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Amazon at risk: economic and environmental challenges and strategies for a sustainable future

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Abstract: The aim of this text is to analyze the environmental and social risks that the Amazon faces due to the expansion of economic activities and the exploitation of natural resources, focusing on the need for integrated policies and sustainable actions to preserve the biome. The Amazon, considered the lungs of the world, is vital for global climate regulation and biodiversity. However, it faces severe threats from deforestation, climate change, and economic pressure. The study is justified by the urgency of finding solutions that balance economic development with environmental preservation, preventing irreversible damage from occurring. The work was conducted through a comprehensive literature review, analysis of environmental and socio-economic data, and case studies on the implementation of public policies in the Amazon region. The interdisciplinary approach allowed an integrated understanding of the environmental, social, and economic impacts of human activities in the Amazon. The results indicate that, despite advances in some conservation areas, the expansion of agricultural frontiers and the exploitation of natural resources continue to exert significant pressure on Amazonian ecosystems. The study highlights the importance of more effective public policies and international cooperation to mitigate the impacts. The study concludes that the preservation of the Amazon requires a multifaceted approach that includes targeted conservation policies, incentives for sustainable economic practices, and greater participation of local communities. Only through coordinated actions will it be possible to ensure the sustainability of the biome and its essential ecosystem services for the planet.

Keywords: Deforestation. Environmental Governance. Sustainable Development.

1 INTRODUCTION

The Legal Amazon is a region of global importance, not only for its vast biodiversity but also for its crucial role in regulating the world's climate. However, this region faces significant challenges resulting from the complex interaction between deforestation, economic pressures, climate change, and governance policies. Deforestation, intensified by agricultural expansion and infrastructure development, compromises biodiversity and increases greenhouse gas emissions, further exacerbating climate change. This degradation makes Amazonian ecosystems more vulnerable, intensifying extreme weather events such as droughts and floods. The interaction between economic pressures and insufficient governance policies amplifies the environmental crisis in the region, threatening its sustainable future.

Figure 1 presents the map of deforestation in the Legal Amazon as of July 2024, illustrating the geographic distribution of areas affected by deforestation and forest degradation. The gray areas indicate locations where deforestation has been detected, while blue points mark regions of degradation. The intensity of deforestation is represented by different shades of red, ranging from "Very Low" to "Very High," with the darkest areas reflecting a higher concentration of deforestation activities. The map reveals that the states of Acre (AC), Rondônia (RO), Pará (PA), and Maranhão (MA) are the most impacted regions, with the most intensely deforested areas located along agricultural frontiers and in zones of urban and rural expansion. These data are crucial for guiding conservation policies and enforcement actions, focusing on areas with higher environmental vulnerability.

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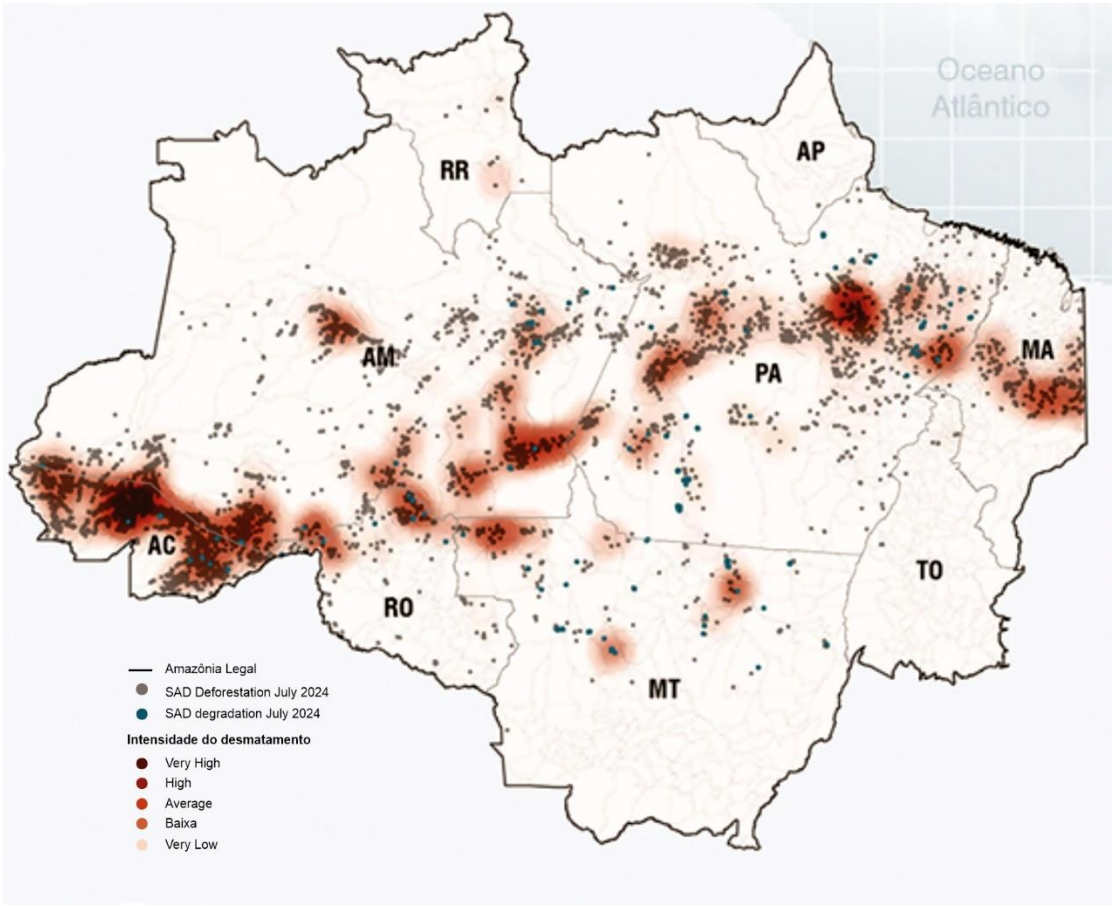
Figure 1 – Map of deforestation in the Legal Amazon in July 2024



