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Challenges for reducing carbon emissions from Land-Use and Land Cover Change in Brazil

Débora Joana Dutra[a,b,*,1], Marcus Vinicius Freitas Silveira[b,1], Guilherme Mataveli[b,c,1], Poliana Domingos Ferro[b,1], Deila da Silva Magalhães[b,1], Thaís Pereira de Medeiros[b,1], Liana Oighenstein Anderson[a], Luiz Eduardo Oliveira e Cruz de Aragão[b,d]

[a] *National Center for Monitoring and Early Warning of Natural Disasters (CEMADEN), São José dos Campos 12247-016, Brazil*
[b] *Earth Observation and Geoinformatics Division and Tropical Ecosystems and Environmental Sciences Laboratory, National Institute for Space Research (INPE), São José dos Campos, SP 12227-010, Brazil*
[c] *School of Environmental Sciences, Tyndall Centre for Climate Change Research, Norwich Research Park, University of East Anglia (UEA), Norwich NR4 7TJ, United Kingdom*
[d] *Geography, University of Exeter, Exeter EX4 4PY, United Kingdom*

H I G H L I G H T S

- Brazil reached 2.8 Mha of native vegetation removal in 2022, the highest rate since 2008.
- 15.8 Mha of Legal Reserve areas need restoration in Brazil's private rural properties, over half in the Amazon.
- 5.46 Mha of forest regrowth occurred in Brazil from 2016 to 2022, 40% in the Amazon and 36% in the Atlantic Forest biome.
- Secondary forests in Brazil lack proper legislation to safeguard their carbon mitigation potential in the long-term.
- Incentives to environmental payment, law enforcement, and legal framework needed for Brazil's 78 Mha surplus vegetation.

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A B S T R A C T

Brazil, a crucial player in global climate change mitigation, faces challenges in reducing its carbon emissions, of which nearly half are from land use changes. Despite potential reductions that can be achieved through halting deforestation and fostering forest restoration, setbacks in environmental governance have heightened emissions. This article assesses challenges and proposes solutions for conserving and restoring Brazilian biomes in line with the Sustainable Development Goals (SDGs) and the Paris Agreement by 2030. Notably, net carbon emissions from land-use change and forestry increased twofold from 2017 to 2022 due to deforestation in the Amazon and Cerrado. Native vegetation clearing peaked at 2.8 Mha in 2022, the largest area since 2008. The deficit of native vegetation within Legal Reserves and Permanent Protection Areas must be addressed through restoration. Achieving SDGs by 2030 demands urgent

* Corresponding author.
E-mail addresses: debora.dutra@cemaden.gov.br, debora.joana@inpe.br (D.J. Dutra), marcus.silveira@inpe.br (M.V. Silveira), guilherme.mataveli@inpe.br (G. Mataveli), poliana.ferro@inpe.br (P.D. Ferro), deila.magalhaes@inpe.br (D.S. Magalhães), thais.pereira@inpe.br (T.P. de Medeiros), liana.anderson@cemaden.gov.br (L.O. Anderson), luiz.aragao@inpe.br (L.E. Aragão).
[1] These authors contributed equally to this work.

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Paris Agreement
Carbon emissions
Environmental compensation
Ecosystem services

action against illegal deforestation, reinforced legislation for secondary forest protection, large-scale restoration programs, and economic incentives for forest conservation through payment for ecosystem services to rural landowners.

Improving environmental governance as a way towards sustainable development

Global Greenhouse Gas (GHG) emissions soared to unprecedented levels in the last decade, undermining efforts to mitigate global surface temperature increases due to climate change (Potenza et al., 2023). Concurrently, the intensification of climate change impacts poses significant challenges as nations grapple with transitioning to sustainable development practices (Shukla et al., 2023). Discussions initiated since the 1980s (Bruntland, 1987), culminating with the formulation of 17 Sustainable Development Goals (SDGs) within the 2030 Agenda, have spurred international agreements aimed at reducing GHG emissions and addressing climate change (UN, 2015). These SDGs encompass society's most urgent needs, closely tied to Earth Science disciplines like water management, energy, infrastructure resilience, and sustainable practices. Acknowledging urgency, the UN designated the 2021–2030 period as the "Decade of Restoration" (UN, 2019), targeting forest restoration and deforestation mitigation to potentially reduce GHG emissions by 7.3 $GtCO_2$-eq yr^{-1} in 2050. This initiative, aligned with SDGs 13 and 15, is particularly crucial in countries like Brazil, where emissions are primarily from Land-Use and Land Cover Change (LULCC), (UN, 2015; Potenza et al., 2023).

