is essential for ensuring sustainable agricultural production, enforcing conservation policies, and reducing GHG emissions. Ideally, intersectoral policies must be integrated to leverage common environmental objectives (Lafferty, 2007; Lafferty and Hovden, 2002).

Effective national governance frameworks also require coordination between state and non-state actors, along with strong domestic-international policy linkages. Harmonization between domestic and international governance frameworks ensures consistency in objectives and actions, facilitating the attainment of shared sustainability goals at a global scale (Lafferty and Hovden, 2002).

Given the large number of national and international strategies developed over different periods examined in this study, we focus on the interactions among policy goals to simplify the assessment of governance strategy interconnections. To achieve this, we employ social network analysis (SNA) and its associated metrics (Hanneman and Riddle, 2005). SNA has been widely used to analyze relationships among actors (Moeliono et al., 2016; Schröter et al., 2018) and has increasingly been applied in policy research, although its use is still more concentrated in European papers (Zhang et al., 2023). In Brazil, network analyses have concentrated on actors' relationships or perceptions (Glaser et al., 2018; Maglia, 2022; Mertens et al., 2011; Olaya-Restrepo et al., 2022). As far as we are aware, its use in assessing interactive relationships among Brazilian governance strategies is still a novel approach. Here, we apply SNA to analyze land-use and conservation policy frameworks.

By assessing policy interconnections at both domestic and international levels, we provide insights into how Brazil's governance strategies contribute to sustainability and compliance with global environmental commitments. Strengthening policy complementarities and governance linkages is crucial for addressing the complex challenges of land management, biodiversity conservation, and climate action

2. Methodology

First, we identified and categorized Brazilian policies and regulations related to climate change, agriculture, forests, and land rights. Commodity trade—particularly the supply chains of soy, beef, palm oil, and timber—is often addressed in Brazilian agricultural and forestry strategies. In addition to state-driven policies, we included non-state and hybrid strategies (Börzel and Risse, 2010) that contribute to policy monitoring, conservation, and sustainable production.

National policies provide general guidance, while specific implementation measures are introduced through supplementary regulations or decrees. To reflect this distinction, governance strategies examined in this study were classified into three categories: (a) national policies, which establish broad legal and strategic frameworks; (b) federal regulations, which define specific implementation rules; and (c) non-state or hybrid initiatives, which encompass agreements, standards, procedural rules, and voluntary commitments developed by non-state actors or in collaboration with state institutions. The identified Brazilian governance strategies were grouped into four main topical categories, namely land rights (LR); conservation (Cons); agriculture, livestock, and forestry (Agr&For); and climate change (Climate) - to facilitate cross-sectoral analyses. Nevertheless, it should be noted that these are broad categories, capturing only the main target areas. They may, to some extent, also encompass aspects of other categories as well.

We examined interconnections among governance strategies in two steps: after we had assessed how Brazilian regulations and non-state/hybrid initiatives relate to high-level national policies, we then evaluated how Brazilian policies align with key international governance strategies (conventions, agreements, and regulations) (Fig. 1).

We identified Brazilian legislation on the topics mentioned above using official government websites and conducted a content analysis focusing on their goals (see below). To complement the analysis, we conducted a non-systematic review of scientific literature and policy reports from 2000 to 2023, using Google Scholar to ensure comprehensive coverage and the selection of relevant governance strategies, especially for non-state/hybrid initiatives.

The selected international governance strategies (Table 1) were adapted from Sotirov et al. (2020), who provide detailed descriptions of these governance frameworks. Regarding trade policies, we focused on the European Union's regulatory framework for deforestation-free commodities (EUDR, EUTR/FLEGT) as a proxy for similar international regulations, whether enacted or under consideration (e.g., UK Environment Act 2021, Schedule 17; US FOREST Act of 2021 – S.2950 – Fostering Overseas Rule of Law and Environmentally Sound Trade), given that these EU policies represent a significant global initiative to reduce the environmental impact of commodity imports.

Governance interconnections were established exclusively based on synergies identified through content analysis. In governance and policy literature, synergy refers to complementary interconnections between policy domains (or goals) that enhance overall impact compared to policies operating in isolation (Carmen et al., 2023; Pedercini et al., 2019). Governance strategies were considered interconnected when one was explicitly mentioned as relevant or referenced in the legal texts or policy documents of another. Additionally, connections were indirectly established when synergies between policy goals were inferred from content analysis. For example, a law preventing illegal deforestation may not explicitly reference climate policy but can be linked through its specific goal of reducing emissions, forming a policy tie. When no such synergy was identified, no tie was established, either due to a lack of relationship or the presence of conflicting objectives (e.g., antagonisms).

Therefore, rather than evaluating the effectiveness or other aspects of policies, our analysis focused on how the stated goals of governance strategies interconnect across different sectors. While this simplification provides useful insights into governance complexity and complementarity, we acknowledge that our de jure (legal) approach may not fully capture the dynamics of policy implementation. To address this, the discussion section incorporates de facto (practical outcomes) assessments of selected relevant governance strategies based on literature.

To systematically map and visualize governance interconnections, we applied Social Network Analysis (SNA) using Gephi, an open-source network analysis tool (Bastian et al., 2009). SNA enables the systematic identification of structures and relationships in a network formed by individuals, institutions, or elements (Hanneman and Riddle, 2005; Liu et al., 2020). The aim is to explain their meanings, relationships, and implications (Knoke and Yang, 2019; Tabassum et al., 2018). This approach allowed us to pinpoint the most and least connected governance strategies and assess their structural significance within the network. In general, SNA relies on nodes, which can be any type of entity, and edges, which are the interconnections and relations between the nodes (Hanneman and Riddle, 2005). In our analysis, nodes of a network represented individual governance strategies (state, non-state, and hybrid), while edges (relations) represented direct or inferred

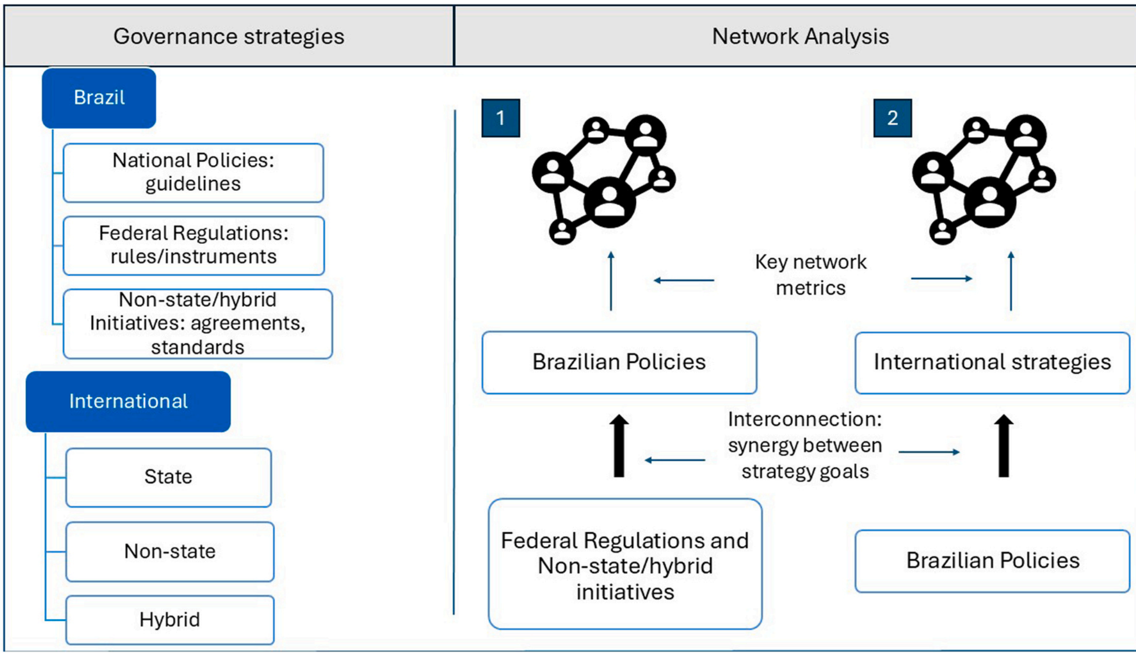

Fig. 1. Typology of governance strategies and their assessment through network analysis: (1) interconnections within Brazil's domestic strategies and (2) linkages between domestic and international governance frameworks.

policy connections based on synergy.