Source 1: Deforestation Alert System (SAD) – Imazon, 2024

Deforestation, intensified by agricultural expansion and infrastructure development, is one of the main drivers of environmental degradation in the region. This process not only compromises local biodiversity but also contributes to increased greenhouse gas emissions, further worsening climate change. Meanwhile, global climate change has heightened the vulnerability of Amazonian ecosystems, with increasingly frequent and intense extreme weather events, such as prolonged droughts and floods.

In this context, the central focus of this research is to understand how land-use practices, public policies, and mitigation initiatives affect the Amazon's ability to maintain its ecological integrity and contribute to global climate stability. With this aim, the primary objective of the study is to discuss the main challenges faced by the Legal Amazon in terms of deforestation, economic pressures, and climate change, in order to find possible responses that integrate environmental conservation with sustainable economic development.

To develop the study, the methodology was structured around a comprehensive review of the existing literature, complemented by data analysis on

deforestation, forest degradation, and evaluation of public policies and ongoing mitigation initiatives in the Amazon. The data were collected from secondary sources, including government reports, scientific articles, and databases monitoring land-use changes. The analysis of results was conducted using a qualitative approach, focusing on identifying the interrelationships between the various factors contributing to environmental degradation and the region's climate vulnerability.

The results analysis reveals that, despite mitigation initiatives and conservation policies implemented, deforestation in the Amazon continues at alarming levels. This phenomenon not only accelerates climate change but also puts its sustainability at risk. The analysis highlights the identification of major failures in environmental governance policies and the urgent need to reassess the development strategies adopted. The results also indicate that to ensure the preservation of the Amazon and global climate stability, it will be essential to integrate scientific knowledge with the traditional practices of local communities, as well as strengthen international cooperation in more effective and sustainable public policies.

2 CHALLENGES AND PERSPECTIVES OF SUSTAINABLE DEVELOPMENT IN THE BRAZILIAN LEGAL AMAZON

In recent decades, the sustainable development of the Brazilian Legal Amazon has been a central theme in discussions on environmental conservation and economic development. Formalized by the Brundtland Commission in 1987, this concept aims to ensure that the needs of the present are met without compromising the ability of future generations to meet their own (Brundtland, 1987). In the Amazon, its application faces unique challenges arising from the complex interaction between biodiversity, economic activities, and local populations. The region, home to about 20% of the world's biodiversity, plays an important role in regulating the global climate through carbon sequestration. However, it faces increasing anthropogenic pressures, such as deforestation and forest degradation, which threaten its sustainability (Fearnside, 2008).

Deforestation in the Amazon, which worsened in the 1970s and 1980s (Mahar, 1979), continues to be one of the main causes of environmental degradation[1] in the region. Studies conducted by INPE (2023) indicate that since then, more than 729,000 km² have already been deforested in the Amazon biome, largely for agricultural and livestock expansion (INPE, 2023). This process not only reduces biodiversity but also

[1] Forest Degradation - Refers to the compromise of the integrity of remaining forests, which lose their ecological functionality due to selective logging, fires, and other disturbances (Asner et al., 2005).

compromises the Amazon's ability to act as a carbon sink, contributing to increased greenhouse gas emissions (Soares-Filho et al., 2010).

In addition, global climate change has exacerbated these problems, intensifying extreme events such as prolonged droughts and floods, which directly affect Amazonian ecosystems. Climate projections suggest that if deforestation persists, the Amazon may reach a tipping point, transforming large areas of forest into savannas, a process known as "savannization" (Lovejoy & Nobre, 2019). This tragic scenario would compromise not only local biodiversity but also global climate stability, given the Amazon's importance in atmospheric circulation and the hydrological cycle (Lovejoy & Nobre, 2019).

In response to this scenario, several conservation policies and environmental governance measures have been implemented over the years to try to curb deforestation and promote sustainable development in the region. Among the most important initiatives is the creation of protected areas and Indigenous Lands, which now cover about 43% of the Legal Amazon (Soares-Filho et al., 2010). These areas have proven effective in reducing deforestation rates, especially when combined with consistent public policy enforcement (Nepstad et al., 2006).

However, these measures face resistance from powerful economic interests that push for changes in environmental legislation, such as the relaxation of the 2012 Forest Code, increasing the risk of legalized deforestation (Sparovek et al., 2012). Another aspect to consider relates to environmental governance, which also faces significant challenges, such as institutional fragmentation, lack of coordination between government levels, and insufficient resources for enforcement (Bebbington et al., 2018). Additionally, promising sustainable development initiatives, such as forest management and agroecology, still lack support to be widely adopted (Guariguata, 2009).

Therefore, the history of sustainable development in the Amazon reveals a scenario of important but insufficient progress in the face of growing environmental threats. It is necessary to strengthen and expand conservation policies and environmental governance to ensure that the Amazon continues to provide the essential ecosystem services on which the world depends, while promoting the sustainable economic development of local populations.