As the sixth largest CO_2 emitter globally and a leading contributor to LULCC emissions (Friedlingstein et al., 2023; Ritchie and Roser, 2020), Brazil is pivotal in global efforts against climate change. However, recent failures in enforcing national policies have weakened environmental protection (Pereira et al., 2020) and promoted illegal environmental exploitation. These failures led, for instance, to the Legal Amazon witnessing its highest deforestation rate in 2022 (1.27 Mha) since 2008 (PRODES, 2023) and an increase in deforestation-related fires (Mataveli et al., 2022). Moreover, the rise of illegal activities near protected areas and undesignated public lands (Brito, 2017; Moutinho et al., 2016; Reis et al., 2021), often serving as sanctuaries for standing forests, further undermines Brazil's progress towards achieving SDGs.

In Brazil's Nationally Determined Contribution (NDC) to achieve the Paris Agreement goals against climate change, targets include reducing net GHG emissions by 48.4% in 2025 and 53.1% in 2030 compared to the 2005 baseline (Brazil, 2023). Despite three updates since its initial submission in 2016 (2020, 2022, and 2023), emission goals have not become more ambitious. Furthermore, strategies outlined in the first NDC submission, such as restoring at least 12 Mha of forests by 2030, have been omitted from subsequent updates.

A critical approach to mitigating Brazil's environmental crisis involves combating illegal deforestation and forest degradation, in line with SDGs 13 and 15. While Brazil allocated US$ 213 million from 2012 to 2023 for these efforts (SIOP, 2023), more substantial action is needed. Identifying ongoing actions, challenges, and solutions is crucial for effectively addressing SDGs 13 and 15. Tackling deforestation requires addressing societal structures, unsustainable practices, political crises, and responsibilization for the socio-environmental crimes committed (Ferrante and Fearnside, 2019). This article addresses challenges in conserving and restoring Brazilian biomes aligned with SDGs and the Paris Agreement by 2030, focusing on combating illegal deforestation and forest degradation, restoring native vegetation, monitoring vegetation regrowth, promoting ecosystem services payments, and offering concluding remarks.

Combating illegal deforestation and forest degradation

Indigenous territories in the Amazon witnessed a staggering 195% increase in deforestation between 2019 and 2021 (Silva Junior et al., 2023). In the Cerrado, approximately 30% of the region is now occupied by cultivated pastures, representing 70% of all converted land (Silva et al., 2023). Among these converted pastures, 39% exhibit some degree of degradation (Pereira et al., 2018). Furthermore, in the Atlantic Forest, changes in forest cover increased forest isolation by 37%, accompanied by a 27% rise in deforestation of older native forests between 1990 and 2017 (Rosa et al., 2021). These processes have emphasized the urgent need for environmental protection action in forests (Gatti et al., 2023).

Brazil's strategies to reduce carbon emissions in recent years lacked political support and effective law enforcement, resulting in a twofold increase in net carbon emissions related to LULCC and forestry from 2017 to 2022 (SEEG, 2023). The LULCC and forestry sector accounted for 48% of total CO_2-eq gross emissions in 2022 (SEEG, 2023). Most of these emissions in Brazil, from 2017 to 2022, originated from the increased removal of native vegetation in the Amazon and Cerrado biomes, contributing, respectively, to 43% and 35% of the old-growth vegetation removal in the country during this period (PRODES, 2023). In 2022, the removal of native vegetation nationwide reached approximately 2.84 Mha, the highest rate since 2008 (SM-Table S2.1).

While emissions from degradation processes are increasing, they are often overlooked in national inventories, resulting in an underestimation of total net carbon emissions. Aragão and Shimabukuro (2010) stressed the critical importance of addressing forest degradation in national inventories, as this process also contributes directly to emissions. Silva Junior et al. (2021) illustrated that, for the Amazon, cumulative carbon emissions attributed to forest degradation factors accounted for 88% of the emissions generated by deforestation (9,108 $TgCO_2$) during the 2003–2015 period. Without efficient actions for wildfire prevention and control, drought-related forest fires alone can counteract a decline in carbon emissions if deforestation rates decrease (Aragão et al., 2018).

