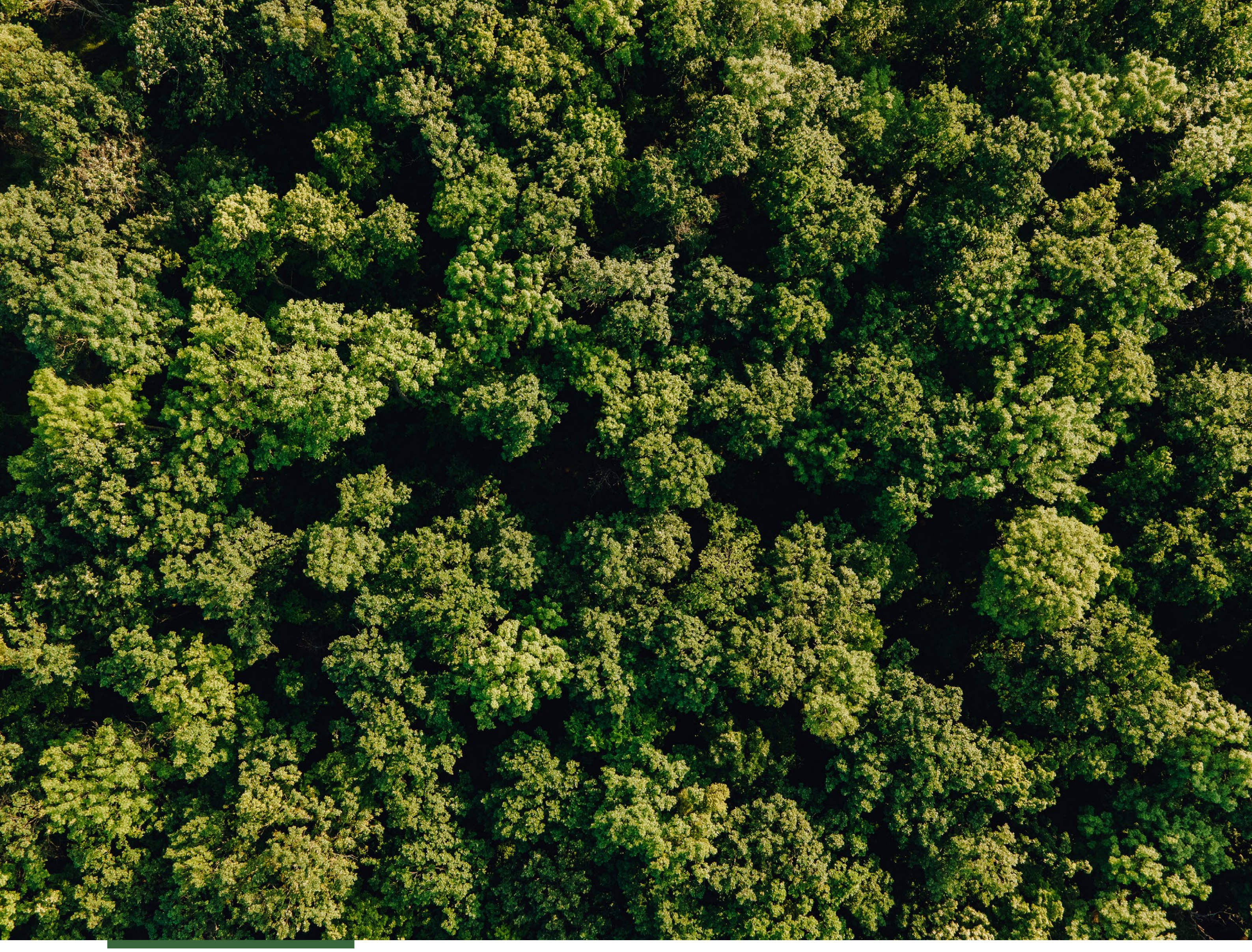

The Forest-Climate Nexus: A Fit-for-Purpose Framework for Climate Impact

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CLIMATE POLICY INITIATIVE

PUC RIO

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About Climate Policy Initiative

Climate Policy Initiative (CPI) is an organization with international expertise in finance and policy analysis. CPI has seven offices around the world. In Brazil, CPI has a partnership with the Pontifical Catholic University of Rio de Janeiro (PUC-RIO). CPI/PUC-RIO works to improve the effectiveness of public policies and sustainable finance in Brazil through evidence-based analysis and strategic partnerships with members of the government, civil society, the private sector and financial institutions.

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List of Acronyms

APP Permanent Preservation Area (*Área de Preservação Permanente*)

CO_2 Carbon Dioxide

CO_2e Carbon Dioxide Equivalent

CPI/PUC-RIO Climate Policy Initiative/Pontifical Catholic University of Rio de Janeiro

DETER Real-Time Deforestation Detection System (*Sistema de Detecção de Desmatamento em Tempo Real*)

DPI Digital Public Infrastructure

EU ETS European Union Emissions Trading System

FSC Forest Stewardship Council

GDP Gross Domestic Product

GFW Global Forest Watch

GHG Greenhouse Gas

GST Global Stocktake

ITMOs Internationally Transferable Mitigation Outcomes

JREDD+ Jurisdictional REDD+

NDCs Nationally Determined Contributions

NPFE Non-permanent Forest Estate

PES Payments for Environmental Services

PFE Permanent Forest Estate

PPCDAM Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (*Plano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal*)

PV Present Value

REDD+ Reducing Emissions from Deforestation and Forest Degradation

SDGs Sustainable Development Goals

SEMAD/GO State of Goiás Secretariat of Environment and Sustainable Development (*Secretaria de Estado de Meio Ambiente e Desenvolvimento Sustentável*)

RDM Reversing Deforestation Mechanism

RL Legal Forest Reserve (*Reserva Legal*)

TFFF Tropical Forest Forever Facility

UNEP United Nations Environment Program

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Executive Summary

Global efforts to tackle climate change are falling short. Despite years of international negotiations and commitments, emissions continue to rise, and the transition to a low-carbon economy remains uneven and insufficient. Current policies and actions are not only failing to curb emissions but are also allowing climate impacts to intensify, leaving ecosystems, communities, and economies increasingly vulnerable. The need for urgent, ambitious, and coordinated measures has never been greater, as the window to avoid irreversible climate impacts continues to narrow.

In this context, scaling carbon removals has become increasingly critical—and tropical forests stand out as one of the most powerful, immediate, and cost-effective solutions. Forest restoration can deliver vast carbon sequestration at a relatively low cost, while safeguarding biodiversity, regulating water cycles, and supporting rural livelihoods.

Yet, despite their immense potential, tropical forests are often regarded as a climate risk rather than recognized as central solutions due to ongoing deforestation. Effectively stopping deforestation, conserving standing forests, and restoring degraded lands could transform this perception, creating a reinforcing feedback loop between climate action and forest health. A better forest management can play an important role in climate mitigation, revenues from climate-related services can be invested to restore and safeguard tropical ecosystems, strengthening forest resilience and reducing the risk of crossing critical tipping points.

In this report, researchers from Climate Policy Initiative/Pontifical Catholic University of Rio de Janeiro (CPI/PUC-RIO) explore the forest-climate nexus, highlighting the deeply reciprocal relationship between tropical forests and climate. By examining 91 countries with tropical forests, the researchers document the diversity of challenges—highlighting the need for differentiated and flexible approaches—and identify a key opportunity in the form of forest restoration. While existing policy instruments offer solutions to protect forests and promote restoration, they are often vulnerable to political cycles, underscoring the need to provide stable incentives for countries to protect tropical forests. **This report presents a fit-for-purpose financial architecture tailored to meet the different realities of tropical forests across the world, and proposes a Reversing Deforestation Mechanism (RDM) to fill a critical gap that would advance restoration and transform the role of forests from a climate risk to a climate solution.**

Through the integration of jurisdictional and results-based approaches, the proposed RDM addresses the current absence of robust financing for large-scale restoration and complements efforts to curb deforestation and safeguard standing forests, such as Jurisdictional REDD+ (JREDD+) and the Tropical Forest Forever Facility (TFFF).

As the world prepares for COP30 in Belém, this report's message is clear: **tropical forests must move from the margins of climate strategies to the forefront. Forests are not just vulnerable to climate change—they are indispensable to solving it.** With tailored policies, robust finance, and long-term political commitment, they can deliver climate mitigation, biodiversity protection, and sustainable development at a scale few other solutions can match. The urgency is paramount: acting decisively now can transform tropical forests into lasting climate assets, while delaying action risks losing an unparalleled opportunity to secure both climate and ecological stability.

The Forest-Climate Nexus

The forest-climate nexus underscores the dual role of tropical forests as climate regulators and climate solutions. Beyond storing immense carbon stocks, tropical forests also influence rainfall patterns through evapotranspiration, regulate water cycles, sustain biodiversity, and support over a billion people, while deforestation and degradation impact emissions and disrupt ecosystems and livelihoods. Forests also play an important role in helping species, people, and countries adapt to climate change. Simultaneously, forests face rising vulnerability to higher temperatures, changing precipitation, prolonged droughts, and more frequent wildfires. This bidirectional dynamic means that forest loss accelerates climate change, while climate change undermines forest resilience.

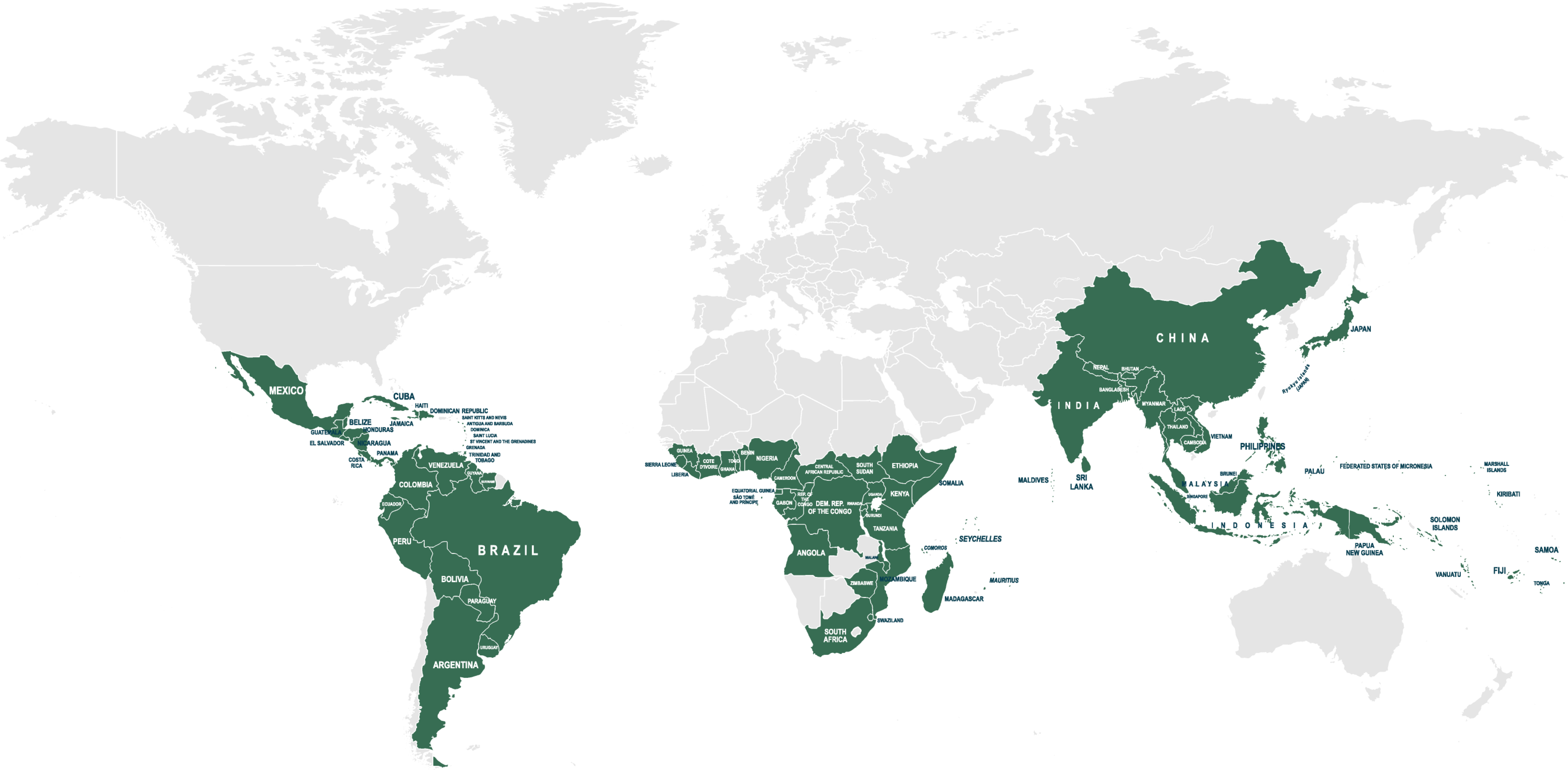
Protecting and restoring forests represents one of the most scalable, cost-effective, immediate, and politically viable options for climate mitigation and adaptation. Climate policy and finance can play a crucial role in implementing the forest-climate nexus, by reinforcing forest protection and fostering restoration.

Tropical Forest Countries: Challenges and Opportunities

Using satellite-based information, this report assesses tropical forests across 91 countries, examining forest cover, deforestation trends, and opportunities for restoration. Figure ES 1 shows how, together, these countries hold 1.27 billion hectares (ha) of tropical forests and store 593 gigatons of CO_2 equivalent ($GtCO_2$), which amounts to approximately one-third of the world's historical emissions. Over the past decade, these countries have lost over 10 million ha per year. Nevertheless, the drivers of deforestation vary widely—from cattle ranching and shifting cultivation to fuelwood collection, illegal logging, and illicit economies.

While deforestation significantly impacts climate mitigation efforts, the restoration of areas deforested since 2001 could capture up to 49 $GtCO_2$. To put this into perspective, in 2024, the remaining carbon budget was estimated at 900 $GtCO_2e$ for limiting warming to below 2°C and 200 $GtCO_2e$ to stay below a 1.5°C limit according to the UNEP Emissions Gap Report (2024).

Figure ES 1. Countries with Tropical Forests, 2023



91 Countries with Tropical Forests

What needs protection

1.27 Billion hectares of forest area

Most biodiverse ecosystem 593 $GtCO_2$ (1/3 historical global emissions)

Current threat

Over 10 Million hectares of deforestation annually in the last decade

Opportunity

49 $GtCO_2$ potential for carbon removals from forest restoration

Source: *CPI/PUC-RIO with data from Hansen et al. (2013) - v1.11, CHIRPS precipitation (2023), and TerraClimate temperature (2020), 2025*

This report recognizes that the reality of countries varies substantially and categorizes them into three groups based on their forest cover, deforestation rates, and carbon potential:

- High Forest Cover, Low Deforestation, Low Carbon Potential
- Low Forest Cover, High Deforestation, Low Carbon Potential
- High Forest Cover, High Deforestation, High Carbon Potential

This classification exercise highlights the importance of understanding the nature and scale of the challenges different countries face and underscores the need for flexible and context-specific strategies that match actions and investments to meet these challenges.

When investigating different forest contexts and socioeconomic conditions across 91 countries, CPI/PUC-RIO observed that deforestation is not directly related to the economic development of countries. This study shows that neither standing forests nor deforestation rates have a direct relationship with countries' per capita income. Thus, it can be inferred that deforestation is not a necessary condition for economic growth, and at the same time, that the protection and restoration of forests do not hinder socioeconomic development.

Forest Policy Toolkit: Effectiveness and Political Risks

Bolstering forests to serve as a climate solution requires robust policy frameworks. Governments have developed an effective toolkit of regulatory measures and economic incentives and subsidies, as shown in Figure ES 2, to reduce deforestation and promote restoration in tropical contexts. Key instruments include protected areas, the protection of species at risk and their habitats, forest and land-use regulations, Payments for Environmental Services (PES), agricultural subsidies, conditions on access to rural credit, and commercial and market-based policies. Evidence indicates these interventions are most effective when they are grounded in local social, political, and economic contexts and are strategically combined in a complementary manner.

Figure ES 2. Forest Policy Toolkit

REGULATORY INSTRUMENTS

- Protected Areas
- Wildlife Protection Regulations
- Forest and Land-Use Regulations
- Enforcement-centered Instruments

ECONOMIC INCENTIVES AND SUBSIDIES

- Payment for Environmental Services
- Subsidies for Increases in Agricultural Productivity
- Policies for Credit Subsidies
- Commercial and Market-Based Policies

Source: *CPI/PUC-RIO, 2025*

The success of policies depends on having the right conditions in place to support their implementation. Clear land tenure and property rights, policy alignment across sectors, coordinated institutional arrangements, accountable decision-making, and consistent enforcement are essential to translate policy into results on the ground.

Politics remains a major source of uncertainty. Deforestation often rises or falls depending on shifts in government priorities. To be effective, policies must therefore be designed to withstand political change. Building resilience can involve strengthening legal frameworks, embedding enforcement in independent institutions, or aligning economic incentives with long-term forest stewardship. The key lesson is that effective forest policy depends not only on good design but also on the conditions that enable it to endure. Having a fit-for-purpose financial architecture is a way of providing such incentives to countries with tropical forests.