3 THE IMPACT OF CLIMATE CHANGE ON THE AMAZON AND MITIGATION INITIATIVES

In recent years, climate change has intensified the impacts on Amazonian ecosystems, raising significant concerns. Studies indicate that the Amazon rainforest, vital for global climate regulation, is becoming increasingly vulnerable to extreme weather events, such as prolonged droughts and floods, whose frequency and intensity have increased due to global warming (Lovejoy & Nobre, 2019).

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Recent research, such as that by Lovejoy and Nobre (2019), suggests that the Amazon is approaching a critical climate tipping point, where much of the forest could transform into savannas. This phenomenon, known as "savannization," is driven by a combination of continuous deforestation and changes in climatic conditions, such as reduced rainfall and rising temperatures. This transition would have catastrophic consequences, affecting not only regional biodiversity but also global climate balance, as the Amazon serves as one of the largest carbon sinks on the planet.

Simultaneously, initiatives to mitigate these impacts have been developed at different scales, from public policies to sustainable management practices. One of the key strategies discussed in the literature is REDD+ (Reducing Emissions from Deforestation and Forest Degradation), which provides economic incentives for forest preservation and contributes to mitigating global climate change (Lapola, 2013).

Bebbington et al. (2018) highlight that Amazonian communities are implementing a range of adaptive practices, such as the management of agroforestry systems and the protection of water resources, to increase their resilience to climate changes. These practices not only help sustain local livelihoods but also contribute to maintaining the ecosystem services that are essential for climate stability.

At the governmental level, the Amazon Deforestation Prevention and Control Plan (PPCDAm), implemented in 2004, has played a fundamental role in reducing deforestation rates. Studies like those by Soares-Filho et al. (2010) show that the protected areas created under this plan have been effective in curbing agricultural expansion and forest degradation, thus contributing to climate impact mitigation. In addition to policy-based approaches, climate adaptation has emerged as a priority in scientific research.

However, significant challenges remain, with pressure for agricultural and mining expansion, as well as recent policies that have weakened environmental enforcement, threatening the progress made over the past two decades. Nepstad et al. (2014) emphasize the importance of strengthening institutions and ensuring adequate funding for mitigation policies, safeguarding the Amazon's critical role in controlling climate change.

Recent research highlights both the growing threats of climate change and the numerous initiatives to mitigate them. The combination of international efforts, national public policies, and local practices offers a promising, though complex, path for Amazon conservation and climate change mitigation.

4 RESULTS AND DISCUSSION

The Brazilian Legal Amazon faces a series of complex challenges that threaten its ecological integrity and the sustainability of local communities. Deforestation and

forest degradation, driven by economic pressures and infrastructure expansion, accelerate the loss of forest cover, affecting biodiversity, the carbon cycle, and ecosystem services. This scenario requires not only the implementation of effective public policies and environmental governance but also an innovative approach that integrates science and technology to promote sustainable natural resource use practices.

The resilience of Amazonian ecosystems and local populations to climate change has become an urgent priority. Adaptive strategies, such as ecological restoration, sustainable management, and the appreciation of traditional knowledge, are essential to address the growing climate impacts. Scientific research and technological innovation are indispensable tools for developing solutions that balance conservation and economic development, ensuring that the Amazon continues to play its role in global climate regulation. Therefore, it is crucial to identify pathways that reconcile environmental preservation with the region's development needs, promoting a sustainable future for the Amazon and future generations.

4.1 Deforestation and Forest Degradation

Deforestation in the Amazon continues to be the greatest threat to biodiversity and environmental sustainability, driven primarily by the conversion of forests into agricultural and pastureland. This process has severe implications for the carbon cycle, biodiversity conservation, and global climate balance (Fearnside, 2005).

Recent studies indicate that deforestation in the Amazon remains at alarming levels, with a significant increase since 2019 due to the relaxation of environmental policies and the expansion of agricultural activities (INPE, 2023). The direct impact of these activities on climate change is substantial. The forest, which plays an important role in the global carbon cycle, risks becoming a net source of carbon emissions, releasing more carbon than it absorbs due to continuous degradation (Gatti et al., 2021). This shift exacerbates global warming and disrupts the regional hydrological cycle, leading to changes in precipitation patterns and increasing the frequency of droughts, which threaten both biodiversity and the human populations that depend on the Amazon's natural resources (Lovejoy & Nobre, 2019).

Regional sustainability is also deeply affected by these destructive practices, as they contribute to the loss of essential ecosystem services such as climate regulation, water purification, and soil fertility maintenance (Foley et al., 2007). The reduction in biodiversity diminishes the Amazon's ability to adapt to new climatic conditions, compromising the stability of ecological systems and opportunities for sustainable development in the region (Laurance et al., 2012).

Given this situation, the complexity of the challenges faced by the Amazon requires integrated responses that address the root causes of the problems. The implementation of stricter conservation policies, combined with the strengthening of environmental governance, is essential to slow the pace of deforestation and mitigate the effects of forest degradation (Nepstad et al., 2014). Initiatives such as the restoration of degraded areas and the promotion of sustainable agroforestry practices show