Restoration Deficits of native vegetation in the Brazilian Biomes

To meet restoration targets, Brazil implemented the National Plan for Native Vegetation Recovery (Planaveg) in 2017. This plan mandates restoration in Legal Reserves (LR) and Permanent Preservation Areas (PPA), as well as in areas with low agricultural suitability due to land degradation (MMA, 2017). LR and PPA, defined by Brazil's Forest Code, require protection on rural properties (Brasil, 2012). LR aims to conserve and sustainably use native vegetation, while PPA aims to preserve natural resources without exploiting native vegetation. Properties lacking the minimum area of native vegetation must be restored.

Approximately 16 Mha of LR require restoration, with 59% located in the Amazon, 25% in the Cerrado, and 14.5% in the Atlantic Forest (Fig. 1 and Table S2.3). PPA exhibits a restoration deficit of 3 Mha nationwide, with one-third in the Amazon, another one-third in the Atlantic Forest, and 23.6% in the Cerrado (Fig. 1 and Table S2.3). Additionally, the Caatinga, Pampa, and Pantanal contribute together with 2% and 11% of LR and PPA restoration deficits, respectively. Another avenue for natural vegetation restoration, in

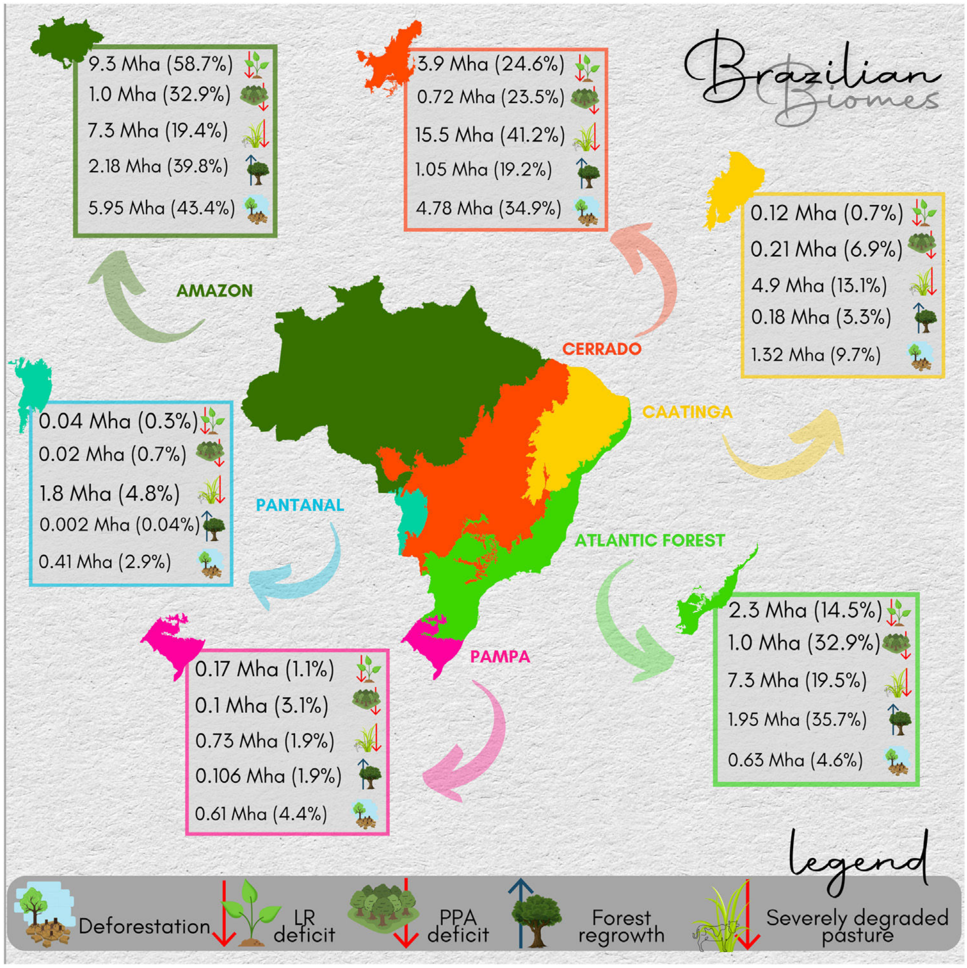

Fig. 1. For each Brazilian biome, the area of native vegetation deficit in Legal Reserves (LR) and Permanent Protected Areas (PPA), severely degraded pastures in 2021, total native vegetation clearing from 2017-2022, and vegetation regrowth between 2017-2022 outside public land, conservation units (except RPPNs and APAs), and Indigenous Lands.
Sources: CSR (2022) - Panorama of Brazil's FC, Lapig (2022) - Atlas das pastagens, Prodes (2023) - Deforest and Authors.

line with Planaveg's recommendations, is the country's extensive area of degraded pasturelands. In 2022, pasturelands in Brazil covered 177 Mha, approximately 21% of the country's extent, with roughly 37.5 Mha severely degraded (Lapig, 2022). Moreover, 41% of severely degraded pasturelands are located in the Cerrado, 19.5% in the Amazon, and 19.5% in the Atlantic Forest (Fig. 1 and Table S2.3).

Tracking vegetation regrowth since the creation of Brazil's first Nationally Determined Contribution

Promoting the growth of secondary forest areas and guaranteeing their permanence is an efficient nature-based solution to mitigate climate change, contributing to counteracting emissions (Elias et al., 2022; Heinrich et al., 2021; Chausson et al., 2023) and providing ecosystem services (Chazdon, 2014). Vegetation regrowth in Brazil from 2017 to 2022 covered an area of 5.46 Mha outside public lands (SM-S1 and S1.5). This value represents nearly half of the targeted amount by the first NDC. However, our computation could be overestimated as we included all areas inside rural properties instead of only the targeted ones by Planaveg (SM-S1.5). From this total, 40% occurred in the Amazon, about 36% in the Atlantic Forest, and 19% in the Cerrado (Fig. 1); combined, the remaining biomes accounted for less than 6% of total regrowth.