We calculated key network metrics to analyze governance structure. Modularity, ranging from −1 to + 1, measures the degree of clustering within the network, with higher values indicating well-defined policy clusters (Newman, 2006). Degree and Density assess the level of connectivity in the network. Degree is the number of connections per node. In-degree is the number of edges a node receives (incoming connections; in this study, links to lower-level strategies), and out-degree is the number of edges that a node directs to others (outgoing connections; in this study, links to higher-level strategies). Degree metrics thus highlight policies or strategies that exert strong influence over others, using the lower-to-higher hierarchical level approach in directional relationships. Density is the proportion of actual connections relative to all possible connections (max density = 1), indicating how close a network is to being fully connected; low density values indicate sparse and loose networks.

We also applied the Hyperlink-Induced Topic Search (HITS) algorithm, a variant of "eigenvector centrality" (ranging from 0 to 1), to measure the relative influence of governance strategies in the network based on their connections. This approach uses two measures: hubs distribution, which indicates the quality of a node's connections (i.e., how well-connected a strategy is), and authority distribution, which measures the value of information stored in a node. A high hub-centrality suggests that a policy links to multiple authoritative governance nodes, while a high authority score indicates that a policy is frequently referenced by other influential governance strategies. The more connected it is to other important elements, the greater the relevance and influence of this strategy in the network (Bonacich, 1972).

3. Results

3.1. Brazil's governance strategies

3.1.1. National policies

We identified 14 main policies that play a central role in governing broad categories: land rights (LR = 3); conservation (Cons = 5); agriculture, livestock, and forestry (Agr&For = 5); and climate change (Climate = 1) in Brazil (Table 2). The National Agrarian Reform Program (Land Statute) is a basic document that has been in force since the 1960s, forming the legal foundation for land governance. The 1988 Federal Constitution introduced environmental protections and reinforced the principle that rural property must serve a social function. Target environmental and agricultural policies were developed and strengthened in the 1980s and 1990s, establishing key principles, guidelines, and objectives for the management of natural resources, forests, and agricultural production. In line with global trends toward sustainability and socio-environmental concerns, the 2000s saw the expansion of policies related to land rights, conservation, and climate change.

3.1.2. Federal regulations

The 26 selected federal regulations (Table 3) were also grouped into land rights ($n = 2$); conservation ($n = 9$); agriculture, livestock, and forestry ($n = 9$); and climate change ($n = 6$).

3.1.3. Non-state or hybrid Initiatives

We identified nine non-state or hybrid governance strategies (Table 4), seven of which may be categorized as closely related to agriculture, livestock and forestry, although conservation and climate issues may be included in their approach. Likewise, two of the nine strategies were more closely related to conservation, although sustainable economic use may be included. These initiatives, developed by private-sector actors, civil society organizations, or multi-stakeholder coalitions, complement state-led policies by contributing to governance monitoring, conservation efforts, and sustainable production standards.

3.2. Domestic policy interconnections

In the network of Brazil's lower-level strategies (federal regulations and non-state/hybrid initiatives) and higher-level national policies (Fig. 2), every regulation/initiative was linked to at least one national policy, with many connected to several policies (average degree = 3.02; range: 1–12). However, low density values (0.06 %) indicate a sparse network, meaning that fewer connections exist than would be theoretically possible in a fully interconnected network. Both measures indicate

Table 1
Selected international conservation policies and governance arrangements (adapted from Sotirov et al., 2020).

Code (Source)	Description	Year
1.State		
UNFCCC	United Nations Framework Convention on Climate Change. The main legally binding goal of the global climate protection accord is “the stabilization of greenhouse-gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system”. Its Nationally determined contributions (NDCs) are the form the signatories are obliged to formulate and implement their commitments to keep global warming below 1.5 ∘C (United Nations, 1992a).	1994
CBD	The Convention on Biological Diversity. Three legally binding policy goals: (a) the conservation of biological diversity; (b) the sustainable use of its components; and (c) the fair and equitable sharing of the benefit (United Nations, 1992b).	1993
ITTA/ITTO	International Tropical Timber Agreement (ITTA)/ International Tropical Timber Organization (ITTO). The ITTA is administered by the International Tropical Timber Organization (ITTO) comprising timber “producer” and “consumer” member countries aiming to promote the expansion and diversification of international trade in sustainable tropical timber, and national forest programs (United Nations, 2006).	1985
CITES	The Convention on International Trade in Endangered Species of Wild Fauna and Flora. A multilateral agreement that regulates the trade of endangered plants and animals through import/export permits, lists of species at risk, among others (United Nations, 1976).	1975
UNCED	The UN Conference on Environment and Development (UNCED), also known as the ’Earth Summit’, held in Rio de Janeiro, Brazil. Its goal was to produce a broad agenda for international action on environmental and development issues that would help guide international cooperation and development policy on a sustainable basis. Provided the basis for: Agenda 21, UNFCCC, CBD, Rio Declaration, and the Declaration on the principles of forest management (United Nations, 1992c).	1992
FORESTArrang	International Arrangement on Forests (IAF) - the basis for international forest governance within the UN system, promoting the management, conservation, and sustainable development of all types of forests. Set of non-legally binding strategies and forest goals, enhancing cooperation, coordination, coherence, and synergies on forest-related issues (United Nations, 2015).	2000
SFM-CI	Sustainable Forest Management Criteria & Indicators. An initiative from ITTO and others to develop C&I for forest management based on expert-driven process to be adopted by tropical countries on a voluntary-basis (United Nations, 2000).	2006
2. State and non-state		
FLEGT	EU Forest Law Enforcement, Governance and Trade (FLEGT) Action Plan. Its goal was to assure legality in forestry and timber supply chain. Introduced the Voluntary Partnership Agreements (VPAs), a legally binding political and trade agreement between the EU and timber producers in tropical countries (European Union, 2005).	2003
EUTR	EU Timber Regulation. Prohibits the placing of illegally sourced timber products on EU markets (European Union, 2010).	2010
EUDR	EU Regulation on Deforestation-free Products. It aims to reduce the to reduce the contribution of EU imports to deforestation and forest degradation and promote sustainable supply chains (palm oil, soy, timber, coffee, cocoa, rubber, and beef; and co-products) and reduce greenhouse gas emissions (European Union, 2023).	2023
REDD+	’Reducing emissions from deforestation and forest degradation’ in developing countries. The ’+ ’ stands for sustainable management of forests and the conservation and enhancement of forest carbon stocks. It aims to directly address drivers of deforestation and forest degradation contributing to climate change. The 2015 Paris Agreement of UNFCCC encourages members to take action to implement and support the existing framework for REDD+ (United Nations, 2008).	2010
BonnChallenge	The Bonn Challenge - a global goal to bring 160 million hectares of degraded and deforested landscapes into restoration by 2020 and 350 million hectares by 2030, contributing to sustainability commitments, biodiversity and water conservation, and rural development (IUCN, 2019).	2011
TROPICALFORESTAlliance	The Tropical Forest Alliance - a multi stakeholder partnership platform established to support companies through the ongoing global transition to deforestation-free supply chains for commodities including palm oil, soy, beef, and paper/pulp (Consumer Goods Forum and US, 2012).	2012
NYFORESTDeclaration	New York Declaration on Forests - a voluntary and non-legally binding political declaration of multistakeholder which grew out of dialogue among governments, companies and civil society, spurred by the United Nations Secretary-General’s Climate Summit held in New York in 2014, calling for global action to protect and restore forests. It includes support to REDD+ , FLEGT, forest restoration and eliminating deforestation from supply chains (Climate summit, 2014).	2014
3. Non-State		
FSC	Forest Stewardship Council. A forest management certification scheme developed by a transnational non-state actor coalition of NGOs, and large multinational firms, based on third party auditing and eco-labelling in line with criteria & indicators for SFM, leading to price premiums and increasing reputation (FSC, 2023).	1993
PEFC	Programme for the Endorsement of Forest Certification. A global alliance of a country-level SFM certification schemes led by non-state and state forest enterprises, domestic forest industries, and some multinational companies, usually supported by governments (PEFC, 2024).	1999
RSPO	Roundtable on Sustainable Palm Oil. An initiative of multi-stakeholders to establish certification rules and standards for a global sustainable palm oil, which includes the ban on the conversion of natural forests and preservation of areas of high conservation value (RSPO, 2018).	2002
RTRS	Roundtable on Responsible Soy Association. An initiative of multi-stakeholders to establish standards for responsible soy production, including deforestation-free production (RTRS, 2022).	2006