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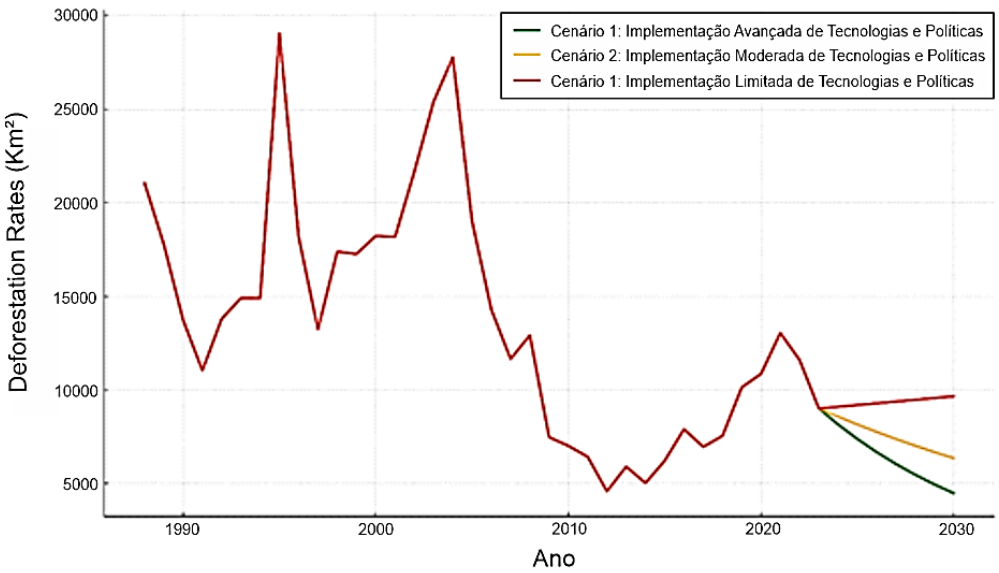
promise in reconciling environmental conservation with economic development in the region (Guariguata, 2009). However, for these initiatives to be effective, a continuous commitment to forest protection and development strategies that prioritize long-term sustainability is necessary.

To illustrate this issue, Figure 2 presents a simulation of projected deforestation rates in the Amazon from 2024 to 2030, based on different levels of implementation of satellite monitoring technologies and public conservation policies. The simulation considers three distinct scenarios:

- **Scenario 1: Advanced Implementation (Green Line)** – In this scenario, the effective application of advanced remote sensing technologies and strict deforestation control policies results in a significant and continuous reduction in deforestation rates. This is an optimistic scenario where the integration of technology and public policies strongly mitigates forest cover loss.
- **Scenario 2: Moderate Implementation (Orange Line)** – Here, the application of technologies and policies is moderate, leading to a slower reduction in deforestation rates. Although progress is made, it is insufficient to achieve a drastic reduction, reflecting the limited impact due to partial implementation.
- **Scenario 3: Limited Implementation (Red Line)** – This scenario assumes a limited application of monitoring technologies and conservation policies, due to constraints such as lack of resources or political support. Deforestation rates may remain high or even increase, reflecting a pessimistic scenario where the measures adopted are insufficient to effectively curb deforestation.

Figure 2 – Scenario Simulation: Projected Deforestation Rates in the Amazon (2024-2030)



Source: Figure created by the authors, based on historical data from PRODES (INPE, 2023).

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The graph (Figure 2) highlights the direct relationship between the degree of implementation of environmental and technological policies and the projected deforestation rates. It serves as an analytical tool to demonstrate the importance of a targeted and integrated approach to preserving the Amazon, emphasizing that the effectiveness of interventions depends significantly on the commitment to the implementation of technologies and conservation policies.

Given this scenario, it is evident that deforestation and forest degradation in the Amazon are global issues, with direct implications for the future of the planet's climate and biodiversity. Mitigating these impacts requires coordinated actions at various levels, from national public policies to international cooperation, ensuring that the Amazon continues to play its vital role in climate regulation and supporting life on Earth.

4.2 Economic Pressures and Infrastructure

The drive for the establishment and expansion of infrastructure and agricultural areas in the Amazon over the years has been one of the main drivers of environmental degradation, fueling deforestation and altering the natural landscape. Since the 1970s, large-scale development projects, such as the construction of the Trans-Amazonian highway and the creation of agricultural colonization areas, have rapidly transformed the region (Fearnside, 2005). These projects, encouraged by government policies aimed at integrating the Amazon with the rest of Brazil, have led to the massive conversion of forests into agricultural and pastoral lands, resulting in significant biodiversity losses and high greenhouse gas emissions (Foley et al., 2007).

Agricultural expansion, especially soy cultivation and cattle ranching, has an alarming impact on the Amazon. The growing demand for agricultural land leads to the direct conversion of forests into arable areas, further encouraging illegal land grabbing, which exacerbates deforestation (Nepstad et al., 2014). Cattle ranching is the main cause of deforestation in the Amazon, responsible for approximately 80% of deforested areas (INPE, 2023). This expansion destroys forest cover, undermines ecosystem services such as the regulation of the hydrological cycle, and depletes soil quality (Barona et al., 2010).

Infrastructure expansion, such as roads, railways, and hydroelectric plants, intensifies environmental pressures in the Amazon. New roads provide access to remote areas, accelerating deforestation and fragmenting habitats, threatening countless species of flora and fauna (Laurance et al., 2012). Hydroelectric plants, while promoting renewable energy generation, cause significant environmental and social impacts,

including the flooding of vast forest areas, altering hydrological regimes, and displacing indigenous and riverine communities (Fearnside, 2016).

Economic and infrastructure pressures in the Amazon are often justified by the pursuit of economic development and the need to boost the national GDP. However, these activities mainly benefit large producers and multinational corporations, while local populations bear the consequences of deforestation and environmental degradation (Moutinho et al., 2016). The development model in the Amazon has been widely criticized for being unsustainable in the long term, as it compromises the region's natural resources and ecological base, which are essential for the survival of future generations (Bebbington et al., 2018).