Building a Fit-for-Purpose Financial Architecture: The Reversing Deforestation Mechanism

Ultimately, this report aims to advance a fit-for-purpose financial architecture to create incentives for effective forest protection and restoration that meet the needs of individual countries and promotes common climate good. Researchers from CPI/PUC-RIO propose a new piece of financial architecture to close the forest finance gap and promote restoration: the Reversing Deforestation Mechanism (RDM). JREDD+, while allowing forest restoration, has primarily been used to halt deforestation. Alternatively, while the recently proposed TFFF rewards restored forests, it mainly focuses on preserving standing forests.

RDM is proposed as a complement to the existing JREDD+ and TFFF mechanisms. It is designed to reward net carbon removals—CO_2 captured through restoration subtracting emissions from deforestation and degradation—at the jurisdictional level. Payments would be results-based, tied to verified annual performance, and managed through dedicated jurisdictional funds to reinvest in forest protection and sustainable land use. Figure ES 3 provides a comparison of these three complementary mechanisms.

Figure ES 3. Forest Finance Mechanisms: JREDD+, TFFF, and RDM

	JREDD+	TFFF	RDM
Object	Carbon credits from avoided deforestation	Hectares of standing forests	Credits from forest restoration carbon removals
Scope	Jurisdictional	Jurisdictional	Jurisdictional
Payments	Results-based	Results-based	Results-based
Incentives	Credits are paid against a baseline, usually computed as previously observed deforestation rates	Each deforested hectare cancels the payment of 100 hectares	Credits are computed on a net basis—carbon from forest restoration subtracted from emissions from deforestation
Potential scale	10 million hectares of yearly deforestation	1.27 billion hectares of tropical forests	186 million hectares deforested between 2001 and 2023 could be reversed
Potential carbon impact	3.77 $GtCO_2$ yearly lost	593 $GtCO_2$ stored in tropical forests in 2023	49 $GtCO_2$ of potential carbon capture in areas deforested in 2001-2023 if fully reversed
Potential revenue	Up to US$ 32 billion if all deforestation is halted	Around US$ 5 billion per year at US$ 4 per hectare of forest	Up to US$ 100 billion if implemented at full-speed with US$ 50 per ton of CO_2

Source: *CPI/PUC-RIO, 2025*

Estimates indicate that at a carbon price of US$ 50 per ton of CO_2, RDM could generate revenues with discounted present value exceeding US$ 5,000 per hectare for 170 million ha worldwide. Restoring forests under this scheme could remove up to 2 $GtCO_2$ per year globally in the first years of operation, which is about 11-13% of the emissions gap to limit climate change to 2.0°C in 2035, according to the UNEP Emissions Gap Report (2024). At US$ 50 per ton, that represents roughly US$ 100 billion in annual revenues—underscoring both the climate significance and the financial opportunity of large-scale restoration. **By tying climate finance directly to verified carbon outcomes, RDM provides a scalable and transparent pathway for transforming tropical forests into high-impact climate assets.**

Achieving the full potential of RDM depends on a set of implementation requirements that ensure environmental integrity, financial viability, and long-term impact. Implementing large-scale restoration through jurisdictional approaches offers a pathway to maximize climate and ecological benefits while enabling effective enforcement and monitoring. By focusing on entire jurisdictions rather than isolated projects, restoration efforts benefit from reduced fragmentation, enhanced carbon permanence, and economies of scale in enforcement. Central to this strategy is a robust carbon accounting framework that ties payments to net carbon outcomes, combining removals from regeneration with penalties for emissions from deforestation and degradation. This ensures environmental integrity while aligning incentives across stakeholders.

To scale and sustain these efforts, long-term financial viability is critical. Regulated international carbon markets—enabled by Article 6 of the Paris Agreement—can provide the necessary demand and predictability, offering effective mitigation for high-income countries while channeling results-based finance to tropical jurisdictions. RDM's permanence safeguards, such as future payments from a dedicated fund or forgivable loans, help protect restored forests over time. Flexibility in the use of proceeds allows alignment with local priorities, while the private sector can enhance delivery, innovation, and the development of sustainable forest-based value chains. Together, these elements form a coherent architecture to unlock the full climate and development potential of tropical forest restoration.

Introduction

International efforts to mitigate climate change remain inadequate. Despite the Paris Agreement's commitments, global greenhouse gas (GHG) emissions have risen from 49 gigatons of CO_2 equivalent ($GtCO_2e$) in 2015 to 53 $GtCO_2e$ in 2023, pushing the world further from its 1.5°C and 2.0°C targets. The United Nations Environment Programme's (UNEP) latest Emissions Gap Report (2024) projects that current Nationally Determined Contributions (NDCs) would lead to a 2.6°C to 2.8°C temperature rise. Recent estimates suggest each additional 1°C of warming could reduce global Gross Domestic Product (GDP) by about 12% (Bilal and Känzig 2024). These risks are exacerbated by the fact that the transition to a low-carbon economy remains slow and politically fraught.

Against this backdrop, scaling carbon removals has become a priority, and tropical forests offer one of the most powerful tools available. **Forest restoration can deliver large-scale, cost-effective, and politically feasible carbon sequestration while supporting broader ecological stability.** Today, however, tropical forests are often perceived as a threat, given their vast carbon stocks and persistent deforestation, than as a climate solution. Halting deforestation, safeguarding remaining forests, and restoring degraded areas could dramatically shift this equation.

Strengthening the forest-climate nexus offers a reciprocal opportunity: forests can deliver meaningful mitigation through large-scale carbon removals, while carbon credit revenues can provide vital resources for countries with tropical forests. Yet these ecosystems face growing pressure from ecological tipping points and governance challenges in developing countries, where competing social demands and limited institutional capacity constrain effective policy implementation. While multiple financial mechanisms for forest conservation and restoration exist, mobilizing funds at the necessary scale remains a critical barrier.

In this report, researchers from the Climate Policy Initiative/Pontifical Catholic University of Rio de Janeiro (CPI/PUC-RIO) examine the forest-climate nexus across 91 countries with tropical forests. The report highlights the diversity of national contexts and the challenges and opportunities facing tropical forests, emphasizing the need for customized and country-led financial solutions to support effective forest management and restoration at scale.

The first chapter sets the stage by introducing the forest–climate nexus and underscoring the global significance of tropical forests. The second chapter investigates forest cover, deforestation patterns, and restoration potential, grouping tropical forest countries into categories that reflect the diversity among them and the scale of challenges and opportunities, illustrating why a flexible, context-specific approach is essential. The third chapter reviews existing forest policy instruments and enabling conditions supporting their implementations, showing that while effective frameworks exist, they are often exposed to political risks. The final chapter proposes a fit-for-purpose financial architecture based on jurisdictional approaches and results-based finance to better integrate tropical forests into global climate strategies, accommodating diverse national realities. It presents a new mechanism for forest restoration designed to complement existing tools: the Reversing Deforestation Mechanism (RDM).

As the global community looks ahead to COP30 in Belém, this report makes a clear case: tropical forests must no longer be treated as peripheral in climate planning. They represent one of the most effective, immediate, and powerful tools available to address the climate crisis.

The Forest-Climate Nexus

Tropical forests are at the heart of the climate system, serving simultaneously as critical regulators of carbon, biodiversity, and water regime. Understanding the full nature of this interdependence requires moving beyond broad statements to examine how exactly forests influence—and are influenced by—the global climate. This chapter examines the multiple functions tropical forests perform and outlines how reframing the forest–climate nexus can strengthen both climate action and forest management.

Carbon Dynamics: From Net Emitters to Net Sinks

Forests are vital to the planet's carbon balance. Intact forests function as carbon sinks, absorbing CO_2 from the atmosphere through photosynthesis. In doing so, they help mitigate climate change by storing billions of tons of CO_2. Nevertheless, this balance can be easily disrupted. When forests are degraded or cleared, they release stored carbon back into the atmosphere, becoming net carbon sources. In fact, land-use change, particularly deforestation, significantly contributes to global GHG emissions (IPCC 2022).

This dual role of forests—as both sinks and sources—depends on human action. Land-use decisions, such as expanding agriculture or infrastructure into forested areas, lead to carbon loss. In contrast, conservation and restoration efforts can turn forests into a powerful climate solution by enhancing their capacity to store carbon.

Contrary to common belief, meeting global food demand does not require further deforestation. Research shows that the current agricultural footprint, if managed efficiently, is sufficient to sustain the global population (Souza and Assunção 2020). Statistics from the Food and Agriculture Organization of the United Nations (FAOSTAT) indicate that despite the observed increase in agricultural production, the global agricultural area has remained stable over the past two decades. This reinforces that forest loss is not required to meet growing demand, but a consequence of policy and market failures.

While climate change brings new threats that can weaken forest resilience, it also amplifies the urgency of forest restoration. This relationship underscores the importance of protecting existing forests and restoring degraded ones. Restored forests not only capture lost carbon but also improve biodiversity, water cycles, and local livelihoods. Among all nature-based climate solutions, forest protection and restoration remain the most scalable and cost-effective options for carbon removal (Assunção et al. 2025).

Whether forests ultimately amplify the climate crisis or help solve it, will be determined by choices made today.

Biodiversity: Tropical Forests as Global Hotspots

Tropical forests are home to more than 50% of all terrestrial species, making them the most biodiverse ecosystems on Earth (Pillay et al. 2021). This biodiversity is not only valuable in itself; it plays a critical functional role in maintaining forest resilience and supporting key ecosystem services, including carbon sequestration, water regulation, and soil fertility (Myers et al. 2000).

Many of these forests fall within biodiversity hotspots: 36 globally recognized regions where exceptional concentrations of endemic species are under severe threat from human activity. These hotspots cover just 2.5% of Earth's land surface, yet they support more than 35% of the ecosystem services that vulnerable populations rely on for survival, such as clean water, food, and climate regulation (Conservation International nd). Because they represent both biological richness and human dependence, protecting these areas yields outsized benefits for both nature and people.

Biodiversity enhances ecosystem resilience, enabling forests to better withstand climate stress while continuing to deliver essential functions. Diverse species and genetic variation help ecosystems adapt to shocks and recover from disturbance. Conversely, biodiversity loss undermines these functions, weakening the capacity of forests to store carbon and regulate water cycles (Myers et al. 2000).

Beyond ecological benefits, biodiversity has profound cultural and economic value. Communities in and around tropical forests depend on a wide array of forest products—nuts, fruits, medicinal plants, rubber, and timber—for their livelihoods and traditions.

Importantly, biodiversity restoration and climate mitigation are mutually reinforcing goals. Well-designed natural regeneration using native species can recover up to 90% of original species richness, significantly outperforming monoculture plantations in ecological function and resilience (Rozendaal et al. 2019). **Protecting existing and restoring degraded forests, especially in biodiversity hotspots, offers a high-impact pathway for achieving both climate and development goals.**

Water and Climate Regulation: Forests as Climate Stabilizers

In addition to their role in carbon storage and biodiversity conservation, tropical forests are fundamental to sustaining the water cycle at multiple scales. Vegetation in these forests continuously recycles moisture through evapotranspiration—the process by which water is transferred from soil and plants into the atmosphere—influencing rainfall distribution both locally and across distant regions (Salati et al. 1979; Aragão 2012; Beveridge et al. 2024). This moisture recycling acts as a climatic bridge between ecosystems, meaning that environmental degradation in one area can disrupt rainfall and ecological balance in others.

Such interdependence renders tropical forests particularly vulnerable to cascading effects. For instance, when large areas of forest are lost in the eastern Amazon, the resulting reduction in atmospheric moisture can impair the resilience of downwind forests, increasing their likelihood of degradation (Lovejoy and Nobre 2018). Araujo (2023) estimates that forest degradation amplifies its reach, often doubling the area of impact through these moisture feedback loops. Alarmingly, some parts of the Amazon already show signs of becoming net carbon emitters rather than sinks, highlighting the destabilizing influence of these hydrological disruptions (Gatti et al. 2021). Flores et al. (2024) further warn that a large portion of the biome could soon reach a critical threshold of exposure to such risks.

The consequences are not confined to the forest alone. Declines in rainfall linked to deforestation have been shown to lower agricultural productivity in downwind areas (Leite-Filho et al. 2021; Spracklen, Arnold and Taylor 2012; Araujo 2023), while also undermining hydropower generation, which is heavily dependent on predictable water flows (Stickler et al. 2013; Araujo 2024; Araujo and Mourão 2023). **These water-cycle disruptions carry wide-ranging economic and social implications, underscoring the need to protect forest integrity as a matter of regional climate and resource security.**

Social and Development Benefits: Forests and Human Well-being

Beyond their ecological and climate value, tropical forests are deeply intertwined with human well-being and development. Forests support the livelihoods of over 1.6 billion people worldwide, particularly in rural areas, by providing food, medicine, fuel, timber, fiber, and income-generating opportunities through both formal and informal markets (Grima et al. 2023). For many communities, especially Indigenous Peoples and traditional populations, forests are not just a source of material sustenance, but also the foundation of cultural identity, spiritual life, and social cohesion (UNEP 2021).

In their landmark study, Levis et al. (2017) analyzed data from thousands of forest plots across the Amazon and found that many of the region's most abundant tree species—including Brazil nut, cacao, and certain palms—were historically cultivated and dispersed by Indigenous peoples. This research challenges the notion of the Amazon as a "pristine wilderness" and instead demonstrates that human management has been integral to the structure and diversity of the forest over millennia. This aligns with archaeological evidence that the Amazon once supported millions of people who actively managed species and landscapes, fundamentally contributing to the forests we observe today (Neves 2016).

Forest protection can deliver significant co-benefits for development. When well-managed, conservation and restoration efforts can strengthen local economies by supporting sustainable value chains, including non-timber forest products, community forestry, ecotourism, and forest-compatible agriculture (FAO et al. 2023). These approaches, when aligned with the rights and knowledge of local communities, offer more inclusive and resilient development pathways (Agrawal et al. 2009)

Evidence also shows that forests are critical to advancing climate justice and social equity. Indigenous and local communities often act as effective stewards of biodiversity and carbon stocks—managing at least 36% of intact forests globally—yet these areas remain among the most vulnerable to deforestation, land grabbing, and climate impacts (IPCC 2022).

Recognizing land tenure rights, ensuring access to benefit-sharing mechanisms, and investing in community-led forest governance are therefore essential not only for conservation outcomes, but also for social and economic justice (FAO 2024).

As countries seek to align environmental priorities with poverty reduction and rural development goals, protecting forests can serve as a strategic tool—one that bridges global climate action with local well-being and long-term development.

Forests and Adaptation

Forests are central to the climate agenda not only for their role in mitigation—absorbing and storing carbon—but also for their capacity to support adaptation. This dual role can be understood as **adaptation for forests**, which refers to measures that help forests remain resilient under climate stress, and **forests for adaptation**, which highlights the services forests provide to strengthen the resilience of societies and economies.

Adaptation for forests refers to the strategies, practices and policies that help forest ecosystems—and the people who depend on them—adjust to the impacts of climate change while maintaining their ecological, economic, and social functions. They aim to address the growing vulnerabilities that forests face from droughts, pests, shifting species ranges, and wildfires. Strategies such as fire management, controlling invasive species, conserving genetic and species diversity, and creating more resilient plantations ensure that forests continue to thrive and provide essential ecosystem services in a changing climate (Keenan 2015).