(continued on next page)

Table 1 (*continued*)

Code (Source)	Description	Year
GRSB	The Global Roundtable for Sustainable Beef. An initiative of multi-stakeholders to establish standards for responsible beef production, including deforestation-free production. Indicators and related practices are developed through regionally based processes (GRSB, 2025).	2010

that the network could benefit from stronger inter-strategy connections to enhance policy synergies. Modularity, which measures the strength of a network's division into clusters, was low (0.259), indicating low grouping between strategies. In other words, different types of governance strategies are relatively well integrated rather than isolated into sector-specific clusters, indicating that the network is less siloed but still loosely connected. To visualize these relationships, we used the Fruchterman-Reingold distribution in Gephi, which positions connected nodes closer together and separates unconnected nodes. The results highlight the above-described cross-sector relationships between policies and federal regulations, as well as non-state and hybrid initiatives.

Regulations/initiatives with higher out-degree values (connections directed to national policies) indicate their potential to influence strategy interactions. The regulations/initiatives most connected to different national policies were PPCerrado and PPCDAM (both with 12 out-degrees, meaning that they are related to nearly all of the 14 policies), followed by the Payments for Environmental Services (PES) program (8). In turn, the national policies most interconnected with governance strategies (high in-degree values) were the National Climate Change Policy (ClimatePOL, 23 connections), the National Forest Policy (ForestPOL, 20), and the National Agriculture Policy (AgriPOL, 20). The graphical representation also shows that among the most central and highly connected policies, the Agriculture Policy is more isolated compared to the Forest, Climate, Biodiversity, and Environment Policies, which are more closely related to each other. The National Environmental Education Policy (EnvironEducPOL) and the National Biodiesel Policy (BiodieselPOL) had the fewest connections (1 each) and thus a more isolated position, indicating a more niche focus with respect to land use.

In terms of authority values, there is a prominence of climate, forest, and agriculture policies in the network, which highlights their central role in Brazil's governance structure. Policies such as ClimatePOL (0.452), ForestPOL (0.440), EnvironPOL (0.399), BiodiversityPOL (0.361), RestorationPOL (0.331), and AgriPOL (0.284) show the highest authority values. Regulations to curb deforestation in the Cerrado (PPCerrado) and Amazon (PPCDAM) biomes have the highest hub values (0.3175), meaning they serve as key connectors within the governance network. These two strategies integrate multiple governance dimensions in their planned actions, including command-and-control mechanisms, land regularization, and economic incentives for sustainable production.

Among non-state/hybrid initiatives, the soy moratorium (SoyMorat) and the G4 cattle agreement (G4Cattle) occupy a more central position in the network, indicating their stronger connection to national policies, especially policies related to agriculture, forest, and climate. In contrast, observatories and coalitions, which are more informational initiatives, tend to be positioned at the network's periphery.

Overall, the analysis suggests that Brazilian national policies are connected to a diverse range of federal regulations and non-state/hybrid initiatives. This interconnected and lowly clustered structure provides potential for synergies in land-use planning, GHG emissions reduction, and sustainable commodity production. However, given the loose structure of the network, it also indicates that further integration between production, conservation, and land governance strategies could enhance cross-sectoral policy synergies.

Table 2
Selected Brazilian policies presented in chronological order of enactment.

Code	Description*	Rule**	Category ***	Main goal
AgrarReformPOL	Agrarian Reform Programme (*"Land Statute"*)	*Law 4504/ 1964*	LR	Ensuring fair and efficient land distribution to rural workers to enhance agricultural productivity, reduce inequality, and support national economic development.
EnvironPOL	National Environmental Policy	*Law 6938/ 1981*	Cons	Improving environmental quality by regulating polluting activities, restoring degraded areas, and establishing environmental standards
AgriPOL	Agricultural Policy	*Law 8171/ 1991*	Agr&For	Fostering agricultural, agro-industrial, fishing and forestry activities through sustainable practices, financial incentives, and technical support.
WaterPOL	National Water Resources Policy	*Law 9433/ 1997*	Cons	Ensuring the sustainable and equitable management of water resources through integrated planning and conservation measures.
Environ EducPOL	National Environmental Education Policy	*Law 9795/ 1999*	Cons	Fostering environmental awareness and responsible practices through education that integrates social values, scientific knowledge, and competencies.
ForestPOL	National Forest Program	*Decree 3420/ 2000*	Agr&For	Aligning forest use and conservation through coordinated sectoral policies that balance economic, social, and environmental needs.
BiodiversityPOL	National Biodiversity Policy	*Decree 4339/ 2002*	Cons	Promoting biodiversity conservation and sustainable use while ensuring fair and

(*continued on next page*)

Table 2 (*continued*)

Code	Description*	*Rule***	Category ***	Main goal
				equitable sharing of its benefits.
TraditPeoplesPOL	National Policy for Sustainable Development of Traditional Peoples and Communities	*Decree 6040/2007*	LR	Promoting the recognition, strengthening, and protection of territorial, social, environmental, economic, and cultural rights of traditional peoples and communities.
ClimatePOL	National Climate Change Policy (NCCP)	*Law 12,187/2009*	Climate	Defining and implementing Brazil's climate change policy, including its voluntary commitment to reducing GHG emissions (NDC).
Technical AssistPOL	National Policy on Technical Assistance and Rural Extension Services	*Law 12,188/2010*	Agr&For	Establishing guidelines for public rural technical assistance to enhance productivity and sustainability for farmers and rural communities.
AgroecoPOL	National Policy of Agroecology and Organic Production - PNAPO	*Decree 7794/2012*	Agr&For	Supporting the transition to agroecological and organic farming by integrating policies and programs that promote sustainable production.
Indigenous LandsPOL	National Policy for Territorial and Environmental Management of Indigenous Lands - PNGATI	*Decree 7747/2012*	LR	Safeguarding the integrity of indigenous heritage and its culture.
RestorationPOL	National Policy of Native Vegetation Restoration	*Decree 8972/2017*	Cons	Restoring native forests and ensuring environmental compliance of rural properties under the Forest Code through integrated policies and programs.
BiodieselPOL	National Biodiesel Production and Use Program (PNPB)	*Decree 10,527/2020*	Agr&For	Implementing sustainable production and use of biodiesel.