While economic pressures and infrastructure expansion continue to drive short-term economic growth, the environmental and social costs are immense, jeopardizing the sustainability of the Amazon itself. To mitigate these impacts, it is essential to rethink development strategies, incorporating sustainability principles that reconcile economic growth with environmental conservation and the well-being of local populations.

4.3 Resilience and Adaptation to Climate Change

The growing vulnerability of the Amazon to climate change urgently requires the development of strategies to increase the resilience[2] of ecosystems and local populations. In the Amazon, this capacity is being severely tested by extreme weather events, such as prolonged droughts and floods (Lovejoy & Nobre, 2019). Forest restoration is one of the most effective strategies to strengthen the resilience of Amazonian ecosystems, as it recovers degraded areas and reestablishes connectivity between forest fragments, improving the stability and capacity of ecosystems to withstand disturbances (Brancalion et al., 2019). It is important to note that restored forests act as carbon sinks, helping to mitigate greenhouse gas emissions and reduce the impact of climate change (Strassburg et al., 2020).

In addition to restoration, the sustainable management of natural resources is essential to strengthen resilience in the Amazon. Practices such as agroforestry have proven effective in increasing productivity while preserving biodiversity and ecosystem services, promoting food security, and facilitating climate change adaptation by diversifying income sources and reducing reliance on vulnerable monocultures. For local populations, particularly indigenous and riverine communities, climate change adaptation requires an integrated approach that considers traditional knowledge and

[2] Ecological Resilience - Refers to the capacity of ecosystems to absorb disturbances and reorganize while undergoing change, essentially maintaining the same functions and structures (Holling, 1973).

cultural practices. These communities possess deep knowledge of Amazonian ecosystems and have developed, over generations, management strategies that promote resilience and adaptation to environmental challenges (Lovejoy & Nobre, 2019). Incorporating this knowledge into public policies and adaptation programs is crucial to ensuring that solutions are culturally appropriate and effective in promoting community resilience (Davidson-Hunt & Berkes, 2001).

Moreover, the creation and effective management of protected areas play an important role in climate adaptation in the Amazon, especially as they serve as refuges for biodiversity and help maintain ecological processes essential to ecosystem resilience (Heller & Zavaleta, 2009).

Ultimately, resilience to climate change in this region also depends on the ability of governmental institutions and local communities to implement adaptation policies and practices. This includes strengthening environmental governance, improving the capacity to monitor and respond to extreme events, and promoting education and awareness of climate risks (IPCC, 2014). International cooperation is also crucial, as partnerships between governments, NGOs, and local communities are necessary to develop and implement effective adaptation strategies that can ensure the long-term sustainability of the Amazon.

4.4 Governance and Public Policies

Effective environmental governance[3] is one of the fundamental pillars for ensuring the sustainability of the Amazon, especially in the face of economic pressures and the impacts of climate change that threaten its ecological integrity. Historically, the region has been the target of policies that prioritize the exploitation of natural resources as a means to drive economic growth (Fearnside, 2005). This development model has proven unsustainable in the long term, resulting in high levels of deforestation, forest degradation, and biodiversity loss (Soares-Filho et al., 2010). To reverse this situation, it is necessary to implement public policies that promote the sustainable use of natural resources, encourage low-impact economic practices, and strengthen protected areas and the rights of traditional populations.

A successful example of environmental governance in the Amazon is the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm) [4],

[3] Environmental Governance - Refers to the framework that involves rules, practices, and institutions that guide and direct the management of natural resources and determine how decisions regarding the environment are made and implemented (Lemos & Agrawal, 2006).

[4] The PPCDAm is a model of public policy that seeks to balance environmental conservation with economic development by promoting the sustainable management of natural resources and encouraging the

implemented by the Brazilian government in 2004, designed to reduce deforestation rates in the Amazon during the first decade of its implementation (Nepstad et al., 2014). However, the recent relaxation of some of these policies and the reduction of the environmental enforcement budget threaten to reverse the gains achieved, highlighting the need for more consistent governance (INPE, 2023).

These aspects highlight how much environmental governance in the Amazon depends on effective coordination between levels of government—federal, state, and municipal—as well as the active participation of local communities and civil society. The decentralization of environmental management, when accompanied by adequate training and resources, can improve the effectiveness of public policies, adapting them to local realities and ensuring greater legitimacy and acceptance by the affected populations (Agrawal & Ribot, 1999). However, a lack of coordination and clarity in responsibilities between different levels of government can lead to overlapping efforts, inefficiencies, and ultimately environmental degradation (Lemos & Agrawal, 2006).

The participation of indigenous and riverine populations is crucial to the success of conservation policies in the Amazon. These communities possess traditional knowledge of natural resource management that can complement modern scientific and technological approaches. Public policies that encourage the co-management of protected areas, such as Extractive Reserves, have shown that it is possible to integrate environmental conservation with local economic development, providing sustainable livelihoods for local populations while protecting the forest (Lovejoy & Nobre, 2019).

International initiatives, such as the Amazon Fund, have provided important resources for conservation and sustainable development projects in the region (Moutinho et al., 2016). However, the continuity and effectiveness of these initiatives depend on lasting commitments from both donor countries and the Brazilian government, which must ensure that resources are used transparently and effectively. Therefore, to address emerging challenges, environmental governance and public policies in the Amazon must be strengthened, balancing forest conservation with the region's economic development needs. Only with effective governance, promoting inclusive participation, transparency, and cooperation, will it be possible to ensure the sustainability of the Amazon and, with it, global climate stability.