Forests for adaptation emphasizes the critical role forests play in helping people, communities and economies adapt to the impacts of climate change by regulating water cycles, protecting soils, reducing the risks of floods and droughts, and providing food, fuel, and other products that serve as safety nets in times of crisis. These services are indispensable for sectors that are particularly climate-sensitive, such as agriculture, water management, and energy. A striking example is the Amazon's "flying rivers," the massive transport of moisture generated by forests that sustains rainfall regimes across South America. Deforestation disrupts this system, with consequences for agriculture, water security, and hydropower (Araujo 2024). **Preserving forests thus becomes an adaptation measure in itself, ensuring stable water flows, reducing sedimentation, and safeguarding the reliability of hydropower generation.**

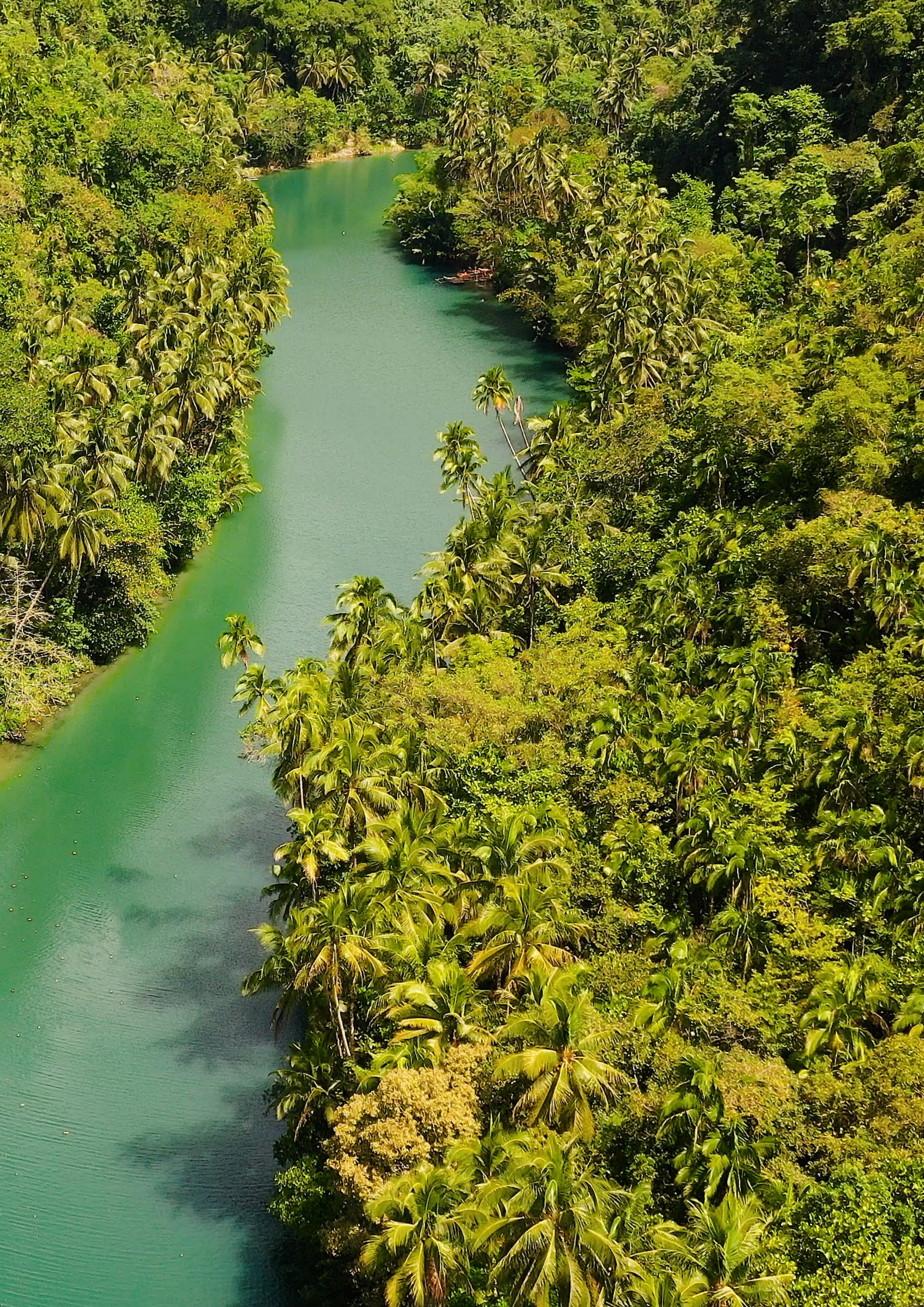
Taken together, these perspectives form the basis of **forest-based adaptation**, an approach that brings together sustainable forest management, conservation, restoration, and afforestation to strengthen resilience. Beyond helping societies cope with climate impacts, forest-based adaptation also generates mitigation co-benefits and contributes directly to most of the Sustainable Development Goals (Libert-Amico et al. 2022).

The Forest-Climate Nexus

Tropical forests and the global climate system are bound by a deeply reciprocal relationship. Forests influence climate by storing vast amounts of carbon, shaping rainfall patterns through evapotranspiration, and regulating surface temperatures. At the same time, they are increasingly vulnerable to the impacts of climate change, including higher temperatures, shifting rainfall regimes, prolonged droughts, and more frequent wildfires. This two-way dynamic means that forest loss accelerates climate change, while climate change erodes forest resilience. **Understanding this forest-climate nexus is central to this report, which explores how tropical forests can contribute to climate mitigation and adaptation and inform effective policy and finance strategies.**

Forests are among the most scalable and cost-effective climate solutions available today. They absorb roughly one-third of annual CO_2e emissions from human activity and are critical to achieving global climate targets. Protecting standing forests conserves immense carbon stocks, while large-scale restoration through natural regeneration and restoration can deliver immediate, low-cost carbon removals.

The climate agenda, in turn, can provide enabling conditions for stronger forest protection. Well-structured climate finance and policy mechanisms can channel significant resources to conservation and restoration, create long-term incentives for sustainable management, and reduce political and economic risks. **By aligning forest and climate strategies, under the forest-climate nexus, countries can establish a reinforcing cycle in which climate action protects forests, and forests advance climate goals.**



Tropical Forest Countries: Challenges and Opportunities

Tropical forests are home to the world's most biodiverse and carbon-rich forests, covering approximately 1.27 billion ha across the world. Over the past decade, countries with tropical forests have collectively lost more than 10 million ha of tropical forest per year. The drivers of deforestation vary widely across regions, and include land clearing for cattle ranching, cultivation and subsistence farming, fuelwood extraction, illegal logging, and even activities linked to illicit economies such as narcotrafficking. **At the same time, CPI/PUC-RIO estimates suggest that the deforested areas from 2001 to 2023 hold a potential to capture up to 49 GtCO$_2$, highlighting the crucial role of restoration efforts in the climate agenda.** This figure is significant because, as of 2024, the UNEP Emissions Gap Report mentions the remaining carbon budget at approximately 900 GtCO$_2$e to limit global warming to below 2°C, and only 200 GtCO$_2$e to stay within the 1.5°C target.

Three key elements in this agenda—protecting remaining forests, combating deforestation, and restoring forests—manifest differently across tropical nations, reflecting variations in geography, land-use pressures, governance, and institutional capacity. **Understanding the prominence and interconnected nature of these dynamics in each context is necessary in strengthening the forest-climate nexus.**

This chapter begins by analyzing the scale of the forest agenda in each tropical country, estimating the area of forest to be protected, current deforestation dynamics, and the potential volume of carbon that could be captured through forest restoration. Using a machine learning approach the analysis classifies countries in three distinct groups according to their forest management challenges: (i) those with high forest cover, low deforestation, and low carbon potential; (ii) those with low forest cover, high deforestation, and low carbon potential; and (iii) those countries with high forest cover, high deforestation, and high carbon potential.[1] This chapter then examines the relationship between economic development and the forest agenda.

The analysis highlights three main insights. First, conserving and restoring tropical forests requires initiatives that match the scale of the challenge to fully unlock their potential for global climate mitigation. Second, the wide variation of national circumstances calls for differentiated and flexible policy approaches. Countries differ significantly in forest cover, conservation status, and biophysical capacity for carbon regeneration, making tailored, fit-for-purpose strategies essential. Third, the data show no inherent trade-offs between the forest agenda and economic development: countries with higher deforestation rates do not necessarily have higher income levels, suggesting that forest loss is not a necessary condition for economic development. Likewise, countries with large, forested areas do not necessarily have low GDP per capita.

1 Countries were classified using hierarchical agglomerative clustering (Ward's method, Euclidean distance) based on three variables: share of forest area within the biome, share of deforestation in 2013–2023, and relative carbon stock.

The Scale of the Forest Agenda

To quantify the scale of the tropical forest agenda, consistent indicators were developed across three dimensions: forest area, forest loss, and potential for carbon sequestration.

The analysis covers countries within the *Tropical & Subtropical Moist Broadleaf Forests* ecoregion. For simplicity, the term "tropical forests" is used to refer to this ecological region. The geographic boundaries of the biome follow the original delineation by Olson et al. (2001) in their global terrestrial ecoregion typology, as later refined by Dinerstein et al. (2017). All sovereign countries with any portion of their territory overlapping the biome were considered, regardless of the relative size of that overlap, totaling 91 countries. National borders were sourced from the Natural Earth dataset. Overseas territories, administrative dependencies, and other non-sovereign subdivisions were excluded.

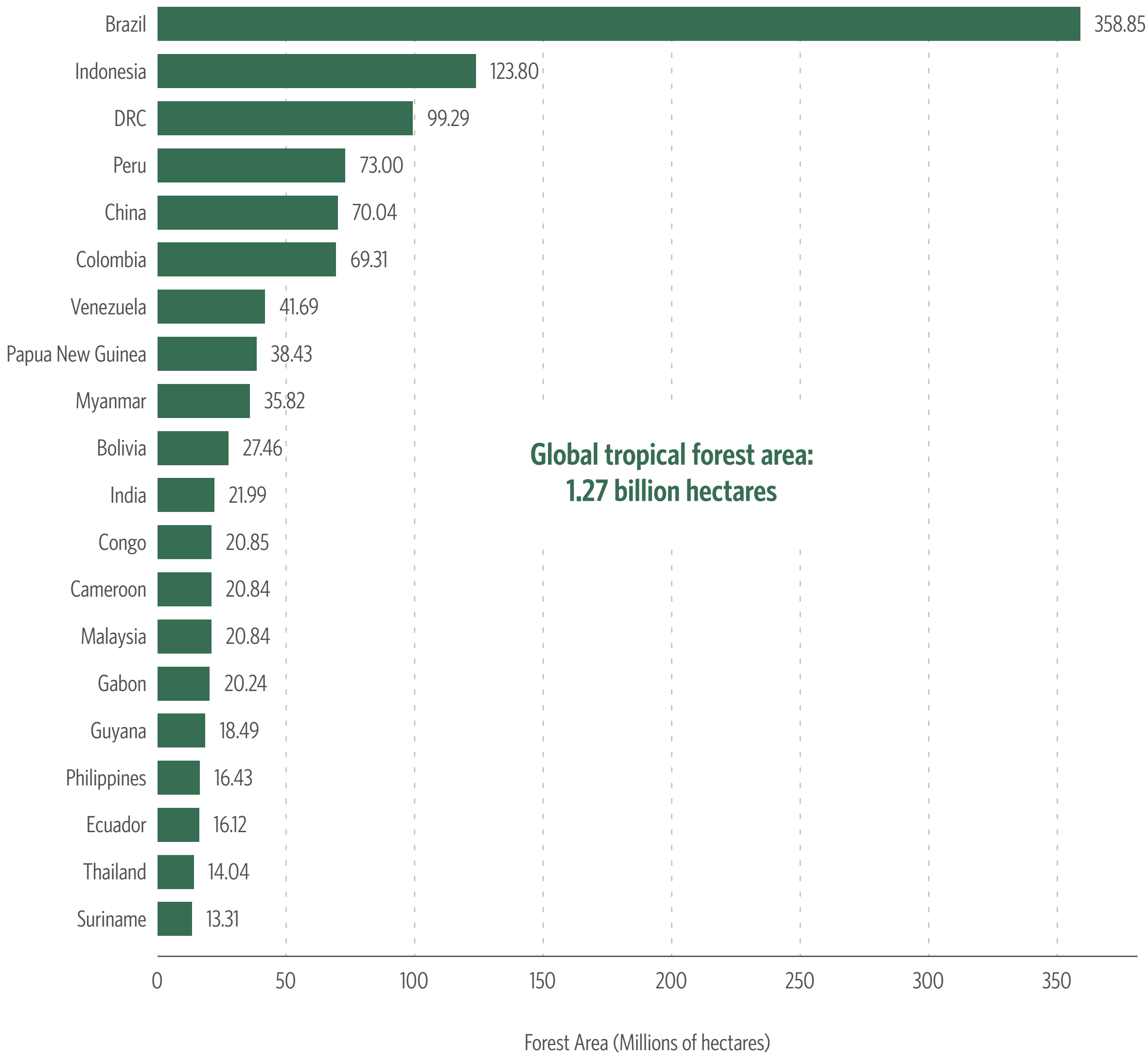
Forest extent is calculated using the latest available version (v1.11, 2023) of the Hansen et al. (2013) global tree cover dataset, restricted to pixels with canopy cover greater than or equal to 30% and vegetation taller than five meters as of the year 2000. Only pixels located within the boundaries of the Tropical and Subtropical Moist Broadleaf Forests ecoregion were considered, using 30-meter resolution data. According to this method, the ecoregion covers approximately 1.93 billion ha globally, of which 1.27 billion ha were forested in 2023, representing approximately 65% of the ecoregion's total area. See Figure 1 for the tropical forest areas in 2023 and the deforested areas.

Figure 1. Tropical Forest Areas in 2023 and Areas Deforested between 2001–2023

Source: *CPI/PUC-RIO with data from Hansen et al. (2013) - v1.11, 2025*

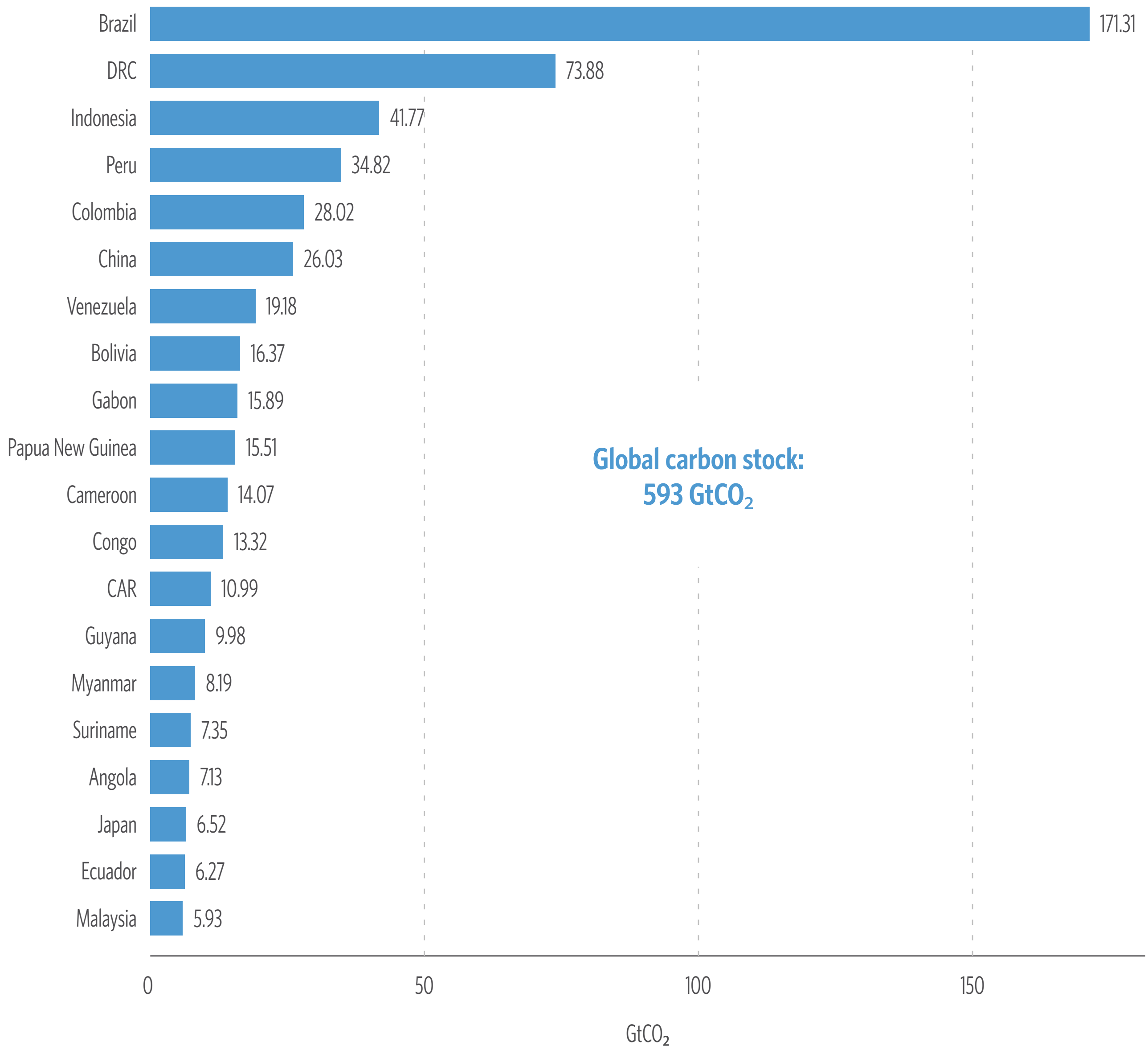
Across the 91 countries analyzed, these forests hold an estimated 593 $GtCO_2$—roughly one-third of all historical global emissions. This value is estimated using the global biomass potential maps by Santoro and Cartus (2024), with 500m resolution. Brazil accounts for the largest share, primarily due to the vast Amazon biome. Notably, while the forested area of the Democratic Republic of the Congo is about 20% smaller than that of Indonesia, it stores over 75% more carbon. This difference, which is also observed in other cases, underscores significant heterogeneity in forest density and biomass across tropical nations. Figures 2 and 3 show the top 20 countries with the largest tropical forest area and the largest carbon stock, respectively.