It is crucial, however, to recognize that vegetation regrowth is highly vulnerable to deforestation and degradation processes, including fires and logging. For example, deforestation of secondary forest has surpassed that of old-growth forests in the Amazon since 2011, with a significant portion of these forests being cleared before reaching six years of age (Nunes et al., 2020). As highlighted by Piffer et al. (2022) in the context of the Atlantic Forest, carbon sequestration from vegetation regrowth since 1985 could have been three times greater than the currently estimated value if part of the secondary forests had not been deforested again.

We compared the total secondary forest area in 2016, the year of Brazil's first NDC, with that in 2022 to identify if the area of vegetation regrowth had surpassed the area of secondary forest removed during this period. For this calculation, we also included secondary forest areas inside public lands (see supplementary material). In Pantanal, there was a 34% loss in total secondary forest area from 2016 to 2022, whereas in Pampa the area was reduced only by 1.5% (SM-Table 2.3). Substantial relative gains in total secondary forest area were found for the Caatinga and Atlantic Forests, 21.7% and 12% respectively, while Cerrado and Amazon had small increases of 8% and 7% (SM-Table 2.3).

Legal compliance of rural landowners to ensure the permanence of Secondary Forests

Weak law enforcement threatens Brazilian secondary forests, notably in Pará state, the only state with specific legislation on secondary forest deforestation control (Vieira et al., 2014). However, this law protects only forests aged five years or older. Pará witnessed increased deforestation of Secondary Forests post-2015 law implementation, revealing loopholes enabling legal circumvention by farmers (Magalhães et al., 2023). Concerted efforts, including defining secondary forests in the Brazilian Forest Code and strengthening the national environmental inspection system, are essential to address this issue effectively (Vieira et al., 2014). Implementing similar legislation across biomes and states is critical to ensure the long-term protection of restored native vegetation for effective carbon sequestration and storage.