4.5 Scientific Research and Innovation

The Amazon, essential for biodiversity and global climate regulation, requires a scientific and technological approach that considers its ecological and social complexity.

recovery of degraded areas. This plan combines actions such as satellite monitoring, the creation of protected areas, and the strengthening of environmental enforcement.

Ongoing scientific research is crucial for developing innovative solutions that reconcile conservation with sustainable development (Laurance et al., 2012). This science-based approach must be interdisciplinary and participatory, integrating scales of analysis, from the molecular to the ecosystem level, and incorporating both scientific knowledge and the traditional knowledge of indigenous and riverine populations (Davidson-Hunt & Berkes, 2003).

In this context, technological innovation is important for the monitoring and sustainable management of natural resources. Technologies such as remote sensing, drones, and artificial intelligence have revolutionized the ability to monitor large areas of the forest, enabling rapid and accurate detection of land-use changes, deforestation, and forest degradation (Souza et al., 2020). The National Institute for Space Research (INPE), a global leader in this field, has been using programs like PRODES to monitor deforestation in the Amazon since 1988, providing essential data for public policies and enforcement (INPE, 2023). When integrated with early warning systems, these technologies enhance conservation strategies and combat illegal activities such as logging and mining.

Technological innovation can also improve management practices, such as ecological restoration, which restores degraded areas, reestablishes ecological connectivity, and increases the forest's carbon sequestration capacity (Strassburg et al., 2020), while promoting biodiversity conservation and the development of a sustainable bioeconomy in the region.

The bioeconomy represents a promising frontier for innovation in the Amazon, valuing non-timber forest products and exploring the biotechnological potential of Amazonian biodiversity (Lovejoy & Nobre, 2019). To realize this potential, investment in scientific research and technological development is needed, ensuring the sustainable exploitation of new products and processes, with equitable benefits for local communities (Moutinho et al., 2016).

Finally, scientific research in the Amazon must be conducted in a spirit of interdisciplinary and international collaboration, given its global importance for climate regulation and biodiversity conservation. It is essential that scientists from various disciplines and countries work together to tackle the complex challenges of the region. Initiatives such as Brazil's Global Climate Change Research Program (PPMCG) demonstrate the importance of integrating different areas of knowledge to develop innovative solutions that are effective, equitable, and ensure the development of the Amazon and the well-being of its populations (Gibbs et al., 2015).

For a better understanding of the issues addressed in this study, an analysis matrix was developed, providing an integrated view of the main challenges faced by the Legal Amazon, addressing deforestation and forest degradation, economic pressures

and infrastructure, resilience and adaptation to climate change, governance and public policies, and scientific research and innovation. Each of these elements is interconnected, affecting regional development in a complex and multifaceted way.

Table 1 - Challenge Analysis Matrix

Topic	Description	Negative Impacts	Proposed Solutions	References
Deforestation and Forest Degradation	The conversion of forests into agricultural and pastoral areas is one of the main drivers of forest destruction, aggravated by selective degradation, fires, and other practices that compromise ecosystem integrity.	- Loss of biodiversity - Changes in the carbon cycle, increase in CO2 and CH4 emissions - Alterations in the hydrological cycle, leading to droughts and changes in precipitation patterns	- Implementation of stricter conservation policies - Restoration of degraded areas - Promotion of sustainable agroforestry practices	Fearnside (2005); INPE et al. (2023); Gatti et al. (2021)
Economic Pressures and Infrastructure	Agricultural expansion, especially soy and cattle, and infrastructure such as roads and hydroelectric plants are key drivers of deforestation and degradation in the Amazon.	- Destruction of forest cover - Habitat fragmentation - Greenhouse gas emissions - Negative impacts on local communities	- Reevaluation of development strategies - Implementation of policies that reconcile economic growth with conservation - Corporate responsibility and global awareness	Eçaosside, (2005); Soares-Filho et al. (2010); Laurance et al. (2012); Nepstad et al. (2014)
Resilience and Adaptation to Climate Changes	The ecological resilience of the Amazon is being tested due to climate changes, requiring the adoption of practices that protect and strengthen ecosystem services.	- Increased vulnerability to extreme weather events - Reduction in the Amazon's adaptive capacity	- Sustainable management of natural resources - Integration of traditional knowledge into public policies - Creation and management of protected areas	Holling (1973); Brancalion et al. (2019); Lovejoy and Nobre (2019)
Governance and Public Policies	Environmental governance and public policies are essential to balance conservation and economic development in the Amazon.	- Institutional fragmentation - Corruption and resource insufficiency - Lack of coordination among government levels	- Strengthening of environmental institutions - Decentralization of environmental management with adequate training - International cooperation for financing conservation projects	Lemos & Agrawal (2006); Bebbington et al. (2018); Nepstad et al. (2014)

Topic	Description	Negative Impacts	Proposed Solutions	References
Scientific Research and Innovation	Ongoing research and technological innovation are fundamental to understanding and mitigating the challenges faced by the Amazon, promoting sustainable development.	- Underexplored potential of the bioeconomy - Challenges in integrating scientific and traditional knowledge	- Use of technologies such as remote sensing and AI for monitoring - Development of sustainable bioeconomy - Interdisciplinary and international collaboration in research	Laurance et al. (2012); Davidson-Hunt & Berkes (2003); Souza et al. (2020); Moutinho et al. (2016)