Figure 2. Top 20 Countries with the Largest Tropical Forest Area, 2023



Source: *CPI/PUC-RIO with data from Hansen et al. (2013) - v1.11, 2025*

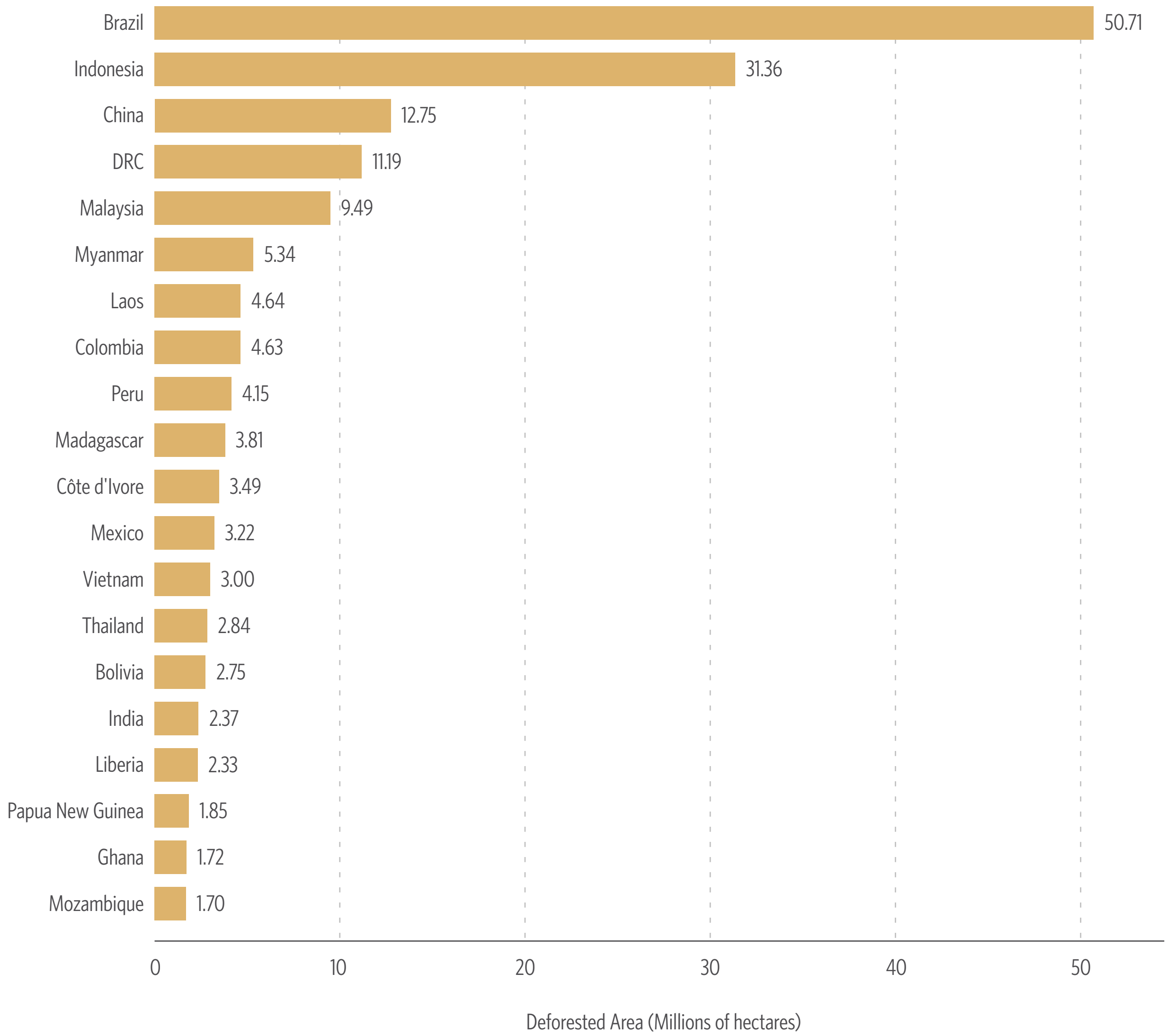
Figure 3. Top 20 Countries with the Largest Carbon Stock, 2023



Source: *CPI/PUC-RIO with data from Hansen et al. (2013) - v1.11, 2025*

Analysis estimates deforestation based on annual tree cover loss from 2001 to 2023 (Figure 4). Over the full 2001–2023 period, around 180 million ha of forest were lost, which represents nearly 10% of the ecoregion's area. In more recent years, the average annual deforestation has exceeded 10 million ha.

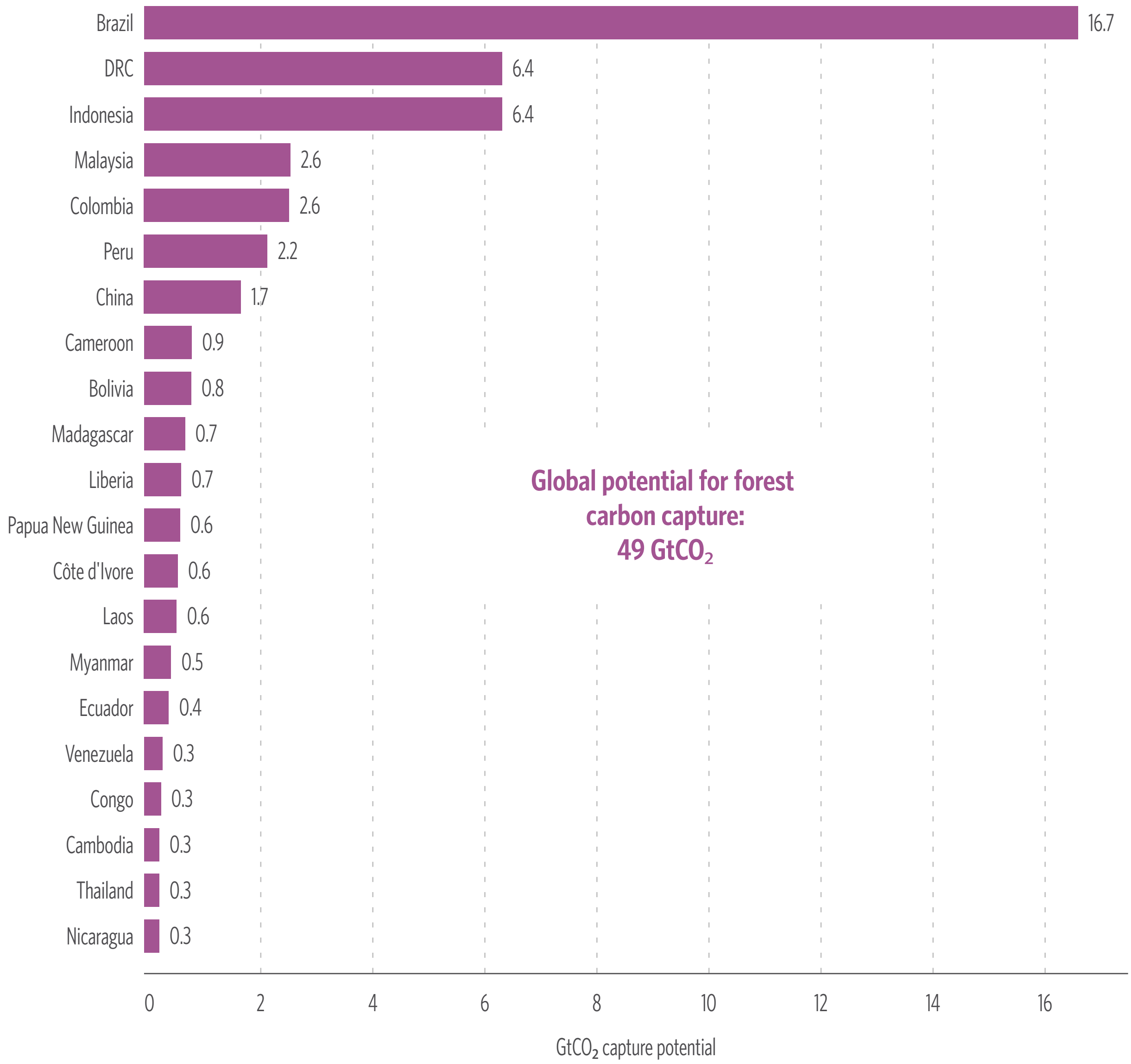
Figure 4. Top 20 Countries with the Highest Tropical Forest Deforestation, 2001-2023



Source: *CPI/PUC-RIO with data from Hansen et al. (2013) - v1.11, 2025*

The potential for carbon capture in areas deforested between 2001 and 2023 is estimated following the methodology developed by Assunção, Hansen, Munson, and Scheinkman (2025), which uses a spatial regression approach based on environmental and geographic covariates. Above-ground biomass is modeled as a function of precipitation, temperature, latitude, and longitude, using observed carbon values from intact forest pixels. This model is then applied to pixels that were deforested between 2001 and 2023 to predict potential biomass that can be captured through natural regeneration. This approach yields a spatially explicit estimate of the carbon that could be recovered if these areas were restored, under the assumption of full biophysical regeneration. The estimate corresponds to a global sequestration potential of 49 $GtCO_2$ captured via restoration of the areas deforested between 2001 and 2023. Figure 5 lists the top 20 countries with the highest $GtCO_2$ capture potential.

Figure 5. Top 20 Countries with the Highest $GtCO_2$ Capture Potential from Deforested Areas between 2001-2023



Source: *CPI/PUC-RIO with data from Hansen et al. (2013) - v1.11, 2025, CHIRPS precipitation (2023), and TerraClimate temperature (2020), 2025*

The Diversity of the Forest Agenda

To capture the diversity of forest-related challenges and opportunities across countries with tropical forests, a classification exercise was conducted based on three core dimensions: recent deforestation, standing forest, and potential for forest restoration.

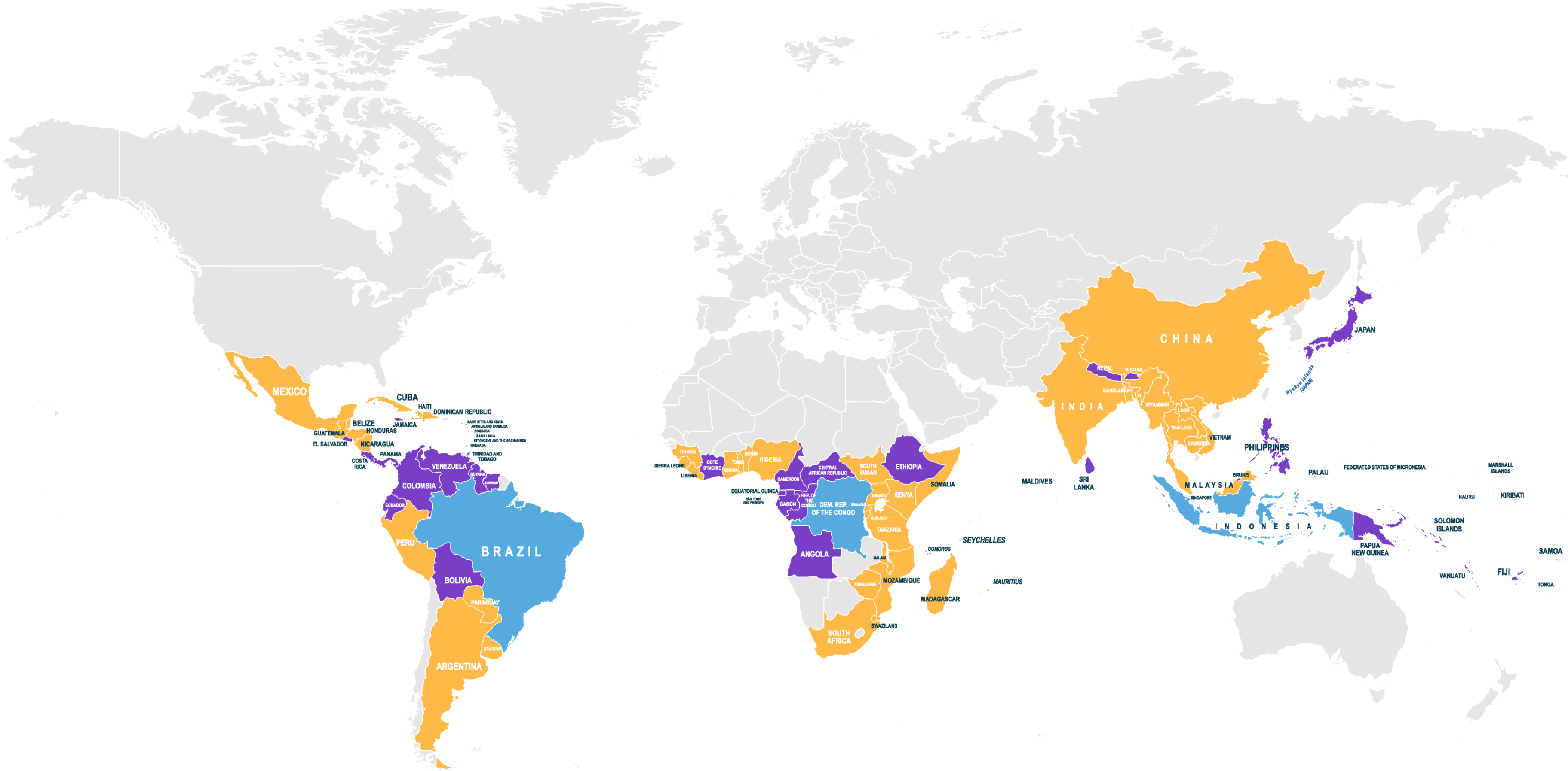
An unsupervised machine learning technique—k-means clustering—was applied using standardized, relative indicators: the share of national territory covered by tropical forest, the share of forest lost to recent deforestation, and estimated carbon removal potential from restoration. The use of relative, rather than absolute values, enables meaningful cross-country comparisons regardless of geographic size. All variables were normalized using z-scores to ensure comparability across different units and scales.

The number of clusters was fixed at three to balance interpretability and differentiation, aiming to capture broad patterns rather than fine-grained distinctions.

- **Cluster 1** (High Forest Cover, Low Deforestation, Low Carbon Potential) includes countries with extensive standing forests and relatively low recent deforestation, such as Guyana and Papua New Guinea.
- **Cluster 2** (Low Forest Cover, High Deforestation, Low Carbon Potential) comprises countries experiencing high deforestation pressures, including Mexico, China, and Nigeria.
- **Cluster 3** (High Forest Cover, High Deforestation, High Carbon Potential) consists of countries with large forested areas and significant restoration potential due to past deforestation, such as Brazil, the Democratic Republic of the Congo, and Indonesia.

As shown in Figure 6, these groups are geographically dispersed, underscoring the role of national governance, economic structure, and land-use policies in shaping forest outcomes.

Figure 6. Clusters of Countries with Tropical Forests



CLUSTER 1

High Forest Area, Low Deforestation, Low Carbon Potential
Includes countries with extensive standing forests and relatively low recent deforestation.

CLUSTER 2

Low Forest Area, High Deforestation, Low Carbon Potential
Comprises countries experiencing high deforestation pressures.

CLUSTER 3

High Forest Area, High Deforestation, High Carbon Potential
Consists of countries with large forest areas and significant restoration potential due to past deforestation.

Source: *CPI/PUC-RIO with data from Dinerstein et al. (2017), Hansen et al. (2013) - v1.11, CHIRPS precipitation, and TerraClimate temperature (2020), 2025*

High Forest Cover, Low Deforestation, Low Carbon Potential

Countries in this group are defined by a consistently high share of tropical forest within the portion of their territory that overlaps with the tropical and subtropical moist broadleaf ecoregion. These countries have maintained relatively low rates of deforestation over the past two decades and, as a result, the central challenge is not to restore what was lost, but to safeguard the standing forests. Policies that focus on long-term conservation, enforcement of protected areas, and support for forest-dependent communities are especially relevant in this group, where natural capital and carbon stocks remain largely intact but not necessarily immune to rising pressures.

This group plays a crucial role in providing global and regional ecosystem services. In Oceania, for example, countries like Papua New Guinea and Vanuatu function as ecological sanctuaries, preserving high levels of endemism and acting as buffers against biodiversity collapse in the region (Oliver et al. 2022; Kier et al. 2009; Hamilton, Klein and Austin 2010). Their forests help regulate rainfall patterns, maintain coastal resilience, and store vast amounts of living biomass (Spraklen et al. 2012; Theeuwen et al. 2023; Smith, Baker, and Spracklen 2023). In South America, Suriname stands out for having one of the highest percentages of intact forest cover in the world, serving both as a carbon sink and a biodiversity reservoir (Potapov et al. 2022; FAO 2020). These forests provide services that go far beyond national borders, including climate stability, hydrological regulation, and pollination corridors.

Despite their relatively strong conservation profiles, some countries in this cluster face emerging threats. While countries in the Congo Basin face increasing deforestation from smallholder clearing and shifting cultivation and charcoal, countries across the Amazon–Andean region confront deforestation largely driven by cattle ranching, crop expansion and, especially in 2024, fires. Suriname maintains low levels of deforestation, while Guyana's deforestation spiked in 2024 and faces increasing pressure from mining (Goldman et al. 2025; Potapov et al. 2022). In Central America and the Caribbean, as well as in the Pacific islands, deforestation is primarily driven by agriculture and settlements, while in Africa and Asia cropland and urban growth, with hydropower flooding in parts of Asia, threaten forest conservation.

Low Forest Cover, High Deforestation, Low Carbon Potential

Countries in this group are characterized by high levels of deforestation. In many of these cases, forest cover was historically low or has been extensively degraded over time, resulting in landscapes dominated by agricultural land, other types of vegetation, or urban settlements. Consequently, the estimates for carbon sequestration potential of restoration are also low, either due to limited forest area or because biophysical and socioeconomic conditions constrain regeneration. While these countries may not be central to large-scale restoration efforts, they are critical to the agenda of halting residual deforestation and avoiding further degradation of already fragile ecosystems.

Deforestation across this set of countries is driven mainly by conversion to permanent agriculture and the expansion of settlements and infrastructure, with region-specific patterns: in Latin America and the Caribbean countries, an exceptional 2024 fire season sharply amplified loss while agricultural clearing remained central—fires accounted for a large share of primary forest loss in Belize, Guatemala, and Mexico (Goldman et al. 2025; Potapov et al. 2022).

In South and Southeast Asia countries, agricultural clearing is prominent, especially in Cambodia, Laos, Vietnam, Thailand. There are also signs of plantations replacing tall forests, small but non-negligible hydropower reservoir flooding, and strong urban/settlement growth, notably in China. In Sub-Saharan Africa countries, forest loss is more diffuse but consistently co-occurs with cropland expansion, together with growth in settlements and infrastructure development (Goldman et al. 2025; Potapov et al. 2022).