Even if Brazil can achieve its restoration target, the mitigation benefit of such achievement is under threat over the long term because the country has over 78 Mha of native vegetation that could be legally cleared (CSR, 2022). These areas occur in rural properties with native vegetation covering a larger percentage than that required as LR. From this total surplus of LR, 38% is in the Cerrado, 23% is in the Caatinga, 13% is in the Atlantic Forest, and 10% is in the Amazon. The Atlantic Forest is the only biome with federal law to restrict deforestation outside LR or PPA (Brasil, 2006). Still, at least 0.079 Mha of older native forests were cleared every year from 2008 to 2022 (SM-Table S2.1) and the law has been threatened by bills such as nº364/2019 and nº311/2022 (SM-S3).

Forest restoration costs for Brazil

Forest restoration is essential in mitigating biodiversity loss and promoting environmental resilience. However, traditional methods such as planting seedlings are up to ten times more expensive than less intensive alternatives such as natural regeneration (Crouzeilles et al., 2017). The estimated total cost for restoration of the 12 million hectares of Brazilian forests, according to PLANAVEG, ranges from US$ 9.12 billion to US$ 15.56 billion per year. This equates to annual per hectare cost between US$ 760.25 and US$1296.49. In nearly 80% of projects maintenance is needed for 30 months (Brancalion et al., 2019). Financial strategies are, hence, required for supporting these actions throughout the time period needed for the successful establishment of the restoration project. In terms of economic and policy implications, the forest restoration costs can be offset by benefits such as job creation and additional revenue (Crouzeilles et al., 2017). Furthermore, it is essential to review policies to promote a more diversified and sustainable approach (Crouzeilles et al., 2017; Brancalion et al., 2019).

Crouzeilles et al. (2017) reveal that natural regeneration is more effective than active restoration in recovering tropical forests, achieving 34–56% greater success in biodiversity and 19–56% in vegetation structure growth. This underlines the importance of considering a diverse range of restoration strategies and policies that encourage more efficient and sustainable approaches to biodiversity conservation, emphasizing the need to stimulate natural regeneration whenever feasible.

Reinforcing forest conservation through ecosystem services payments

Another key strategy to prevent extensive legal deforestation is to financially compensate rural landowners that conserve native vegetation above the legally established requirements. In 2021, Brazil initiated the National Policy for the Payment of Environmental Services (PNPSA) to outline the principles for such compensation. According to the PNPSA, ecosystem services payments should occur through voluntary transactions, where an investor or donor transfers financial resources or other forms of remuneration to a provider, under agreed conditions, while adhering to relevant legal and regulatory provisions (Brasil, 2021 - Law nº 14,119). This policy significantly supports sustainable development by encouraging private sector involvement as both providers and payers of environmental services. Successful examples of this approach include the *Floresta + Amazônia* project in the Amazon (Floresta + Amazonia, 2023), the *Guardiões da Floresta* and *Conexão Mata Atlântica* projects in the Atlantic Forest (São Paulo, 2023; Conexão Mata Atlântica, 2024), and the *Guardião dos Igarapés* project in the Cerrado (Minas Gerais, 2023). Nonetheless, these projects remain small in scale, and the country lacks large-scale coordinated plans.

Concluding remarks

To achieve the targets set for 2030, Brazil must adjust its environmental policy to ensure concise actions are taken to conserve and restore its biomes. Strengthening current policies focused on safeguarding the nation's standing forests and environmental services is crucial while avoiding new factors that may lead to their decline. This includes (i) controlling illegal deforestation and degradation, (ii) incorporating goals to combat illegal deforestation and restore 12 Mha of native vegetation into the NDC, (iii) reinforcing and expanding policies for environmental services, (iv) legalizing the protection of secondary forest nationally, (v) establishing consistent mechanisms to attract investment from external sources to finance these activities across all biomes, and (vi) promoting sustainable use of non-designated lands, including demarcating new protected areas and incentivizing bioeconomy based activities. Brazil requires government actions to maintain its global leadership in sustainable development. While reinstating the Action Plan for Deforestation Prevention in the Legal Amazon and extending it to all biomes shows progress, reconciling environmental policy rhetoric with actual government actions to achieve SDG goals remains a significant challenge.

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Appendix A. Supplementary data

Supplementary material related to this article, including tables and descriptions of materials and methods, can be found, in the online version, at doi:https://doi.org/10.1016/j.pecon.2024.04.004.

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