The analysis matrix presented highlights convergences and conflicts in addressing the environmental and socioeconomic issues of the Amazon, with an emphasis on sustainability and environmental conservation. It emphasizes the need for sustainable strategies, such as agroforestry practices, restoration of degraded areas, and sustainable management of natural resources, aligned with the global need to conserve the Amazon and address climate change. The matrix underscores the importance of integrating knowledge and strengthening institutions, combining scientific and traditional knowledge to tackle the complex challenges of the region. It highlights the importance of collaboration among multiple agents and the combination of different forms of knowledge, ensuring a more holistic and inclusive approach. It also emphasizes social responsibility and global awareness, noting that solving problems in the Amazon requires international cooperation, with implications for the entire planet. However, the matrix reaffirms previously identified conflicts between economic pressures, infrastructure expansion, and environmental conservation efforts. Balancing economic growth and environmental preservation represents a considerable challenge, especially in the face of powerful economic interests. Additionally, the tension between adaptive practices and extreme weather events highlights the complexity of implementing sustainability amid the Amazon's growing vulnerability to environmental changes. Finally, the matrix highlights technological and knowledge challenges, particularly in integrating scientific knowledge with traditional knowledge and the underexploitation of the bioeconomy. The tension between the potential of technological and scientific innovations and the practical difficulties of applying them is evident. The cultural complexity and biological diversity of the Amazon make implementing these solutions even more challenging. Thus, solutions require balance, so as not to compromise conservation and sustainable development in the region.

5 CONCLUSION

The Amazon faces interconnected environmental and socioeconomic challenges, such as deforestation, economic pressures, climate change, governance, and scientific innovation. Agricultural expansion and infrastructure construction intensify deforestation and forest degradation, transforming the Amazon from a carbon sink into a significant source of greenhouse gas emissions. Although justified by growth,

economic pressures follow an environmentally and socially unsustainable path. Agricultural expansion and infrastructure accelerate environmental degradation, compromising local ecosystems and global climate stability, depleting natural resources, and threatening the well-being of local populations and the ecological resilience of the Amazon. In the face of these challenges, it becomes imperative to prioritize the resilience of Amazonian ecosystems and dependent populations through forest restoration practices, sustainable management, and the integration of traditional knowledge. This requires improved environmental governance capable of balancing environmental conservation and economic development, strengthening institutions, decentralizing management, and involving local communities. Furthermore, scientific research and technological innovation are essential to address the challenges of the Amazon. Continuous investments in research and development are necessary to explore the bioeconomy and promote the sustainable use of natural resources. Interdisciplinary and international collaboration can develop innovative solutions that integrate environmental conservation and economic development, ensuring that the Amazon continues to play a central role in global climate regulation. To conclude, it is recommended to strengthen environmental governance institutions in the Amazon, promoting the restoration of degraded areas, sustainable management of natural resources, and the incorporation of traditional knowledge. Revising development strategies with a focus on sustainability and encouraging scientific research and technological innovation are essential to ensure a sustainable future for the Amazon.

5 REFERENCES

AGRAWAL, A.; RIBOT, J. Accountability in Decentralization: A Framework with South Asian and West African Cases. **Journal of Developing Areas**, v. 33, n. 4, p. 473-502, 1999.

ARAGÃO, L. E. O. C. et al. 21st Century Drought-Related Fires Counteract the Decline of Amazon Deforestation Carbon Emissions. **Nature Communications**, v. 9, n. 1, 2018. https://doi.org/10.1038/s41467-017-02771-y

ASNER, G. P. et al. Selective logging in the Brazilian Amazon. **Science.** 2005 Oct 21;310(5747):480-2. https://www.science.org/doi/10.1126/science.1118051

BARONA, E. et al. The Role of Pasture and Soybean in Deforestation of the Brazilian Amazon. **Environmental Research Letters**, v. 5, n. 2, 2010. https://doi.org/10.1088/1748-9326/5/2/024002

BEBBINGTON, A. et al. Resource extraction and infrastructure threaten forest cover and community rights. **Proceedings of the National Academy of Sciences**, 115(52), 13164-13173, 2018. https://doi.org/10.1073/pnas.1812505115

BRANCALION, P. H. S. et al. Global Restoration Opportunities in Tropical Rainforest Landscapes. **Science Advances**, v. 5, n. 7, 2019. https://doi.org/10.1126/sciadv.aav3223

BRUNDTLAND, G. H. **Our Common Future: Report of the World Commission on Environment and Development.** United Nations, 1987. Disponível em: https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf. Acesso em: 20 ago. 2024.

DAVIDSON-HUNT, I. J. AND BERKES, F. (2001). Nature and society through the lens of resilience: toward a human-in-ecosystem perspective. **Navigating Social-Ecological Systems,** 53-82,2001. https://doi.org/10.1017/cbo9780511541957.006

FEARNSIDE, P.M. Deforestation in Brazilian Amazonia: History, rates and consequences. **Conservation Biology** 19(3): 680-688, 2005. https://doi.org/10.1111/j.1523-1739.2005.00697.x

FEARNSIDE, P. M. Environmental and Social Impacts of Hydroelectric Dams in Brazilian Amazonia: Implications for the Aluminum Industry. **World Development,** v. 77, p. 48-65, 2016. https://doi.org/10.1016/j.worlddev.2015.08.015

FEARNSIDE, P. M. The Roles and Movements of Actors in the Deforestation of Brazilian Amazonia. **Ecology and Society**, vol. 13, no. 1, 2008. Disponível em: http://www.jstor.org/stable/26267941 . Acesso em: 20 ago. 2024.