High Forest Cover, High Deforestation, High Carbon Potential

The last group includes three countries—Brazil, Indonesia, and the Democratic Republic of the Congo—which concentrate a disproportionately large share of the world's tropical forests. These countries combine vast remaining forest areas, significant deforestation in recent decades, and an extremely high potential for carbon regeneration. All three hold portions of the planet's major tropical forest basins: the Amazon, the Congo Basin, and the tropical archipelagos of Southeast Asia. Their land-use trajectories have global implications, as changes in forest cover within these territories directly affect atmospheric carbon, biodiversity conservation, and hydrological cycles across continents. In climate terms, they are irreplaceable.

Despite commonalities, deforestation dynamics in these countries differ markedly. In Brazil, a mix of land speculation, cattle ranching, soy expansion, and infrastructure development, especially in the Amazon biome, drive deforestation. Legal ambiguities, weak enforcement, and political oscillations have shaped a landscape of intense land-use conflict (Lima Filho, Bragança, and Assunção 2021; Santos et al. 2025; Skidmore et al. 2021).

In Indonesia, forest clearing has historically been tied to palm oil production, timber extraction, and peatland drainage, leading not only to deforestation but also to significant GHG emissions from peat oxidation and fires. More recent policy shifts, including moratoria on primary forest conversion and peatland restoration programs, have slowed loss but not eliminated it (Austin et al. 2017; Austin et al. 2019).

In the Democratic Republic of the Congo, the deforestation drivers are more fragmented and localized, including slash-and-burn agriculture, fuelwood collection, and artisanal logging, often underpinned by rural poverty and limited state presence (Ickowitz et al. 2015; Achille, Zhang, and Anoma 2021). Across all three countries, land governance remains a key bottleneck, and forest loss continues even in areas officially protected.

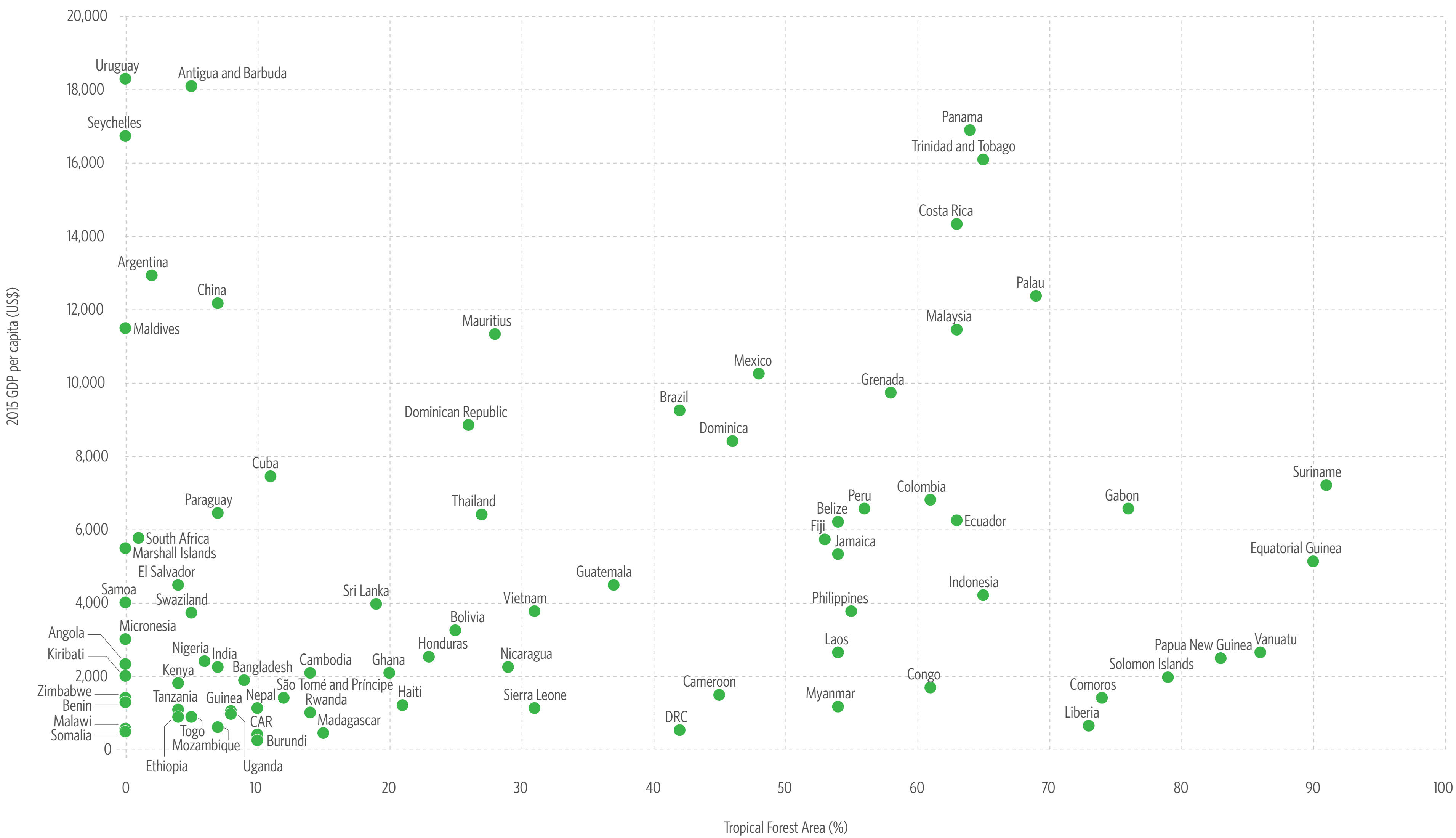
Together, these three countries account for an estimated 29.45 $GtCO_2$ in potential carbon that could be removed from the atmosphere through restoration of areas deforested between 2001 and 2023. Individually, the figures are staggering: Brazil alone holds 16.67 $GtCO_2$, equivalent to the total emissions of all passenger vehicles worldwide for over 4 years (IEA 2024). Indonesia and the Democratic Republic of the Congo each hold more than 6 $GtCO_2$. These numbers demonstrate how forest restoration can play a critical role in the fight against climate change.

Forests and Economic Development

Forest conservation is often regarded as involving costly policies that restrict agricultural expansion, infrastructure development, and resource extraction, suggesting a trade-off between environmental protection and economic growth. However, environmental conservation and economic growth can be compatible goals and advance together depending on the nature of technological progress and the historical pattern of land occupation.

Figures 7 and 8 examine the relationship between the share of the tropical forest area and per capita income as well as GDP growth. The distribution of income levels shows no consistent pattern relative to forest cover, with countries spanning low to high incomes regardless of their forest share. GDP growth rates similarly exhibit wide variation among nations with large and small proportions of forest. **These visual analyses demonstrate the absence of a clear association between forest area and economic performance and reinforce the compatibility of economic and environmental goals.**

Figure 7. Tropical Forest Cover and GDP per capita, 2023



Source: *CPI/PUC-RIO with data from Hansen et al. (2013) and World Development Indicators (World Bank 2023), 2025*
Note: *Mexico's forest area figure is sourced from INEGI (2019) and refers to the year 2014. Countries with GDP per capita above US$ 20,000 and with no GDP information available were removed to facilitate visualization. The base year for US$ parity is 2015.*

Figure 8. Tropical Forest Cover and GDP Growth, 2023

Source: *CPI/PUC-RIO with data from Hansen et al. (2013) and World Development Indicators (World Bank 2023), 2025*

Note: *Mexico's forest area figure is sourced from INEGI (2019) and refers to the year 2014. Guyana, with GDP growth of 34% and forest area of 87%, was removed to facilitate visualization.*

Charting a Differentiated Forest-Climate Strategy

Collectively, these findings reveal the considerable diversity of forest contexts across tropical nations and reinforce the need for strategies that are both ambitious in scale and tailored in design. A one-size-fits-all approach will fall short. Countries differ not only in the extent of their standing forest and loss but also in their restoration potential, economic structure, and institutional capacity. Moving forward, a successful forest-climate strategy must account for this diversity while leveraging the shared opportunity that tropical forests offer: an immediate, cost-effective, and globally significant instrument for climate mitigation. The next chapter builds on this foundation to explore how customized policy instruments, innovative finance, and international cooperation can unlock this potential in practice.

Forest Policy Toolkit: Effectiveness and Political Risks

Acknowledging the diversity of forest contexts and the need for tailored approaches, this chapter examines the policy instruments that can operationalize a differentiated forest-climate agenda to achieve conservation and restoration outcomes.

Across tropical regions, governments have pursued, with varying degrees of success, a range of initiatives to curb deforestation, safeguard remaining forests, and promote large-scale restoration. Over time, a robust toolkit has emerged—combining regulatory measures, economic incentives, and targeted subsidies—adapted to local challenges and opportunities.

This chapter provides a curated overview of forest policy instruments, focusing on those that have shown evidence of effectiveness in tropical contexts. It highlights a range of command-and-control regulations, including the creation of protected areas, the protection of species at risk and their habitats, and forest and land-use regulations such as zoning laws and legal requirements for conservation on private lands. It also includes economic incentives and subsidies, such as PES programs, subsidies to increase agricultural productivity, conditions on access to subsidized rural credit, and commercial and market-based policies.

The policies described in this chapter are not an exhaustive catalogue of every possible intervention, but rather a synthesis of key mechanisms that have demonstrated impact and offer lessons for broader applications. **The goal is to connect the forest-climate opportunity to practical policy pathways, clarifying what tools are available and what strategic choices are required. Together, these policies demonstrate that effective forest management is both feasible and achievable.**

However, the effectiveness of forest policies depends not only on their design but also on the broader enabling environment that supports their implementation. This includes factors such as clear land tenure and property rights, policy alignment across sectors, coordinated institutional arrangements, accountable decision-making, and consistent implementation. These elements help determine whether regulatory instruments and economic incentives can translate into meaningful outcomes on the ground. In this context, the chapter also examines key enabling conditions, such as secure property rights and land tenure, that are essential for forest policies to be effective.

A critical dimension of this discussion is the recognition that forest policies are deeply intertwined with political cycles. Deforestation rates often rise or fall in tandem with shifts in political priorities and electoral incentives. Therefore, while the policy instruments reviewed here have significant potential, their long-term success depends on embedding them within stable, resilient governance frameworks that can withstand political fluctuations.

Overview of Policy Instruments and Evidence on Effectiveness

A diverse and complementary set of policy instruments has been developed in different regions to address deforestation and forest degradation, reflecting the complexity of forest governance and the range of economic, legal, and institutional factors at play. These instruments generally fall into two broad categories: (i) regulatory instruments and (ii) economic incentives and subsidies (Figure 9).

Figure 9. Forest Policy Toolkit

REGULATORY INSTRUMENTS	ECONOMIC INCENTIVES AND SUBSIDIES
• Protected Areas	• Payment for Environmental Services
• Wildlife Protection Regulations	• Subsidies for Increases in Agricultural Productivity
• Forest and Land-Use Regulations	• Policies for Credit Subsidies
• Enforcement-centered Instruments	• Commercial and Market-Based Policies

Source: *CPI/PUC-RIO, 2025*

Regulatory Instruments

In the context of forests, command-and-control regulations refer to legally binding laws, rules, and standards established by governments to control land use, forest management, and conservation. These instruments define what is permitted, restricted, or prohibited, and are enforced through penalties such as fines, sanctions, or loss of rights. Instruments under this approach are often supported by monitoring systems that enable detection of violations and guide enforcement actions.

The command-and-control approach can take various forms depending on the legal and institutional context. These include the designation of protected areas, the protection of species at risk and their habitats, forest and land-use regulations that either permit forest conversion or impose conservation and restoration obligations on public or private lands, and enforcement-centered instruments that rely on monitoring and penalties to ensure compliance.

Protected Areas

Protected areas are among the most widely used policy tools to reduce deforestation. They consist of geographically defined zones, established through legal or other effective means, designed to conserve biodiversity and safeguard ecosystem services by protecting natural features of ecological, biological, or cultural value. Their effectiveness often derives from the combination of heightened oversight and legal deterrence.

In the Brazilian Amazon, forest protection works by increasing monitoring, which raises the likelihood that environmental violations will be detected, while the legal framework imposes stricter penalties for crimes within protected lands. This increases the cost of illegal clearing compared to unprotected areas, discouraging offenders from targeting these zones. Although this significantly lowers deforestation rates in high-pressure regions, protection may displace deforestation rather than eliminate it entirely, as clearing can shift to unprotected areas (Gandour 2018).

Evidence from other countries reinforces the protective effect. In Costa Rica, the national network of protected areas reduced deforestation by about 10% (Andam et al. 2008). Joppa and Pfaff (2010), analyzing 147 countries, find that in 75% of cases protection reduced land conversion. In the Peruvian Amazon, Miranda et al. (2016) show that land-use restrictions within protected zones helps lower deforestation. Effectiveness varies with the protection regime: Nelson and Chomitz (2011) find that, across Latin America and the Caribbean, strictly protected areas reduce fire incidence—a proxy for deforestation—by 3–4%, multiuse protection by 5–6%, and indigenous territories by 16–17%.

Indigenous lands stand out as highly effective in contexts of high deforestation pressure. Nolte et al. (2013) highlight their strong deterrent effect in the Brazilian Amazon, while Baragwanath, Bayi, and Shinde (2023) show that these territories not only reduce deforestation but also encourage secondary forest regrowth on previously cleared lands. Sze et al. (2022) extend this evidence across the tropics, finding that Indigenous lands avoid deforestation at rates comparable to other protected areas, with even greater effectiveness in Africa.

The contrast with undesignated public lands is stark. In Brazil, areas with undefined tenure status are particularly vulnerable to illegal deforestation and land grabbing, as shown by Azevedo-Ramos and Moutinho (2018) and Azevedo-Ramos et al. (2020). These findings underscore the critical role of regulatory protection and secure land tenure in preventing forest loss, and the value of designated protected areas as a core component of effective forest governance.

Wildlife Protection Regulations

Wildlife Protection Regulations aim to conserve species-at-risk by prohibiting the killing of endangered species and requiring the protection of their habitat—actions that, in turn, help conserve forests.

Regulatory frameworks are used to safeguard biodiversity and fauna. Wildlife sanctuaries—protected areas specifically designed to preserve biodiversity—and national parks in Thailand significantly increase forest cover, as well as the size and continuity of forested areas (Sims 2014). These areas experienced increases in both the average size of individual forest patches and the size of the largest remaining patches of continuous forest. Comparisons between the two types of protected areas show that wildlife sanctuaries are more effective than national parks at protecting forest within core areas (as opposed to edges) and at preventing fragmentation, which occurs when forests are broken into smaller, isolated areas.

Forest and Land-Use Regulations

Forest and land-use policies impose different types of land limitations, ranging from fully protecting forests to granting permission to convert forests into other land uses. Consequently, they guide where different economic activities can take place—especially those related to agriculture. Bruggeman, Meyfroidt, and Lambin (2015) evaluate a zoning law in Cameroon that separated forested areas in a permanent (PFE) and non-permanent forest estates (NPFE). The PFE includes forests dedicated to protection but also to production. The NPFE comprises remaining forestlands that may be cleared or managed by local populations through community forests. Results show that the land-use zoning effectively curtails deforestation in the PFE, indicating that forest production units can be an effective tool to control deforestation.

Brazil's Forest Code stands as the country's primary legal framework regulating land use on private rural properties. It mandates the conservation of native vegetation through two core mechanisms: Legal Forest Reserves (*Reserva Legal* - RL), which require that 80% of land in the Amazon and 20% in other biomes remain forested, and Permanent Preservation Areas (*Áreas de Preservação Permanente* - APPs), which aim to conserve water resources and prevent soil erosion. Soares-Filho et al. (2014) estimate that these two requirements protect 193 ± 5 Mha of native vegetation, containing 87 ± 17 $GtCO_2$. They argue that while the Forest Code has severely restricted deforestation on private properties, it has proved challenging to enforce, particularly in the Amazon. A consequence of this legislation is the accumulation of "environmental debt"—areas where the legal thresholds for RL and APPs are unmet, requiring restoration at the landowner's expense. Authors estimate that this debt is around 21 ± 1 Mha, and that its elimination via forest restoration would sequester up to 9 ± 2 $GtCO_2$. As such, the Forest Code exemplifies both the transformative potential and the implementation challenges of large-scale regulatory instruments aimed at forest conservation and land-use management.

Enforcement-Centered Instruments

A subset of command-and-control instruments prioritizes enforcement to ensure compliance with environmental laws and regulations. **These include monitoring systems—often using advanced technologies like satellites—and enforcement actions such as fines or sanctions for illegal deforestation. These approaches are particularly important in contexts where governance capacity is uneven, and where deterrence plays a significant role in shaping land-use decisions.**

Technological advancements have enhanced the effectiveness of enforcement-centered measures. Real-Time Deforestation Detection System (*Sistema de Detecção de Desmatamento em Tempo Real* - DETER), a system that processes satellite imagery and issues near-real-time deforestation alerts, has played a pivotal role in enforcement in Brazil. This tool has enabled the country to overcome law enforcement shortcomings by targeting environmental enforcement in the Amazon in regions indicated by the alerts. Assunção, Gandour e Rocha (2023) finds that this system reduced municipality-level deforestation by 25% between 2006 and 2016. Complementary evidence from Assunção et al. (2023) shows that, by issuing a "priority list" of municipalities to be targeted with more intense environmental monitoring and enforcement, deforestation reduced by 43%, with spillover effects extending to neighboring areas. These findings illustrate how targeted enforcement—especially when combined with credible deterrence—can achieve substantial gains.