* some acronyms as in the original text in Portuguese.
** all rules can be found in https://www.planalto.gov.br/ccivil_03/ by providing number and date
*** Broad categories: land rights = LR; conservation = Cons; agriculture, livestock and forestry = Agr&For; and climate change = Climate.

3.2.1. *Connectivity of strategies in different categories*

Based on the network of policies and regulations/initiatives (Fig. 2), we calculated the average degrees of connectivity for strategies in different thematic categories. Strategies in the Climate category show the highest average degrees — 23 for national policies and 6.3 for regulations/initiatives — indicating stronger integration across the governance network (Table 5). The policies in the Agriculture & Forestry and Conservation categories exhibit intermediate levels of connectivity, whereas Land Rights policies exhibit the lowest degree of connectivity. This suggests that production-related strategies included in the Agriculture & Forestry category are equally well integrated into the network as the conservation-focused ones. The particularly high degree of climate-related strategies — especially the prominent role of the National Climate Change Policy — likely reflects the cross-cutting nature of climate governance, which depends on coordinated actions in agriculture, forestry, and conservation.

3.3. *International connections in Brazil's governance*

Brazilian policies are, on average, linked to one international governance strategy (average degree = 1.09). The network remained sparse (density = 0.03 %), indicating weak overall integration. Modularity (0.528) is at an intermediate level, indicating that national and international strategies are more clustered than in the national network of policies and regulations/initiatives (Fig. 3).

The national policy most interconnected with international frameworks (high out-degree values) is the National Forest Policy (ForestPOL, 11 out-degrees), followed by the Agriculture Policy (AgriPOL, 4), and the National Restoration Policy (RestorationPOL, 4). ForestPOL is connected to different types of international strategies associated with conservation and agriculture, while AgriPOL connects mainly to the UNFCCC and international non-state strategies associated with sustainable commodity standards. The National Forest Policy primarily connects to international strategies that are not linked to any other national strategy, thereby forming a distinct forest cluster within the network, with little cross-sector interconnections.

Among international strategies, the most connected to Brazilian policies (high in-degree values) are the UNFCCC (9 in-degrees) and the EUDR (6). Both the CBD and the New York Forest Declaration show three connections. On the other hand, FLEGT and the Tropical Forest Alliance appear isolated, with no ties to Brazilian policies. Brazil has not formally engaged with FLEGT/VPA, and the lack of connections with the Tropical Forest Alliance may reflect its limited adoption at the federal governance level.

Certain Brazilian policies, particularly ForestPOL (hub = 0.696), followed by RestorationPOL (0.381), and AgrarReformPOL (0.360), prove to be influential national policies, linking to high-authority international strategies such as the UNFCCC (Authority = 0.611) and the EUDR (0.497).

Overall, the analysis suggests that while Brazilian policies are linked to international governance frameworks, these connections remain relatively weak and unevenly distributed.

4. Discussion

4.1. *Interconnectivity*

At the national level, the study unveils a broad number of governance strategies in Brazil's land-use and conservation sectors. The findings indicate that Brazilian policies are well integrated with both state-driven and non-state/hybrid initiatives, forming a weakly clustered, cross-sectoral, yet loosely structured, governance framework which does not support sectoral silos. National policies, such as the National Climate Change Policy; the National Forest Program; and the National Biodiversity Policy, stand out as highly connected domestic policies. They may serve as a backbone for efforts to regulate land use in

Table 3
Selected Brazilian federal regulations in chronological order of enactment.

Code*	Description*	Rule**	Category ***	Main Goal
MinPrice	The Guaranteed Minimum Price regulation	*Decree-Law 79/1966*	Agr&For	Ensuring income stability for small producers and cooperatives by guaranteeing a minimum marketing price for their products
AgrarianReform	Regulates articles on agrarian reform in the federal constitution	*Law 8629/1993 (amended by Law 13,001/2014)*	LR	Ensuring fair and efficient land distribution by expropriation properties that fail to meet their social function for agrarian reform, while defining compliance conditions and legal ownership contracts.
EnvirCrime	Brazilian Law of Environmental Crime	*Law 9605/1998*	Cons	Strengthening environmental protection and accountability by defining environmental crimes, establishing criminal and administrative sanctions, and addressing offenses related to flora, fauna, pollution, and waste management.
SNUC	National System of Conservation Units (SNUC)	*Law 9985/2000*	Cons	Safeguarding biodiversity and ecosystem health by creating conservation unit categories to support scientific research, ecosystem restoration, water resource management, and the protection of traditional communities and their territories.
PRONAF	National Program to Strengthen Family Farming	*Decree 3991/2001*	Agr&For	Empowering family farmers and promoting rural development by supporting agricultural and non-agricultural activities through training, credit access, and infrastructure development in rural and peri-urban areas.
CropLoan	Regulates articles on Crop Loan Plan ("Plano Safra") in Agricultural Policy	*Law 10,246/2001*	Agr&For	Optimizing agricultural planning, investments and productivity by ensuring that harvest and multi-year development plans consider product type, regional and state-specific factors, ecosystems, and supply chain needs.
ZEE	Regulates the Environmental Economic Zoning (ZEE)	*Decree 4297/2002*	Cons	Balancing territorial development with environmental sustainability by regulating land use planning for public and private projects through protection measures that safeguard ecosystems, water resources, and soil quality.
PPCDAM	Action Plan for Prevention and Control of Deforestation in the Legal Amazon	*Decree of 15 March 2004 (resumed by Decree 11.367/2023)*	Climate	Combating deforestation and promoting climate resilience in the Legal Amazon through land regularization, protected area strengthening, and support for the sustainable use of natural resources by traditional communities.
PublForest Manag	On public forests management for sustainable production	*Law 11,284/2006*	Cons	Promoting sustainable forest management by ensuring that public forests are managed through national, state, and municipal conservation areas, community-based reserves, settlement projects, and forest concessions.
AtlanticForest	Atlantic Forest Law	*Law 11,428/2006 (last amended 2012)*	Cons	Protecting and restoring the Atlantic Forest biome by establishing rules for vegetation management, deforestation control, and sustainable use while supporting traditional communities.
Family Farming	the National Policy on Family Farming and Rural Family Enterprises	*Law 11,326/2006*	Agr&For	Strengthening family farming and rural livelihoods by aligning the National Family Farming Policy with Agricultural Policy, defining the concept of farmers, and ensuring access to credit, technical assistance, and rural extension services.
EnvInfraction	Environmental infractions and administrative assessments	*Decree 6514/2008*	Cons	Ensuring accountability for environmental infractions by defining violations related to fauna, flora, and pollution, establishing sanctions, and regulating the federal investigative process
LTruralUrban	Rural and Urban Land tenure in the Amazon	*Law 11,952/2009 (amended by Law 13,465/2017)*	LR	Promoting legal certainty in land tenure in the Legal Amazon by defining eligible occupations for regularization and specifying conditions for legal recognition.
BeefTrack	Traceability in the beef and buffalo meat production chain	*Law 12,097/2009; Decree 7623/2011*	Agr&For	Enhancing transparency and sustainability in livestock production by ensuring the registration and monitoring of beef and buffalo supply chains for full traceability.
OilPalm zoning	Oil palm Agroecological zoning and financing regulation	*Decree 7172/2010*	Agr&For	Promoting sustainable palm oil production by guiding its expansion in anthropized areas based on Ecological and Economic Zoning, and technical and scientific principles, ensuring economic and social sustainability while offering a viable alternative for rural producers.
TechAssist	National Program for Technical Assistance and Rural Extension in Family Farming and Agrarian Reform	*Decree 7215/2010*	Agr&For	Ensuring the effective implementation of rural technical assistance by defining accreditation requirements for implementing entities and verification methods for service delivery to family farmers and rural enterprises.
EnvLicInstitution	regulates the competence of public entities regarding environmental licensing	*Complementary Law 140/2011*	Cons	Clarifying environmental governance roles by defining the responsibilities of federal, state, and municipal authorities in implementing and enforcing environmental protection, including licensing and authorization processes.
BolsaVerde	Program for the Promotion of Rural Productive Activities and Environmental Conservation Support Program.	*Law 12,512/2011*	Agr&For	Incentivizing sustainable forestry practices by providing financial compensation (Bolsa Verde) to rural communities for conservation efforts, along with funding for productive activities and technical assistance.
Forest Code	On the protection of Native Forests (Brazilian Forest Code)	*Law 12,651/2012*	Cons	Strengthening native vegetation protection, especially in rural properties, by setting general standards for permanent preservation areas, legal reserves, forest exploitation, product traceability, and fire prevention.