FOLEY, J. A. et al. Amazonia Revealed: Forest Degradation and Loss of Ecosystem Goods and Services in the Amazon Basin. **Frontiers in Ecology and the Environment**, v. 5, n. 1, p. 25-32, 2007. https://doi.org/10.1890/1540-9295(2007)5[25:ARFDAL]2.0.CO;2

GATTI, L. V. et al. Amazonia as a Carbon Source Linked to Deforestation and Climate Change. **Nature**, v. 595, p. 388-393, 2021. Disponível em: https://www.nature.com/articles/s41586-021-03629-6 . Acesso em: 20 ago. 2024.

GIBBS, H. K. et al. Brazil's soy moratorium. **Science,** 347(6220), 377-378, 2015. https://doi.org/10.1126/science.aaa0181

GUARIGUATA, M. R. Tropical forest management and climate change Adaptation. **rev.estud.soc.** [online], n.32, pp.98-112, 2009. ISSN 0123-885X. Disponível em: http://www.scielo.org.co/scielo.php?script=sci_abstract&pid=S0123-885X2009000100008 . Acesso em: 20 ago. 2024.

GUARIGUATA, Manuel R. Tropical Forest Management and Climate Change Adaptation. rev.estud.soc. [online]. 2009, n.32, pp.98-112. ISSN 0123-885X.

HELLER, N. E.; ZAVALETA, E. S. Biodiversity Management in the Face of Climate Change: A Review of 22 Years of Recommendations. **Biological Conservation**, v. 142, n. 1, p. 14-32, 2009. https://doi.org/10.1016/j.biocon.2008.10.006

HOLLING, C. S. Resilience and Stability of Ecological Systems. **Annual Review of Ecology and Systematics,** v. 4, p. 1-23, 1973. https://doi.org/10.1146/annurev.es.04.110173.000245

IMAZON - Instituto do Homem e Meio Ambiente da Amazônia**. Sistema de Alerte do Desmatamento (SAD)**, 2024. Disponível em: https://imazongeo.org.br/#/ . Acesso 24 ago 2024.

INPE - Instituto Nacional de Pesquisas Espaciais. **Monitoramento da Floresta Amazônica Brasileira por Satélite.** Brasília: INPE, 2023. Disponível em: http://www.obt.inpe.br/OBT/assuntos/programas/amazonia/prodes . Acesso em: 20 ago. 2024.

IPCC **-** Intergovernmental Panel on Climate Change. **Climate Change 2014: Impacts, Adaptation, and Vulnerability**. Cambridge: Cambridge University Press, 2014. https://doi.org/10.1017/cbo9781107415379.

LAPOLA, D. M. et al Pervasive transition of the Brazilian land-use system. **Nature Climate Change**, v. 4, n. 1, p. 27-35, 20 dez. 2013.

LAURANCE, W. F. et al. Averting Biodiversity Collapse in Tropical Forest Protected Areas. **Nature**, v. 489, p. 290-294, 2012. https://doi.org/10.1038/nature11318

LEMOS, M. C.; AGRAWAL, A. Environmental Governance. **Annual Review of Environment and Resources,** v. 31, n. 1, p. 297-325, 2006. https://doi.org/10.1146/annurev.energy.31.042605.135621

LOVEJOY, T. E.; NOBRE**, C.** Amazon tipping point: Last chance for action. **Science Advances**, v. 5, n. 12, p. eaba2949, 2019. https://doi.org/10.1126/sciadv.aba2949

MAHAR, D.J. **Frontier Development Policy in Brazil: A Study of Amazonia.** Praeger, Nova York, E.U.A., 1979.

MOUTINHO, P.; et al. Achieving Zero Deforestation in the Brazilian Amazon: What is Missing? **Elementa: Science of the Anthropocene**, v. 4, n. 000125, 2016. https://doi.org/10.12952/journal.elementa.000125

NEPSTAD, D. et al. Inhibition of Amazon deforestation and fire by parks and indigenous lands. **Conservation Biology,** v. 20, n. 1, p. 65–73, 2006. https://doi.org/10.1111/j.1523-1739.2006.00351.x

NEPSTAD, D. et al. Slowing Amazon Deforestation Through Public Policy and Interventions in Beef and Soy Supply Chains. **Science**, v. 344, n. 6188, p. 1118-1123, 2014. https://www.science.org/doi/10.1126/science.1248525

LOVEJOY, T. E.; NOBRE, C. A. . Amazon tipping point: last chance for action. **Science Advances,** 5(12), 2019. https://doi.org/10.1126/sciadv.aba2949

SOARES-FILHO, B. et al. Role of brazilian amazon protected areas in climate change mitigation. **Proceedings of the National Academy of Sciences,** 107(24), 10821-10826, 2010. https://doi.org/10.1073/pnas.0913048107

SOTERRONI, A. C. et al. Expanding the soy moratorium to brazil's cerrado. **Science Advances,** 5(7), 2019. https://doi.org/10.1126/sciadv.aav7336

SOUZA, C. M. et al. Reconstructing three decades of land use and land cover changes in brazilian biomes with landsat archive and earth engine. **Remote Sensing**, 12(17), 2735, 20220. https://doi.org/10.3390/rs12172735

SPAROVEK, G. et al. Brazilian agriculture and environmental legislation: status and future challenges. **Environmental Science &Amp; Technology**, 44(16), 6046-6053, 2010. https://doi.org/10.1021/es1007824

STRASSBURG, B. B. N. et al. Global Priority Areas for Ecosystem Restoration. **Nature**, v. 586, p. 724-729, 2020. https://doi.org/10.1038/s41586-020-2784-9