Indeed, near-real-time forest monitoring and alert systems based on satellite imagery have contributed to tracking deforestation on a global scale. One such tool available worldwide is Global Forest Watch (GFW), a platform that offers open data on deforestation and forest cover. By interviewing users of these systems in Madagascar, Indonesia, Bolivia, and Peru, Musinsky et al. (2018) find that the use of such tools made significant contributions to improving the ability of conservation and forest management organizations to respond to and reduce the impacts of fires, deforestation, and other illegal or undesirable forest activities.

MapBiomas Alerta, a system for validating and refining alerts on the deforestation of native vegetation across all Brazilian biomes using high-resolution images, has also contributed to these efforts. The government of the state of Goiás has adopted this tool to combat illegal deforestation since 2020. According to the State of Goiás Secretariat of Environment and Sustainable Development (*Secretaria de Estado de Meio Ambiente e Desenvolvimento Sustentável* - SEMAD/GO), the alerts have enabled more effective monitoring (Cardoso et al. 2024).

Economic Incentives and Subsidies

Unlike command-and-control approaches that rely on legal obligations and penalties, economic incentives and subsidies are designed to encourage forest conservation by altering the economic conditions under which land-use decisions are made. They aim to shift the cost-benefit calculus of land users by providing positive incentives to conserve forests rather than convert them. Examples include PES programs, subsidies that promote agricultural intensification, credit subsidy regulations, and commercial and market-based policies.

Payments for Environmental Services

PES programs provide financial incentives for forest owners to keep their forests intact. Payments are made conditional on voluntary pro-environment behaviors, such as conserving biodiversity, sequestering carbon, and maintaining water quality. An important aspect in this context is the sustained monitoring and enforcement of the conditions for cash transfers. Many cases have demonstrated strong potential of these programs to reduce deforestation.

For example, Jayachandran et al. (2017) find that PES contracts in Uganda, which offered annual payments per conserved hectare to forest-owning households, significantly reduced deforestation without shifting deforestation into adjacent areas. Similarly, Arriagada et al. (2012) document that Costa Rica's PES program increased farm forest cover by 11–17%.

Other studies underscore the importance of local context: Alix-Garcia et al. (2015) observed that a PES program in Mexico, which paid landowners for protecting forest, reduced the expected land cover loss by 40-51%, being more effective in areas with lower poverty rates. Wong et al. (2023) show that a PES program in Brazil was able to keep forest cover in rural communities above 80%, and the underlying mechanism to reduce deforestation was an increase in reports of illegal deforestation. Finally, Moros et al. (2023) find that conservation gains in Colombia persisted even after payments ended, suggesting that PES can have lasting impacts when properly structured.

Subsidies for Increased Agricultural Productivity

Subsidies aimed at increasing agricultural productivity—for example, by providing fertilizers, high-yield seeds, or training—also show promise in reducing deforestation. The underlying mechanism is that increased productivity can reduce the need to expand farmland, especially in small-scale agricultural areas, thus lowering deforestation pressures.

Fertilizer and seed subsidy program in Malawi reduced pressure for agricultural expansion by improving productivity on existing farmland (Abman and Carney 2020). Such a policy, which aimed at increasing small-scale agricultural productivity, had positive environmental spillovers. Similar findings have emerged from Uganda (Abman et al. 2023) and Zambia (Pelletier et al. 2020), where agricultural intensification efforts—through training and subsidies for better seeds and fertilizers, respectively—were associated with lower deforestation rates. These cases highlight the value of integrating conservation goals with agricultural development policies.

Credit Subsidy Policies

Since rural credit is a primary tool through which governments in developing countries support agriculture—and given that agricultural expansion is a major driver of deforestation—linking credit subsidies to strict environmental requirements provide an effective strategy to curb deforestation.

Assunção et al. (2020) show that tying rural credit in the Brazilian Amazon to stricter environmental requirements was effective in reducing deforestation. The authors evaluate the impact of a credit policy established by the Brazilian Central Bank, which made the concession of subsidized rural credit in the Amazon conditioned upon proof of compliance with legal titling requirements and environmental regulations. The estimates show that the total deforested area during the study period was about 60% smaller than it would have been in the absence of the policy.

Commercial and Market-Based Policies

Commercial and market-based tools harness the power of markets to drive conservation outcomes. Examples include voluntary or mandatory zero-deforestation supply chain policies, certification schemes, and trade policies that condition market access in compliance with environmental standards. These measures can amplify state-led conservation efforts by aligning commercial interests with sustainability goals.

In this context, Heilmayr et al. (2020) evaluate the Amazon Soy Moratorium in Brazil—an agreement by grain traders not to purchase soy grown on land deforested after 2008. The authors find significant deforestation reductions linked to the policy, particularly where it was bolstered by public property registries and monitoring systems.

Certification schemes, such as those governed by the Forest Stewardship Council (FSC), also contribute. FSC is a voluntary forest certification that promotes the sustainable management of forests through a range of practices, e.g., selective logging and improved fire management. Such certifications may provide a price premium or reputational benefits to timber producers. Miteva, Loucks, and Pattanayak (2015) show that FSC-certified timber concessions in Indonesia reduced deforestation by 5% compared to non-certified concessions, underscoring how market mechanisms can align commercial interests with forest conservation.

Enabling Environment: Securing Land and Property Rights

As demonstrated above, regulatory instruments and economic incentives and subsidies can provide effective results in reducing deforestation. However, complementary efforts are needed to address the enabling conditions that support their implementation. Specifically, **structural governance reforms play a crucial role in removing persistent barriers that undermine conservation and restoration outcomes, such as policies to ensure the security of land tenure and property rights.**

Secure land tenure and clear property rights provide landowners with the confidence and incentives to invest in sustainable land management. Without them, land users may overexploit resources due to weak accountability. Measures such as land demarcation, registration, and formal certification strengthen tenure security, promoting land-use intensification and reducing pressure to clear new areas. Additionally, resolving conflicts, clarifying boundaries, and formalizing usage rights reduce transaction costs and foster cooperation, enabling more effective self-governance of common-pool resources, including forests.

A land registration program in Benin, which formalized customary land rights to improve agricultural productivity and support community forest management, reduced deforestation by around 20% by increasing tenure security (Wren-Lewis et al. 2020). Similarly, titling indigenous communities in the Peruvian Amazon significantly reduced both forest clearings and degradation (Blackman et al. 2017). Granting full property rights was also found to significantly decrease deforestation within indigenous territories in the Brazilian Amazon (Baragwanath and Bayi 2020). Such findings underscore that formal and collective property rights might provide an effective way to reduce deforestation.

A meta-analysis of over 30 publications on the relationship between land tenure and tropical deforestation found that land tenure security is associated with reduced deforestation, regardless of the form of tenure (Robinson et al. 2014). In Indonesia, the legal status of land was shown to influence land-use practices, with weak property rights in surrounding areas increasing the likelihood of forest clearing by fire, highlighting the importance of secure land tenure at the landscape scale (Balboni et al. 2024).

Political Risks

Deforestation is deeply intertwined with political cycles and incentives, which can either mitigate or exacerbate forest loss depending on the context. Multiple studies illustrate how electoral dynamics and political instability shape land-use decisions, often in ways that undermine conservation gains.

In Indonesia, forest fires decline in election years, as they may jeopardize electoral chances (Balboni et al. 2021). However, deforestation rates in the same country increase in the year leading up to a district head election (Cisneros, Kis-Katos, and Nuryartono 2021). Similar evidence exists for Brazil, where deforestation in election years is higher when the mayor of a municipality ran for reelection compared to municipalities where the incumbent did not seek reelection, reflecting electoral manipulation of forest resources (Pailler 2018).

Beyond electoral cycles, political risks also arise from shifts in governance structures and rent-seeking behavior as candidates manipulate economic or political systems to gain wealth or advantage without creating new wealth for society. In Indonesia, politicians lose power through district splits, illegal deforestation rates increase—and they point that such illegal activity might be facilitated by such officials. However, when alternative sources of rent increase, such as through oil and gas exploration, politicians have more to lose from being found engaging in illegal activity in the forest sector, decreasing forest extraction (Burgess et al. 2012).

Another example of the connection between politics and deforestation is the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (*Plano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal* – PPCDAM), a set of deforestation-related policies in the Brazilian Amazon, and how it affected special interest groups operating in the region (Bragança and Dahis 2022). The policies had greater impacts in municipalities governed by politicians who were also agricultural producers, showing thatenvironmental policies can change political incentives at a local level, increasing its impact on environmental and social outcomes.

Together, this literature underscores that deforestation is highly susceptible to political cycles, institutional volatility, and the incentive structures of local elites. These findings point to a critical need: policies must be designed not only for technical effectiveness but also for political resilience. Shielding conservation efforts from short-term political pressures—whether by embedding enforcement in independent institutions, strengthening legal frameworks, or aligning economic incentives with long-term forest stewardship—is essential for sustained impact.

The Reversing Deforestation Mechanism (RDM)

The previous chapters have highlighted both the scale of the forest agenda and the diversity of challenges across countries. Tropical forests store vast amounts of carbon and offer exceptional potential for large-scale CO_2 sequestration through forest restoration. While effective conservation and restoration policies exist—and have delivered results in many contexts—their adoption remains uneven and often vulnerable to political shifts. **Establishing a robust, long-term financial architecture is essential to sustain climate ambition and incentivize governments to manage forests accordingly.**

In the early 2000s, the inclusion of forests in the Kyoto Protocol's Clean Development Mechanism (CDM)—the first multilateral carbon pricing mechanism—represented an attempt to recognize that removals generated by the planting of new forests were eligible to generate carbon credits, while forest protection projects were excluded.

In its relatively short years of existence, CDM was able to establish an internationally recognized carbon offset market for restoration activities that relied on the creation of methodological tools to prove additionality generated by projects, internationally approved forms of accounting to address risk of non-permanence, and on UN-led institutional structures.

However, this framework burdened CDM with a regulatory complexity that resulted in a low number of forest-related projects. Barriers that contributed to the underutilization of the mechanism included high transaction and financing costs and the temporary nature of carbon credits from forest activities, which denied fungibility of forest credits in the carbon market, and culminated in constraints on the demand side, including the exclusion of forest credits of the largest demand markets.

Currently, **JREDD+** is the main internationally recognized framework for halting deforestation, with a track record in multilateral agreements. More recently, the **Tropical Forest Forever Facility (TFFF)** was proposed at COP28 to reward the maintenance of standing forests. While still under discussion, TFFF is gaining traction in international forums. Together with other initiatives, these mechanisms address deforestation and forest protection, but they do not prioritize forest restoration, which remains a critical gap.

Also, at COP28, the first **Global Stocktake** reaffirmed forests as indispensable for meeting the Paris Agreement's temperature goals. Governments agreed on the urgency of conserving, protecting, and restoring forests and ecosystems to halt and reverse deforestation by 2030. Article 33 states the decision for parties to emphasize "the importance of conserving, protecting and restoring nature and ecosystems towards achieving the Paris Agreement temperature goal, including through **enhanced efforts towards halting and reversing**

deforestation and forest degradation by 2030" (UNFCCC 2024). The decision also stressed the priority in providing enhanced financial, technical, and capacity-building support, and highlighted the non-carbon benefits of forests, including biodiversity conservation, ecosystem resilience, and social safeguards.

In this context, CPI/PUC-RIO proposes the Reversing Deforestation Mechanism (RDM), building on the framework developed by Assunção, Hansen, Munson, and Scheinkman (2025). RDM aims at compensating countries for net carbon removal outcomes—the carbon captured through forest restoration subtracting emissions from deforestation and degradation—at the jurisdictional level.

RDM aims to address the restoration finance gap and complement JREDD+, TFFF, and related mechanisms to form a flexible and scalable strategy that can be adapted to diverse national circumstances. This chapter outlines its core concept design, implementation requirements, and potential to transform tropical forests into high-impact climate assets.

The Mechanism

RDM is a results-based payment system designed to scale up forest restoration through jurisdictional agreements. It aims to create results-based incentives for countries with tropical forests to restore ecosystems and reduce emissions from deforestation and forest degradation.

At its core, the mechanism is structured as a **bilateral agreement** between a buyer—typically a government, multilateral institution, or private entity—and a jurisdiction (such as a national or subnational government) responsible for forest management. The main objective is to generate **carbon removal credits** through forest restoration, with credits calculated annually on a **net basis**. This net metric accounts for the amount of CO_2 sequestered through forest regrowth, minus emissions resulting from deforestation, forest degradation, and agricultural land-use activities within the jurisdiction.

The mechanism involves an offtake agreement—the buyer commits to paying a **price** for each verified ton of net CO_2 removed in the jurisdiction. Verified credits trigger disbursements that are directed into a **dedicated jurisdictional fund**. This fund can be used for activities that reinforce the climate and ecological goals of the mechanism—specifically, preventing deforestation and forest degradation, and scaling up forest restoration efforts, particularly through natural regeneration and sustainable land-use strategies.

By aligning financial incentives with measurable climate outcomes at the jurisdictional level, this mechanism offers a scalable and transparent model for integrating forest restoration into the global climate finance architecture, complementing mechanisms such as JREDD+ and TFFF and filling a gap for tropical forests (Figure 10).

Figure 10. Forest Finance Mechanisms: JREDD+, TFFF, and RDM

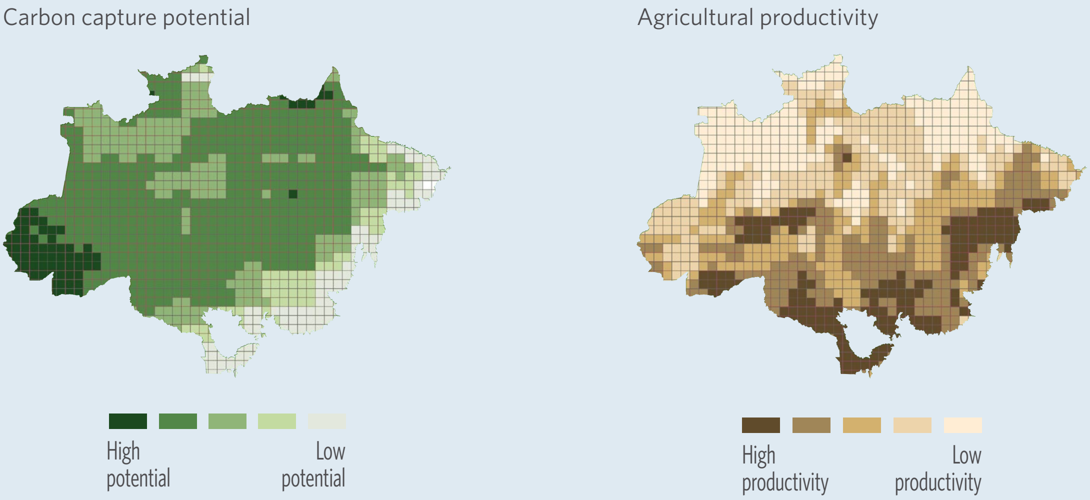
	JREDD+	TFFF	RDM
Object	Carbon credits from avoided deforestation	Hectares of standing forests	Credits from forest restoration carbon removals
Scope	Jurisdictional	Jurisdictional	Jurisdictional
Payments	Results-based	Results-based	Results-based
Incentives	Credits are paid against a baseline, usually computed as previously observed deforestation rates	Each deforested hectare cancels the payment of 100 hectares	Credits are computed on a net basis—carbon from forest restoration subtracted from emissions from deforestation
Potential scale	10 million hectares of yearly deforestation	1.27 billion hectares of tropical forests	186 million hectares deforested between 2001 and 2023 could be reversed
Potential carbon impact	3.77 $GtCO_2$ yearly lost	593 $GtCO_2$ stored in tropical forests in 2023	49 $GtCO_2$ of potential carbon capture in areas deforested in 2001-2023 if fully reversed
Potential revenue	Up to US$ 32 billion if all deforestation is halted	Around US$ 5 billion per year at US$ 4 per hectare of forest	Up to US$ 100 billion if implemented at full-speed with US$ 50 per ton of CO_2

Source: *CPI/PUC-RIO, 2025*

Simulating the Impact of the RDM for the Brazilian Amazon

The Brazilian Amazon offers a powerful illustration of how RDM could deliver both climate and economic benefits. In a recent study, Assunção, Hansen, Munson, and Scheinkman (2025) analyze the implications of implementing such a mechanism in the region. Their analysis leverages rich spatial data on carbon sequestration potential and agricultural revenues across more than 1,000 sites, with a particular focus on cattle ranching—the dominant land use in deforested areas. The Amazon exhibits high levels of heterogeneity: some sites have high carbon capture potential and low agricultural productivity, while others show the opposite pattern (Figure 11). This variation is central to understanding where and how forest restoration can be most effective.

Figure 11. Carbon Sequestration Parameters and Agricultural Productivity Heterogeneity for the Brazilian Amazon



Source: *CPI/PUC-RIO with data from Assunção et al. (2025), 2025*

The analysis contains two main features:

- **Detailed Carbon Dynamics:** The study models how carbon is emitted when forests are cleared and how it is sequestered over time through natural regeneration once cattle are removed. Carbon uptake is front-loaded—over 60% of the total potential is captured within the first 30 years, though the forest continues to sequester CO_2 for up to a century. This timing aligns well with the urgency of the global climate agenda.
- **Robustness to Deep Uncertainty:** The model incorporates not only price fluctuations in cattle markets but also ambiguity around key parameters, such as carbon uptake rates and agricultural productivity. This approach ensures that the conclusions are not overly sensitive to any single assumption.