(*continued on next page*)

Table 3 (*continued*)

Code*	Description*	Rule**	Category ***	Main Goal
ABC Plan	Low carbon agriculture program (ABC/ ABC+ Plan)	Decree 9578/2018	Agr&For	Advancing climate change mitigation in agriculture by establishing the ABC Plan to promote pasture restoration, sustainable agricultural practices, and improved waste management in livestock production.
NCCP	National Climate Change Plan (aligned to National Policy of Climate Change -PNMC)	Decree 9578/2018	Climate	Guiding Brazil's climate policy and emissions reduction by defining actions to curb greenhouse gas emissions and adapt to climate change, with updated goals set for 2035.
LTbeneficiaries	Process of selection, permanence, and title of beneficiary families of the National Agrarian Reform Program	*Decree 9311/2018 (Decree 11,637/2023)*	LR	Ensuring fairness and transparency in agrarian reform by defining the selection process for beneficiaries, their obligations, and mechanisms for monitoring compliance and addressing irregular occupations.
NatClimChange	Regulates the National Climate Change Policy	*Decree 9578/2018*	Climate	Strengthening climate policy implementation by defining key concepts of the National Policy on Climate Change, creating the National Fund on Climate Change, and establishing governance and emission projection frameworks.
PES	National Policy on Payment for Environmental Services	*Law 14,119/2021.*	Climate	Expanding environmental service compensation by defining payment methods, creating the Federal Program for Payment for Environmental Services, and prioritizing support for traditional communities, Indigenous peoples, and family farmers.
PPCerrado	Programme to control deforestation in the Cerrado biome	*Decree of 15 September 2010 and Decree 11,367/2023*	Climate	Reducing deforestation and fire risks in the Cerrado biome through targeted measures to prevent, monitor, and control illegal burning and forest degradation.
DeforestationControl	Federal Government with Municipalities Program for the Reduction of Deforestation and Forest Fires.	*Decree 11,687/2023*	Climate	Strengthening deforestation prevention and enforcement by implementing monitoring, control, and blacklisting municipalities with high deforestation rates in the Amazon Biome for priority environmental actions.

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producing countries (Ladu et al., 2020). They are umbrella policies that can provide general guidelines beyond the limits and coverage of others related to climate, forests, and conservation, and can serve as key points for further integration. This might be achieved by establishing further links to more isolated regulations and initiatives in the Brazilian land-use strategy network.

At the international level, Brazilian policies connect to global governance strategies—especially to those to which Brazil is a signatory (e.g., UN conventions)—highlighting Brazil's effort to contribute to international governance. However, the overall network remains sparse. As seen, some Brazilian policies (e.g., Forest Policy) have higher connections to international strategies, while some international strategies (e.g., UNFCCC) also stand out more than others in their relations with Brazilian policies.

This mapping of governance strategies sets the stage for assessing their strengths and limitations, also with respect to effectiveness and resilience. On the one hand, the diversity of national strategies and cross-sectoral links enhance Brazil's capacity to comply with domestic and international sustainability commitments. The presence of complementary governance strategies reduces dependency on any single policy, creating a buffer against political fluctuations that could otherwise weaken environmental regulations (Abessa et al., 2019; Raftopoulos and Morley, 2020). This structural resilience ensures that even if certain policies are weakened or repealed, alternative mechanisms—such as non-state monitoring initiatives or economic incentives—or complementary policies can continue to uphold sustainability efforts through a smart mix of policies that integrate soft and hard measures (Williamson and Lynch-Wood, 2021). For instance, Brazil's policy mix—including protected areas, land rights, enforcement tools, payments for environmental services regulations—has proven effective in slowing down illegal deforestation in the Amazon, even under pressure (Nepstad et al., 2014; Tacconi et al., 2019). However, from 2019 to 2022, an anti-environmental agenda weakened institutions, suspended the PPCDAM, and led to a deforestation peak of 13,000 km^2 in 2021—the highest since 2007 (Nunes et al., 2024). Yet, two factors contributed to the resistance and to the prevention of a further dismantling of the environmental agenda: the institutional architecture of environmental policies in Brazil, based on the Federal Constitution, and the crucial role played by civil society organizations (Neves, 2023), as also expressed in the non-state and hybrid initiatives (see below). The reactivation of sectoral strategies, including monitoring and agency support, contributed to a 30.6 % reduction in deforestation, down to 6288 km^2 between 2022 and 2024, the lowest recorded in the past nine years (INPE, 2024). These experiences show that institutional frameworks and networks need to be in place, yet their effectiveness ultimately depends on political will for implementation.

On the other hand, a loose governance network may hinder the potential effectiveness of national and international strategies. Brazilian policies designed to integrate multiple sectors from their inception—such as the Forest Policy—can play a key role in strengthening policy networks. Thus, a network may function effectively with a few specialized strategies, though this can pose risks to its resilience. Embedding this broad vision in the creation or revision of other policies can enhance network density by increasing connections.

Likewise, certain Brazilian strategies, like forest and agriculture policies, are highly interconnected with domestic governance strategies. However, the reliance of the Brazilian network on a few hub strategies — such as PPCDAM and PPCerrado (strategies to curb deforestation) — means that while well-articulated strategies tend to endure and produce long-term effects (West and Fearnside, 2021), if these key programs weaken, several governance instruments could become disconnected, reducing overall cross-sectoral policy interconnection and broader governance efforts.

The findings imply that some strategies are crucial for maintaining alignment and synergy between sectoral policies, while others may vary in approach across different sectors/strategies. Alignment helps prevent contradictions and inconsistencies between policies (Wiegant et al., 2024), while synergy enhances their overall effectiveness (Rogge and Reichardt, 2016).

Table 4
Selected non-state or hybrid initiatives.