The results are striking. At a modest carbon price, RDM could reverse the Amazon's carbon trajectory. Instead of emitting approximately 16 GtCO_2 over 30 years, the region could capture up to 18 GtCO_2 through large-scale natural regeneration. A carbon price of US$ 50 per ton of CO_2, which is much lower than the current market rate, would yield around US$ 30 billion annually, making restoration the more profitable land use for vast areas currently dedicated to low-productivity cattle ranching.

This case highlights the two-way nature of the forest-climate nexus: the Amazon can make a major contribution to global climate goals, while climate finance can generate transformative economic opportunities in a region that continues to face development challenges. It also illustrates the scale of the challenge ahead, since realizing this potential depends on high-income countries driving demand for carbon removals, when facing considerably higher mitigation costs.

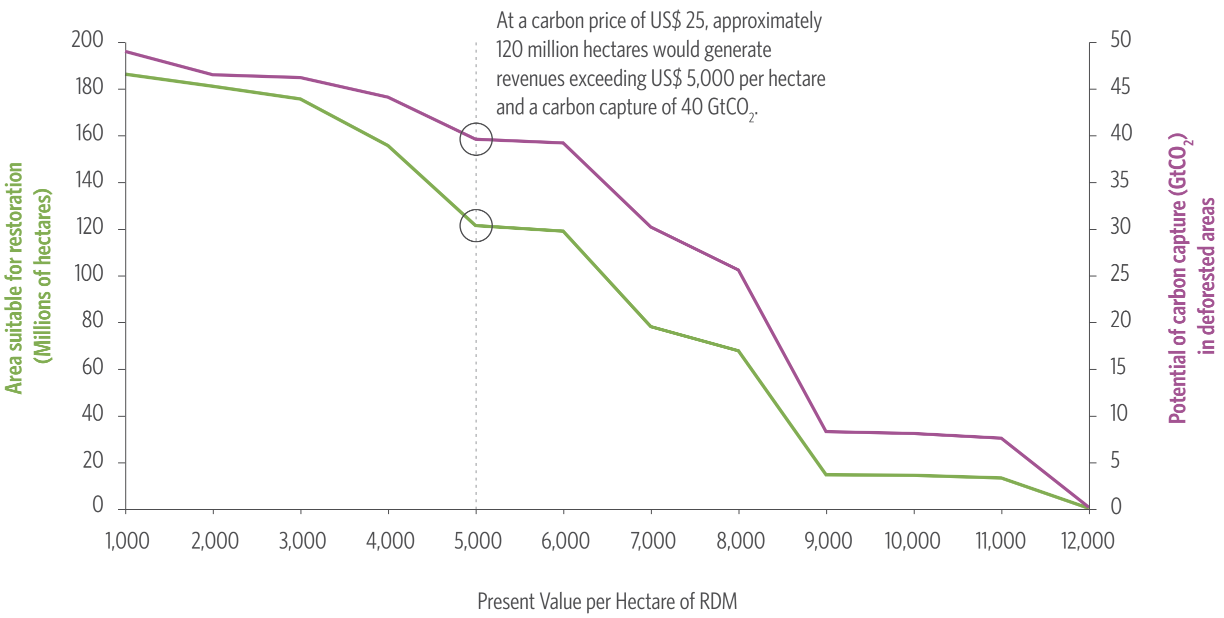
Simulating RDM's Potential

To assess the potential of RDM to deliver large-scale forest restoration and carbon sequestration, CPI/PUC-RIO's researchers simulate a scenario that places all 180+ million ha of tropical land deforested between 2001 and 2023 under restoration. They then compute the present value (PV) of future income flows under RDM using country-level estimates of carbon removal potential, assuming no additional deforestation occurs. The simulation considers two carbon price scenarios: US$ 25 and US$ 50 per ton of CO_2.

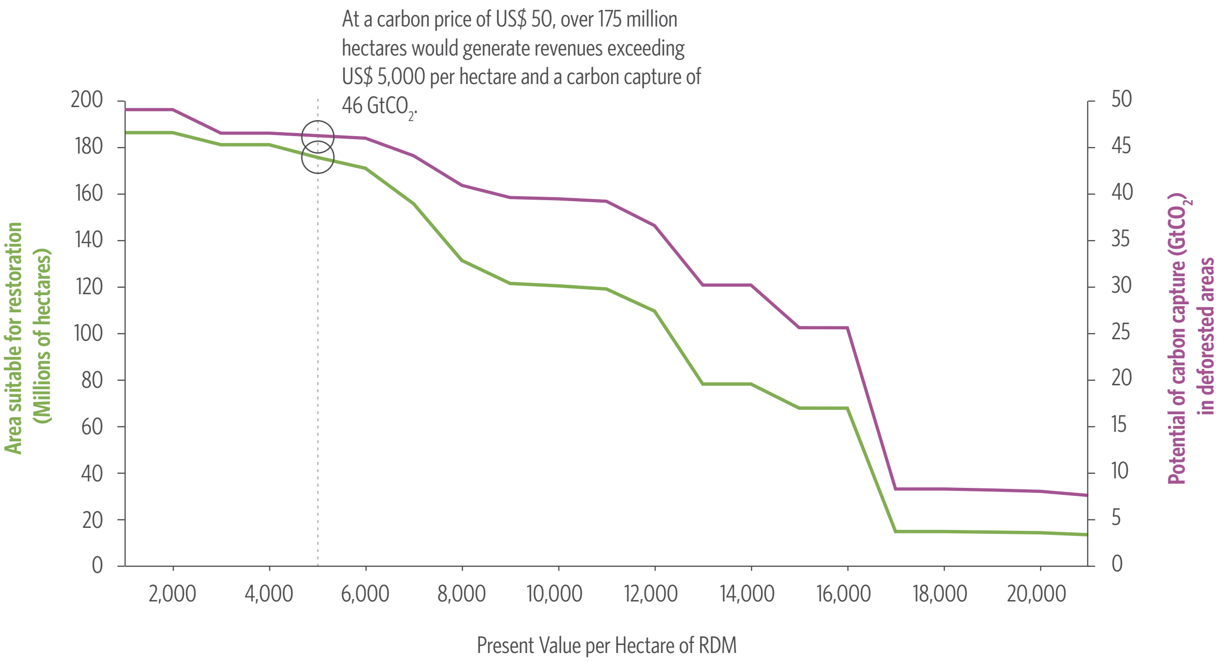
The PV metric enables direct comparison with local land prices. For example, Figure 12 shows that under a carbon price of US$ 25, approximately 120 million ha would generate revenues exceeding US$ 5,000 per ha—making RDM financially viable in areas with relatively low land prices. At US$ 50 per ton, the total area for which RDM would create more than US$ 5,000 per ha in revenues expands to over 170 million ha. This illustrates the potential for carbon finance to drive restoration at scale, particularly where opportunity costs are low.

Figure 12. Simulating RDM's Potential Impacts on Forest Restoration and Carbon Capture Potential

12a. Present Value RDM at **US$ 25/tCO_2**



12b. Present Value RDM at **US$ 50/tCO_2**

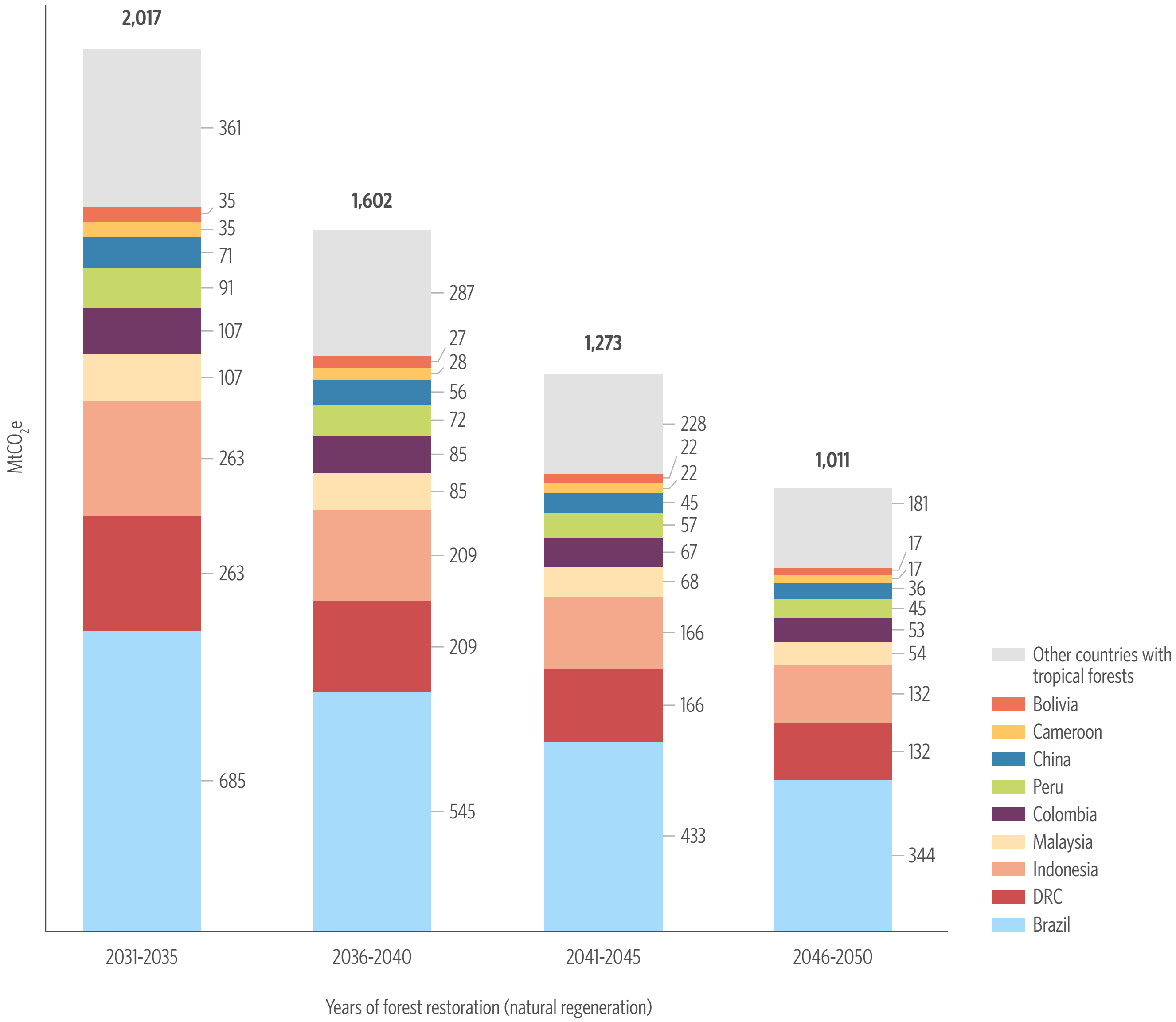


Source: *CPI/PUC-RIO with data from Hansen et al. (2013), CHIRPS precipitation (2023), and TerraClimate temperature (2020), 2025*

To evaluate the timing and climate relevance of these removals, Figure 13 presents projected annual carbon sequestration by country, assuming full restoration begins in 2031, as suggested by the COP28 Global Stocktake. The model assumes all countries start immediately at full pace. Removals decline over time as forest growth—and thus carbon uptake—slows with ecosystem maturation.

Figure 13 demonstrates that in the first five years (2031–2035), restored forests could remove about 2 $GtCO_2$ per year. At US$ 50 per ton of CO_2, this represents roughly US$ 100 billion in annual revenues, underscoring both the climate significance and the financial potential of large-scale restoration.

Figure 13. Simulating RDM's Yearly Carbon Capture Potential

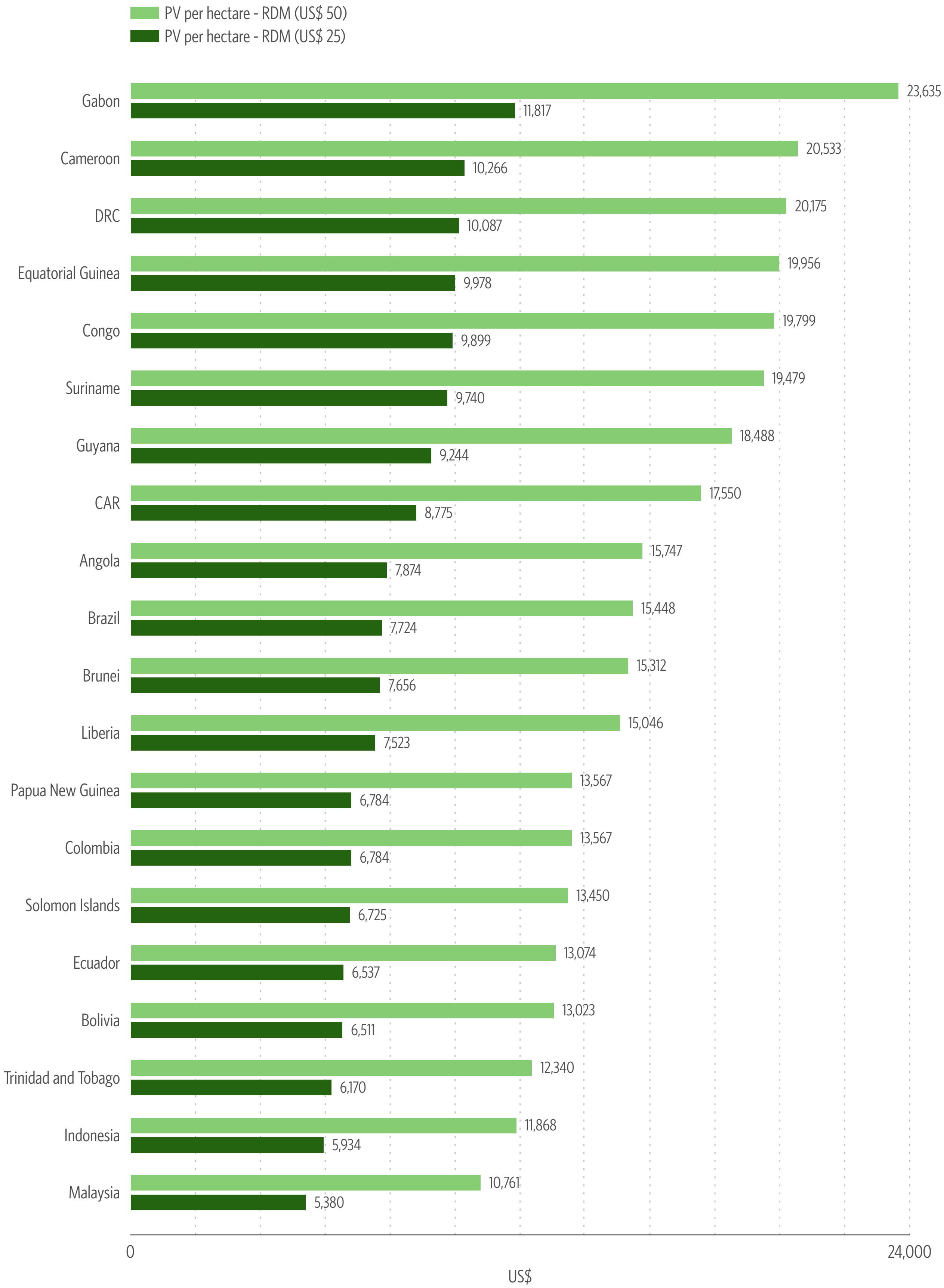


Source: *CPI/PUC-RIO with data from Hansen et al. (2013) - v1.11; CHIRPS precipitation (2023); and TerraClimate temperature (2020), 2025*
Note: *The countries with the highest carbon capture potential are shown individually. The rest was aggregated as "Other countries with tropical forests".*

Given the diverse context of tropical forest countries, it is important to assess the carbon removal potential across countries. Tropical forests differ significantly in biomass density and carbon storage capacity, which directly affects the productivity of restoration efforts under RDM. Some countries are able to sequester substantially more carbon per hectare, making restoration more economically attractive.

Figure 14 presents the PV per ha for countries with the highest carbon capture productivity, under two carbon price scenarios (US$ 25 and US$ 50 per ton of CO_2). These PV estimates per ha offer a useful benchmark when compared to local land prices, helping to evaluate the financial viability and attractiveness of the RDM implementation in each national context. As indicated in the initial classification of countries in chapter two, RDM would particularly be impactful for Brazil, Indonesia, and the DRC.

Figure 14. Top 20 Countries with the highest RDM Present Value per Hectare



*See full list of countries in the Annex

Source: *CPI/PUC-RIO with data from Hansen et al. (2013), CHIRPS precipitation (2023), and TerraClimate temperature (2020), 2025*

Implementation Requirements

Successful deployment of jurisdictional forest restoration mechanisms requires careful attention to design and operational principles that ensure environmental integrity, scalability, and long-term impact. This section outlines the core elements essential to achieving impact, along with potential implementation pathways.

Jurisdictional Approach

Implementing forest restoration at the jurisdictional level—rather than through isolated projects—offers ecological and operational advantages. Larger, contiguous areas reduce exposure to fire and enhance long-term carbon retention. They also help prevent emission leakages across neighboring lands, which is a common challenge in smaller-scale interventions.