Code*	Description*	Year	Category **	Main goal
Forest Dialog	Forest Dialog (hybrid strategy) – (The Forests Dialogue, 2025)	*2005*	Cons	Facilitating multi-stakeholder dialogue on forest use and conservation by fostering interaction between different actors.
SoyMorat	Brazilian Soy Moratorium (hybrid strategy) – (Moratória da Soja, 2025)	*2006*	Agr&For	Eliminating deforestation in the Amazon biome by a hybrid agreement that promotes deforestation-free soy production.
G4cattle	G4 cattle agreement – (Zero Deforestation Impacts, 2025)	*2009*	Agr&For	Ensuring deforestation-free beef production by strengthening traceability and zero-deforestation commitments by four largest beef processors in the country.
FC Obs	Forestry Code Observatory - (Observatório Do Codigó Florestal, 2025)	*2013*	Cons	Enhancing transparency and accountability in Forest Code implementation through independent monitoring.
ClimForAgr Coalition	Brazil Climate, Forest and Agriculture Coalition (Brazilian Coalition, 2025)	*2015*	Agr&For	Advancing climate resilience and sustainable land use by mobilizing private and non-state actors to protect, conserve, and sustainably manage forests, agriculture, and climate adaptation.
PaodeAcucar	Pão de Açúcar Group Zero-Deforestation Commitment (Greenpeace, 2025))	*2016*	Agr&For	Reducing environmental and social risks in the beef supply chain by implementing the Zero-Deforestation Commitment of the largest food retail groups in South America, controlled by the French group Casino.
Soft Commod Forum	Soft Commodities Forum (SCF/ WBCSD) (Soft Commodities Forum, 2025)	*2018*	Agr&For	Eliminating deforestation in Cerrado soy production through collaboration among six agribusinesses in developing sustainable solutions.
Interstate Consortium	Interstate Consortium for the Sustainable Development of the Legal Amazon (Consórcio Interestadual Amazonia Legal, 2025)	*2019*	Agr&For	Promoting sustainable development and low-carbon economy by coordinating policies, regional integration, and rural productivity through a consortium of the 9 states of the Brazilian Amazon.
OCAA	Amazon Trade and Environment Observatory (Observatório de Comércio e Ambiente na Amazônia, 2025)	*2020*	Agr&For	Informing policy and trade debates on the Amazon's environmental and economic challenges through independent research and analysis.

[*] Broad categories: land rights = LR; conservation = Cons; agriculture, livestock and forestry = Agr&For; and climate change = Climate.
[**] some acronyms as in the original text in Portuguese

4.2. Policy design vs policy implementation

Of fundamental importance in determining effectiveness is policy implementation (Rogge and Reichardt, 2016), which, in the case of Brazil, has been a recurring issue. From a regulatory (de jure) standpoint, Brazil's governance strategies suggest readiness to meet international governance expectations. While adjustments are still needed to strengthen cross-sectoral integration, domestic strategies formally reflect the goals of major international frameworks. However, the extent to which these goals are effectively translated and integrated remains uneven and requires further analysis.

Brazilian measures have contributed to important outcomes, yet the specific implementation of individual strategies needs to be further analyzed. Overall, outcomes can be seen particularly in reducing deforestation and strengthening forest protection — most notably through the PPCDAM program, in place since 2004 (West and Fearnside, 2021). Brazil's network of public and private protected forests supports biodiversity, socio-environmental wealth, and ecosystem services. By 2020, 2446 protected areas covered 18 % of Brazil's land and 26 % of its marine territory (SFB, 2022). Moreover, the Forest Code requires all rural properties to maintain a legal forest reserve. Regulatory instruments such as environmental regularization, commodity traceability, and remote monitoring systems (Tacconi et al., 2019), further reinforce Brazil's efforts to support legal production chains, implement REDD+ strategies, and meet its Nationally Determined Contributions (NDC).

The ability of protected areas to prevent forest loss, preserve biodiversity, and mitigate the effects of global warming (Rochedo et al., 2018), combined with restoration programs, supply chain monitoring, and privately managed forests, strengthens Brazil's commitment to international environmental agreements.

However, disparities in institutional responsibilities, funding, and enforcement capacity may create misalignments that weaken governance coherence. The persistence of historically interlinked challenges—such as illegality, corruption, and land tenure uncertainty—raises concerns about their de facto implementation (Azevedo-Ramos et al., 2020; Reydon et al., 2022; Villén-Pérez et al., 2020). While regulatory frameworks have strengthened over time, weak governance structures, law enforcement gaps, and political volatility continue to undermine domestic governance (Barbosa et al., 2021; Gregersen et al., 2005; Jonsson et al., 2015; Pereira et al., 2019).

Challenges in policy alignment also need to be considered. The presence of de jure synergies between policy goals does not rule out the existence of misalignments in practical requirements or actions. For instance, the EUDR was the second most connected international strategy in our analysis, as its sustainability and legality requirements align with Brazil's forest protection policies and supply chain standards. However, while Brazil's Forest Code permits authorized land conversion, the EUDR does not differentiate between legal and illegal deforestation, banning imports from any areas deforested after 2020. Such regulatory mismatches can create tensions around sovereignty and raise the risk of trade disputes (Azevedo-Ramos and Murakami Lima, 2024), which may provoke de facto disordering of complementary policies.

Moreover, legal provisions do not always ensure compliance in

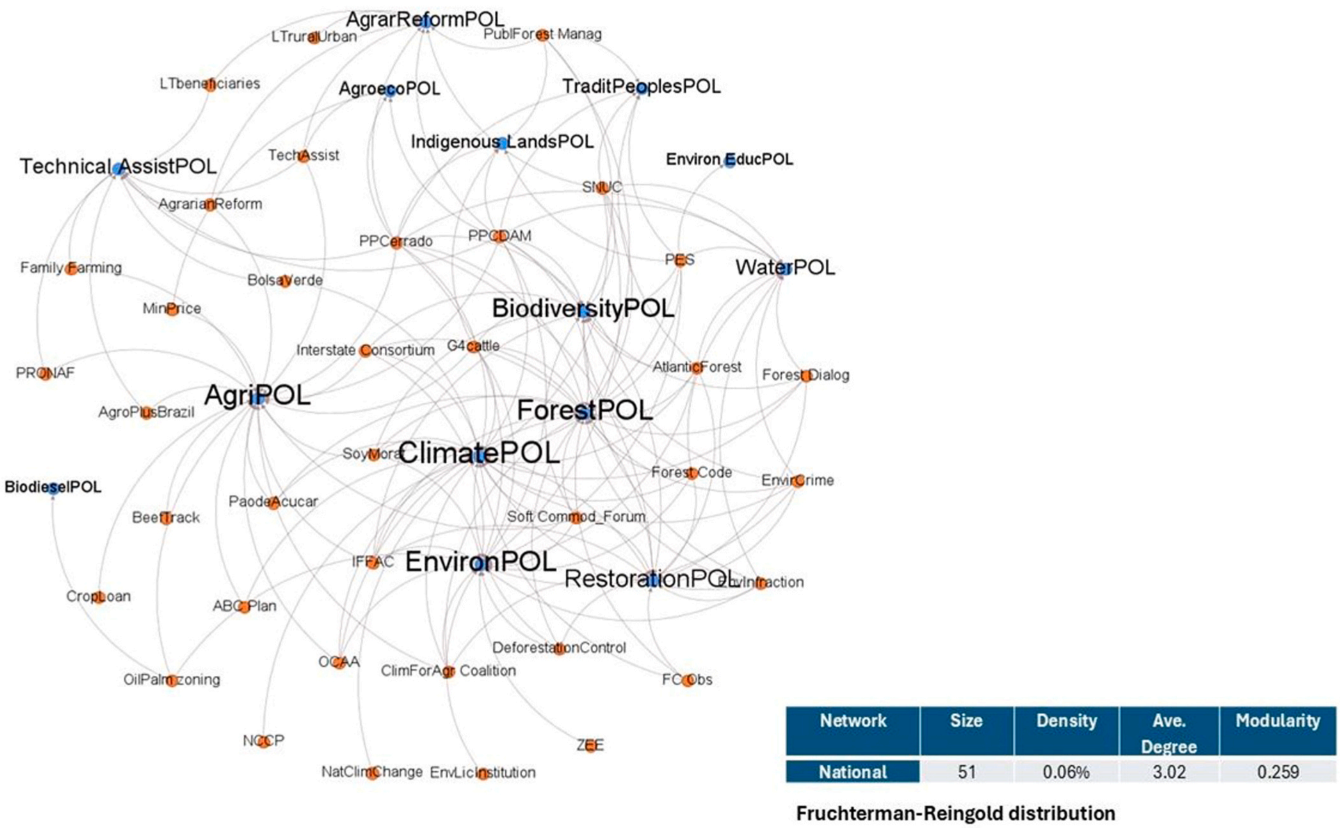

Fig. 2. Network of Brazilian policies (blue nodes) and federal regulations/non-state and hybrid initiatives (orange nodes). See Tables 2–4 for codes. Font and node sizes of national policies are proportional to number of in-degrees. Summary network statistics and graph layout distribution shown in the lower right corner.

Table 5
Number and mean degrees of strategies in different categories.

Categories*	National policies		Regulations/Initiatives	
	N	Average degrees	N	Average degrees
LR	3	5.5	2	2.0
Agr&For	5	10.8	16	3.4
Cons	5	11.6	11	4.8
Climate	1	23	6	6.3

* Broad categories: land rights = LR; conservation = Cons; agriculture, livestock and forestry = Agr&For; and climate change = Climate

practice—either due to weak enforcement domestically or divergence from international standards abroad. Finally, although frameworks like the UNFCCC shape Brazil's sustainability agenda, their translation into national law is often selective and mediated by domestic interests (Faggin and Behagel, 2017; Siegel and Bastos Lima, 2020), reflecting the weak but strategic interlinkages observed in this study.

Another disruptive factor occurs when there is an imbalance in priorities between policies from different sectors. For instance, domestic agricultural policies receive significantly more financial support than forestry policies, which may inadvertently facilitate antagonism rather than complementarities. Greenpeace (2024) found that Brazilian rural loans financed 21,700 farms with environmental irregularities, highlighting ongoing challenges in biodiversity risk management in the Brazilian banking sector and sustainable trade. Banks lend to companies—representing 46 % of the corporate loan portfolio and 20 % of the total credit portfolio—that rely heavily on ecosystem services for production (Calice et al., 2021). The degradation of these ecosystem services, in turn, can result in significant financial losses. Ultimately, the disproportionate emphasis on agriculture over forestry and the consequent financial misalignment may lead to unintended contributions to deforestation.

Governance challenges are also the result of political choices in the form of occupation, integration, and development of a region (Garrett et al., 2021). Even when the legal framework is aligned, integrating sustainable policies across different sectors of the Brazilian government remains a challenge, often leading to conflicting actions and increased GHG emissions (Fearnside and Filho, 2025). These misalignments, also shared by other tropical countries (Obidzinski and Kusters, 2015), reveal the difficulty for countries of production to rely primarily on law measures for de facto implementation. Political choices also include the selection of the government personnel, which may have an effect on how domestic contexts can link or de-link global environmental networks from domestic policymaking. A comparative study of three Brazilian presidencies (Dilma Rousseff, Michel Temer, Jair Bolsonaro) used network analysis to examine ties between Environment Ministry officials and national/international organizations (Maglia, 2022). While international links were generally limited, Rousseff and Temer's administrations maintained similar types of ties with IGOs and NGOs. In contrast, Bolsonaro's government (far-right, anti-environmental populist government) reduced connections with those, favoring consultancy, finance, and agribusiness. The findings highlighted how political appointments can reshape policymaking, implementation, and global engagement.

Participatory processes and hybrid governance strategies can play an important role in balancing governance.

4.3. *The role of non-state and hybrid governance strategies*

Given these governance complexities, non-state and hybrid governance strategies play a crucial role in reinforcing sustainability efforts (Garrett et al., 2021; Sotirov et al., 2022). In some cases, Brazil's domestic political economy and discursive alliances (agribusiness vs.

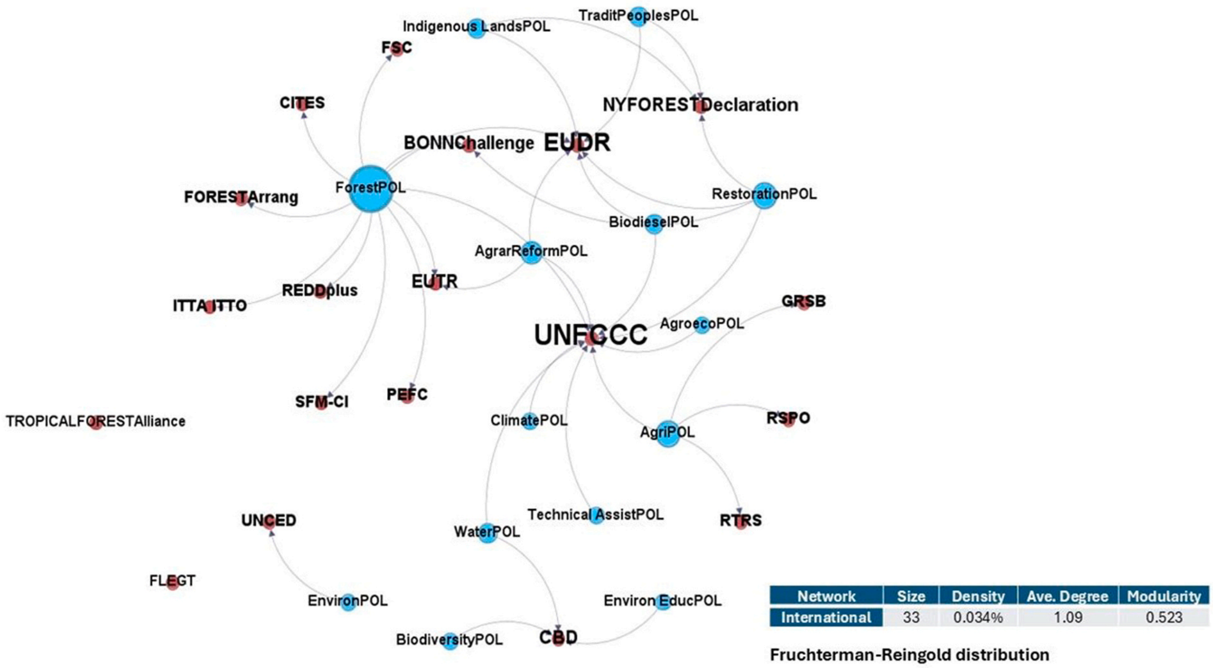

Fig. 3. Network of Brazilian policies and international strategies. Blue nodes = Brazilian policies. Red nodes = International strategies. National policies with more connections (out-degrees) to international strategies are represented by larger nodes, while international strategies with more incoming connections (in-degrees) are highlighted by larger font size. See Tables 1 and 2 for codes, respectively. Summary network statistics and graph layout distribution shown in the lower right corner.

conservationists) have largely shaped sectoral policies (Faggin and Behagel, 2017). In this study, their complementary role to state initiatives on the network could be verified by synergetic links. Private sector arrangements, such as the G4 Agreement and the Brazilian Soy Moratorium, have demonstrated the capacity to restrict deforestation in commodity supply chains (Gibbs et al., 2016; Paim, 2021). Although they are not flawless in fully delivering on commitments (ISSU, 2020; Rajão et al., 2020), the common sustainable goals shared with agriculture and environmental policies tend to reinforce governance in supply chains. Nevertheless, greater involvement of government support in endorsing private standards and covering associated costs, especially for small producers, would encourage self-regulation of companies (Lambin et al., 2018) and strengthen the mix of governance strategies. In fact, the need for integration between public policies and private initiatives has been an agenda pursued by the Brazil Climate, Forest, and Agriculture Coalition, which itself is one of the analyzed initiatives.

Independent monitoring institutions, civil society engagement, and media scrutiny have also emerged as key governance assets in Brazil (De Jong, 2009; Ladu et al., 2020). Observatories, transparency mechanisms, and cross-sectoral coalitions help bridge gaps in governance enforcement, complementing state-driven strategies. This underscores the importance of multi-stakeholder engagement in maintaining governance resilience — particularly in contexts where political instability may weaken formal environmental protections (Abessa et al., 2019; Moraes et al., 2021; Pereira et al., 2019). However, the peripheral position of these strategies in the network suggests they have untapped potential to strengthen Brazil's internal governance.

4.4. Links to the international governance framework and leakage effects

Assuming the international land-use governance framework (Kleinschmit et al., 2024) provides a balanced set of strategies related to climate change, conservation, agriculture and forestry, its clustered network with domestic Brazilian strategies (Fig. 3) requires specific attention. While Brazilian policies formally align with global commitments (e.g., UNFCCC, EUDR, CBD), low-density interconnections centered on few strategies may lead to gaps in effective implementation of international strategies, reducing effectiveness.

In view of interconnected trade relations, dependencies with the international governance framework are of specific importance. Brazil is the world's largest cattle and soy exporter. Reduced agricultural and forest related production under Green Deal legislation in Europe raises concerns about potential leakage of risks to biodiversity and carbon sequestration to non-EU countries like Brazil (Fischer et al., 2024; Schier et al., 2022). Even though relations with the international framework are loose and clustered, the balanced distribution of Brazilian strategies at the domestic level - into the Forest & Agriculture category on one side and the Conservation category on the other - can provide a basis to counteract such leakage. Yet, strategies of both categories need to be evenly implemented and related legislation needs to be enforced (see above). The Forest Code has been highlighted to be of specific relevance in this respect (Ferrante and Fearnside, 2019).

4.5. Recommendations

Further strengthening cross-policy synergies can help prevent sectoral imbalances. This may involve interdepartmental alignment, public–private alignment, donor-recipient alignment, and inter-donor alignment (Wiegant et al., 2024). Necessary law amendments may also be required; however, these should consider a policy mix perspective, i.e., always accounting for the links and relationships with other legislative instruments. Alignment and amendments do not rule out the need for enforcement, and better public support for private self-regulation and civil society monitoring within the domestic governance framework is needed to meet current and future challenges.

Supporting de facto implementation of de jure governance frameworks may help leverage the achievement of synergic goals. Reinforcing transparency, monitoring mechanisms, and multi-stakeholder engagement would help bridge the gap between policy design and real-world outcomes. Considering institutional challenges (e.g., illegality; corruption) increases the likelihood of achieving targets (Bahn-Walkowiak and Wilts, 2017; Ladu et al., 2020).

Due to Brazil's federal political structure, states and municipalities typically align their policies and regulations with national frameworks when developing their own. Strengthening the integration of federal legal frameworks can help streamline policy adoption across different jurisdictions, ensuring a more cohesive governance approach.

At the international level, harmonizing Brazil's regulatory framework with global sustainability requirements, while preserving its specificities, is essential for avoiding trade conflicts and leakage effects, as well as for reinforcing Brazil's credibility in environmental governance. For instance, aligning national regulations in supplier countries with international sustainable trade standards - such as those required by the EUDR - is necessary to ensure compliance and facilitate market access. (Azevedo-Ramos and Murakami Lima, 2024). This includes increasing interconnections among regulations, certification, and private agreements to enhance network coherence. Engaging in active bilateral and multilateral dialogue, combined with strengthening global governance strategies, can help align objectives and minimize disagreements.

Finally, the use of SNA to assess complex interactions in governance research should be encouraged as an innovative approach. According to Zhang et al.'s (2023) review study, as a new analytical paradigm, it may promote alignment, diversification, and rationalization of policies. By combining methods and theoretical frameworks, complex interactions may be identified and visualized to better solve problems. The study of evolving networks across time may also be promising (Tabassum et al., 2018).

5. Conclusion

Governance strategies are essential for steering land use in countries with high agricultural and forest production towards sustainable practices. Our study contributes to a better understanding of systemic interactions between governance strategies in land-use policies, given the various demands and complex policy mixes that have emerged in many countries. Specifically, this study assessed Brazil's governance strategies to determine their readiness to meet both domestic and international expectations regarding sustainable land use and conservation. The study offers a quantitative application of Social Network Analysis (SNA) to reveal the complexity of the interconnectivity within the country's governance framework. SNA has proven useful for visualizing, quantifying, and identifying interconnections in governance frameworks.

Our findings reveal that Brazil has developed a broad and interconnected governance framework, combining state-driven and non-state/hybrid initiatives. National governance strategies are interlinked across sectors, reducing policy silos. The analysis also revealed key governance strategies, like those related to climate, forest, and conservation, and those that emerged as central hubs (like those strategies associated with deforestation reduction), facilitating interactions between sectoral policies. Additionally, policies related to forests, agriculture, and land restoration were the most connected to international governance strategies, especially those established from conventions to which Brazil is a signatory. Overall, these findings show that Brazil has a functional de jure basis to respond to comprehensive and multi-faceted land-use demands.

Brazil shows integrated governance strategies both domestically and internationally. The steering of such a complex framework, however, may pose challenges for policy effectiveness (e.g., coordination) and implementation (e.g., resources). Strengthening policy coherence, reinforcing monitoring mechanisms, and ensuring political stability in governance strategies will be critical for enhancing Brazil's long-term compliance with global sustainability commitments. Effective implementation of these strategies can further position the country as a reliable actor in conservation and sustainable land use and strengthen Brazil's role as a key partner in international environmental cooperation and negotiations. Decision-makers interested in improving the resilience of governance systems should strengthen the connections between strategies and reduce their vulnerabilities.

Therefore, further improvements may be needed to enhance connections between strategies and decrease dependence on bridging strategies. While Brazil's extensive network provides a foundation for achieving sustainability goals, challenges persist in translating policy frameworks into effective action. Implementation gaps, conflicting cross-sectoral incentives, and shifts in political priorities may weaken policy synergies and enforcement, increasing environmental and socioeconomic risks. These vulnerabilities can contribute to deforestation, environmental degradation, and risks to land rights. Further strengthening the network's policy synergies — particularly better integrating agricultural production (more isolated) with conservation policies (closely related) — would enhance governance effectiveness.

New insights may come from analyzing the related specific policy instruments — the tools to implement the legislation on the ground — not included in this analysis, and by adding other features of a policy mix to the analysis.

CRediT authorship contribution statement

Jessica Pacheco: Writing – review & editing, Formal analysis, Data curation. **Claudia Azevedo-Ramos:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **von Lüpke Heiner:** Writing – review & editing, Project administration. **Paulo Moutinho:** Writing – review & editing, Project administration. **Murakami Lima Raysa Yuki:** Writing – review & editing, Formal analysis. **Richard Fischer:** Writing – review & editing, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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