Threats to forest integrity are often linked to edge effects. Forest fragmentation increases the likelihood of fires and other degradation processes. However, larger and contiguous forest areas contribute to the ecosystem's integrity and long-term carbon retention.

From an enforcement perspective, jurisdictional implementation enables substantial economies of scale. Brazil's experience with the DETER satellite-based monitoring system illustrates this point: by enabling rapid enforcement actions, DETER helped avoid over 10 $GtCO_2$ emissions at a cost of less than US$ 1 per ton (Assunção, Gandour and Rocha 2023). These outcomes highlight the potential of jurisdictional approaches to deliver high-impact, cost-effective climate results.

Carbon Accounting

A robust and widely accepted carbon accounting system is essential to ensure the credibility and effectiveness of RDM. This system must be capable of tracking carbon flows across entire jurisdictions with a high degree of accuracy and at a reasonable cost. Leveraging remote sensing technologies and satellite data and growing Digital Public Infrastructure (DPI) initiatives are central to achieving this goal, allowing for consistent, low-cost monitoring of vast forested areas.

A defining feature of RDM carbon accounting is its net-based approach. Rather than crediting gross sequestration alone, the mechanism accounts for the net carbon balance within each jurisdiction. This balance is calculated as the carbon sequestered through forest regeneration minus the emissions from deforestation, forest degradation, and agricultural activities. By tying payments to net outcomes, this approach ensures that jurisdictions are rewarded for restoration efforts while also facing a clear disincentive for deforestation. The result is a coherent incentive structure aligned with both climate mitigation and land-use integrity.

Scaling through International Agreements

Scaling forest restoration to meet global climate goals requires large, stable, and predictable financial flows—something voluntary carbon markets are unlikely to deliver at the necessary scale. In contrast, regulated carbon markets offer the depth and reliability required but have, so far, remained largely closed to international credits due to concerns over environmental integrity, delayed domestic mitigation, and fairness.

RDM carbon accounting framework directly addresses many of these concerns. **By issuing credits on a net basis—accounting for both carbon sequestration through forest regeneration and emissions from deforestation and land-use activities—RDM ensures that credits reflect real, additional, and verifiable climate benefits.** This structure not only rewards forest restoration but also imposes an opportunity cost for deforestation, enhancing both accountability and environmental credibility.

These features make RDM well-suited for integration into international (possibly regulated) markets. Under Article 6 of the Paris Agreement, countries can engage in the transfer of Internationally Transferable Mitigation Outcomes (ITMOs). High-integrity Forest carbon credits generated through jurisdictional RDM programs could meet this standard, unlocking access to demand at scale while maintaining the integrity of national and international climate goals.

Assunção, Hansen, Munson, and Scheinkman (2025) demonstrate the potential efficiency gains: while not directly comparable to removal, the current cost of one allowance (equivalent to one ton of CO_2) in the European Union's Emissions Trading System (EU ETS)—that has recently been trading at an average of about US$ 80 (EU$ 70)—could finance the removal of at least three tons through restoration in the Brazilian Amazon. This illustrates how the use of international credits can lower compliance costs for high-income countries while expanding their mitigation ambition.

For tropical jurisdictions, access to international markets would translate into predictable, results-based finance to support large-scale restoration, strengthen enforcement, and promote inclusive development. Far from being a loophole, high-integrity international credits offer a pathway to do more, faster, and more cost-effectively—while channeling climate finance to the countries best positioned to deliver results.

In the face of tightening climate timelines, excluding credible mitigation opportunities from regulated markets comes at a global cost. RDM can help bridge this gap by aligning robust accounting systems with the financial architecture needed to scale climate solutions.

Permanence

Ensuring the permanence of carbon sequestration is one of the main challenges in forest-based carbon mechanisms. As restored forests mature, the rate of carbon uptake naturally declines, leading to fewer new credits being issued. This dynamic creates a time-consistency problem: jurisdictions that initially commit to restoration may later find it economically attractive to revert to deforestation, especially once payment flows diminish. Beyond these economic pressures, forest fires and illegal deforestation remain persistent threats that can compromise long-term carbon storage and undermine the environmental integrity of the mechanism.

Scheinkman (2024) examines this issue in the context of the Brazilian Amazon, showing that the stream of payments under RDM peaks and then gradually declines as forests reach carbon equilibrium (Scheinkman 2024). While defection is unlikely in the early years, the incentive to abandon restoration becomes positive after roughly four decades, when the net present value of alternative land uses exceeds the value of continued compliance.

To address this challenge, RDM incorporates explicit permanence safeguards, creating financial and institutional costs for future governments that might default on conservation commitments. Two complementary approaches can be considered:

Permanence Fund: For every carbon credit issued under RDM, a small fee would be deposited into a dedicated permanence fund. After 40 years—when regular credit payments taper off—the fund would reward jurisdictions through TFFF-type payments, ensuring ongoing incentives for conservation. Scheinkman (2024) estimates that the required fee would be less than US$ 3 per ton of CO_2, and the resulting TFFF parameters would be sufficient to deter defection.

Forgivable Loan Structure: As proposed by Harstad (2025), carbon payments could take the form of forgivable loans instead of grants or unconditional payments. Countries could receive upfront financing for restoration but would be required to repay the loan if the restored areas are subsequently deforested. As long as forests remain intact, no repayment is due. This approach leverages sovereign debt frameworks to enforce compliance and ensure long-term permanence. Note that if the mechanism is implemented with a zero interest rate, it does not increase the country's debt burden—received funds would only be returned in the event of deforestation of the restored areas. Embedding such long-term commitment mechanisms—whether incentive-based (carrot) or sanction-based (stick)—is essential to address both the economic risks of land-use shifts and the physical risks from fires or degradation. These measures are critical to guarantee the durability and credibility of emission reductions over multi-decade horizons.

Long-Term Credit Viability

Jurisdictions participating in RDM will undertake significant shifts in land use—moving away from activities like cattle ranching and crop cultivation toward large-scale forest restoration. These decisions involve irreversible economic costs at the local level, particularly once land is transitioned from productive agriculture to natural regeneration. Reversing course is often difficult and costly, making it essential that jurisdictions receive credible assurances of continued financial support over time.

Ensuring long-term credit viability is therefore a two-sided challenge. On the one hand, it is necessary to mitigate permanence risks, as discussed in the previous section. On the other hand, jurisdictions need confidence that demand for carbon removal credits will remain strong and predictable well into the future—especially after they have already committed land and resources to restoration.

This stresses the importance of anchoring RDM within international carbon markets, which can offer the scale, stability, and institutional backing needed to secure long-term demand. Without such guarantees, the economic and political risks of committing to forest restoration may outweigh the perceived benefits, undermining the effectiveness of the mechanism.

Use of Proceeds

As a results-based mechanism, RDM should provide jurisdictions with flexibility in the allocation of funds, enabling alignment with national priorities and respect for domestic political processes. Proceeds may naturally be used to support a range of forest-related actions, including the creation and maintenance of protected areas, enforcement of environmental regulations, support for indigenous and traditional peoples, and broader conservation programs.

Given the potential scale of revenues in some jurisdictions, funds can be integrated into existing public finance systems and allocated in accordance with local rules and institutional frameworks. In many countries with tropical forests, pressing development needs—such as poverty reduction, improved access to education and healthcare, public safety, and urban infrastructure—compete for scarce resources.

Ensuring that RDM revenues contribute to both environmental protection and socioeconomic development can help build broad-based political support for forest restoration efforts. When forest-based climate finance visibly improves livelihoods, it reinforces the legitimacy of the mechanism and strengthens the long-term commitment to conservation.

Role of the Private Sector

The private sector can play a significant role in forest restoration. **Under RDM, carbon revenues can be directed to private actors acting as service providers for restoration activities.** In many contexts—especially in degraded or fragmented landscapes—active restoration approaches such as assisted natural regeneration, enrichment planting, or agroforestry systems may be more effective than relying solely on passive forest regrowth. Contracting private entities, cooperatives, or community organizations to deliver these services can enhance implementation capacity, encourage innovation, and accelerate restoration outcomes.

In addition, there is a significant wedge between the cost of forest restoration and prevailing carbon prices in regulated markets. This differential opens opportunities for private sector actors to participate in results-based arrangements or blended finance models that combine RDM payments with revenues from other sources.

Beyond carbon markets, the private sector can also play a role in developing forest-compatible value chains—such as açaí, cacao, Brazil nuts, and other non-timber forest products—that support sustainable livelihoods and reinforce conservation goals. Mobilizing private expertise and capital in these sectors can help align forest restoration with inclusive economic development.

Simulating Revenues from JREDD+, TFFF and RDM across Countries with Tropical Forests

As a reference, this work seeks to simulate the revenue potential of JREDD+, TFFF, and RDM mechanisms under a common scenario: all lands deforested between 2001 and 2023 are restored, and no further deforestation occurs (Figure 15). In this simulation JREDD+

payments are tied to avoided deforestation, TFFF provides rewards for the conservation of standing forests, and RDM offers compensation for forest restoration. For clarity—and to emphasize the key differences among these mechanisms—potential interactions between them are not considered.

Figure 15. Simulating JREDD+, TFFF, and RDM Revenue Potential across Top 20 Countries with Tropical Forests

Country	2023 Forest area (Million ha)	2001-2023 Deforested area (Million ha)	2023 Carbon stock ($GtCO_2$)	Potencial carbon capture ($GtCO_2$)	JREDD+ (US$ Million)	PV TFFF (US$ Million)	PV RDM US$ 50/tCO_2 (US$ Million)
Brazil	358.85	50.71	171.31	16.67	10,732	70,404	783,354
Indonesia	123.80	31.36	41.77	6.39	4,612	24,289	372,193
DRC	99.29	11.19	73.88	6.39	4,153	19,479	225,758
Malaysia	20.84	9.49	5.93	2.61	1,196	4,088	102,120
China	70.04	12.75	26.03	1.73	1,158	13,741	73,602
Colombia	69.31	4.63	28.02	2.59	887	13,598	62,817
Myanmar	35.82	5.34	8.19	0.48	696	7,028	38,151
Bolivia	27.46	2.75	16.37	0.84	520	5,387	35,813
Liberia	7.02	2.33	2.90	0.66	694	1,377	35,057
Cameroon	20.84	1.63	14.07	0.85	693	4,089	33,468
Laos	12.57	4.64	2.84	0.58	587	2,466	31,514
Madagascar	9.07	3.81	2.02	0.73	473	1,779	25,804
Papua New Guinea	38.43	1.85	15.51	0.64	427	7,539	25,100
Côte d'Ivore	8.73	3.49	1.79	0.60	246	1,713	21,142
Vietnam	10.14	3.00	2.39	0.19	370	1,989	19,553
Thailand	14.04	2.84	3.12	0.27	310	2,755	18,331
Mexico	12.92	3.22	5.48	0.20	245	2,534	14,490
Nicaragua	3.76	1.57	1.13	0.27	169	737	12,504
Congo	20.85	0.63	13.32	0.30	233	4,091	12,473
Ghana	4.84	1.72	1.04	0.21	232	949	12,416
Other countries with tropical forests*	299.85	27.29	155.81	5.84	3,796	58,831	163,270
Total	1,268	186	593	49	32,431	248,865	2,118,929

*See full list of countries in the Annex

Source: *CPI/PUC-RIO with data from Hansen et al. (2013) - v1.11, CHIRPS precipitation (2023), and TerraClimate temperature (2020), 2025*
Note: *Mexico's forest area figure is sourced from INEGI (2019) and refers to the year 2014. JREDD+ values represent the estimated cumulative amounts countries would have received over the last ten years under a counterfactual of zero deforestation in Tropical & Subtropical Moist Broadleaf Forests. TFFF and RDM figures represent the present value (PV) of all future payments under those instruments.*

Considering a reference price of US$ 10 per ton of CO_2, the simulation estimates the potential of JREDD+ revenues by linking avoided deforestation to the carbon stored in the tropical forests that were cleared. The baseline for carbon credit is defined as the average annual deforestation of 10 million ha observed between 2013 and 2023, with an associated carbon stock of approximately 375 tons of CO_2 per ha. To estimate the maximum potential of JREDD+ for halting deforestation, the exercise assumes an extreme scenario in which all deforestation ceases immediately during the first crediting period—resulting in a one-time payment. An alternative approach would be to model a possible gradual reduction in deforestation, which would imply a schedule of payments over time. However, the PV of such a schedule would necessarily be lower than that of the immediate zero-deforestation scenario.

Multiplying this carbon density by a reference price of US$ 10 per ton of CO_2 and by the average annual deforestation yields an estimate of the revenue countries could have earned under JREDD+ by immediately halting forest loss. For all countries combined, this amounts to US$ 32.4 billion. This figure should be understood as a one-time gain, reflecting the immediate halt of deforestation at the 10 million-hectares baseline and the reference price of US$ 10 per ton of CO_2.

In contrast with JREDD+, both TFFF and RDM mechanisms necessarily involve payment schedules distributed over time. For TFFF, payments are made annually, while for RDM, the schedule is determined by the natural pace of forest regeneration or tree planting. Given these distinct trajectories, the potential revenues from each mechanism are estimated using the discounted PV of expected payments, applying a 2% discount rate. The potential of TFFF is based on the total tropical forest area of 1.27 billion hectares. Assuming a value of US$ 4 per hectare of standing forest, this translates to approximately US$ 5 billion in annual payments, resulting in a PV of nearly US$ 250 billion.

The simulation of RDM potential assumes that all areas deforested between 2001 and 2023 are placed under regeneration from 2031 onwards. Using a carbon price of US$ 50 per ton of CO_2, this yields a PV of roughly US$ 1.7 trillion across tropical forest countries.

This difference across the three mechanisms reflects the distinct objectives of each one: JREDD+ is a mechanism that, in practice, has been primarily used to stop deforestation; TFFF provides standing forest payments, including in areas not under immediate deforestation pressure; and RDM compensates for large-scale carbon removals by incentivizing the restoration of previously forested lands.

The comparative results highlight strong variation across countries. Brazil, with the largest amount of forest cover, highest deforestation and the greatest restoration potential, registers the highest potential revenues under all mechanisms. However, the relative benefits differ significantly elsewhere. Most countries with tropical forests are projected to benefit more from RDM, but countries such as Gabon, and Guyana—where forests are largely intact and deforestation is low—stand to benefit more from TFFF. Note that the values of JREDD+ are significantly lower because, in the best-case scenario, where deforestation is immediately halted, they represent a one-off payment. In contrast, TFFF and RDM provide ongoing flows. **These findings reinforce the value of an integrated approach, allowing policy tools to be matched to the specific profiles and needs of each country.**

Establishing effective restoration mechanisms that complement existing conservation efforts is critical to unlock the full climate, ecological, and social benefits of tropical forests. Restoration must be designed to work in tandem with conservation incentives, ensuring that gains from forest recovery do not come at the expense of standing forests. The urgency of the climate crisis demands innovative, scalable solutions that respond to diverse national realities and integrate seamlessly with ongoing forest protection efforts. Moving forward, advancing such complementary mechanisms will be essential to maximize the role of tropical forests as pillars of global climate mitigation.

Building a Fit-for-Purpose Financial Architecture for Forests

Tropical forests are one of the world's most powerful yet underused tools against climate change. They store vast carbon stocks and offer exceptional potential for large-scale CO_2 removal through natural regeneration. But despite proven conservation and restoration successes, efforts remain inconsistent and vulnerable to political shifts and competing pressures. The scale and diversity of the forest agenda demand financial incentives that address all three key issues: halting deforestation, protecting standing forests, and driving large-scale restoration.

While JREDD+ has long provided a recognized framework for reducing deforestation and the newly proposed TFFF targets the protection of standing forests, a critical gap remains in climate finance regarding country-level incentives for forest restoration. RDM can fill this void, serving as a model for mechanisms that reward jurisdictions for restoring ecosystems. By generating carbon removal credits, RDM directly supports climate mitigation while also strengthening the resilience of tropical forests, safeguarding biodiversity, and reducing the risks of crossing ecological tipping points.

Built on jurisdictional, results-based payments, RDM is scalable, adaptable, and designed to work alongside existing mechanisms. In this way, the jurisdictional and results-based designs of JREDD+, TFFF, and RDM are mutually reinforcing, providing a flexible, fit-for-purpose financial architecture for forests. By connecting financial incentives to measurable restoration outcomes, RDM demonstrates how well-designed mechanisms can translate international commitments into tangible action on the ground.

Importantly, RDM operates within an established international forest regime, building on decades of multilateral agreements, conventions, and initiatives. Recent guidance from the first Global Stocktake at COP28 has already directed countries to halt and reverse deforestation, highlighting the urgent need for mechanisms like RDM. Simulations confirm that RDM can not only make a substantial contribution to climate mitigation but also channel significant revenues to countries with tropical forests.

COP30, to be held in the Amazon, is a unique opportunity to bring forest finance to the center of global climate action. Anchoring international climate ambition in the world's largest tropical forest can catalyze political commitment and channel resources to the countries best positioned to deliver both restoration and conservation at scale.

If adopted, this approach can transform tropical forests into lasting climate assets—boosting carbon sequestration, curbing deforestation, safeguarding biodiversity, and supporting forest-dependent communities. But the window to act is closing fast. Mobilizing political will, financial resources, and cross-sector partnerships is essential to unlock the full climate, ecological, and economic potential of tropical forests.

Annex

Figure A 1. RDM Present Value per Hectare for Countries with Tropical Forests

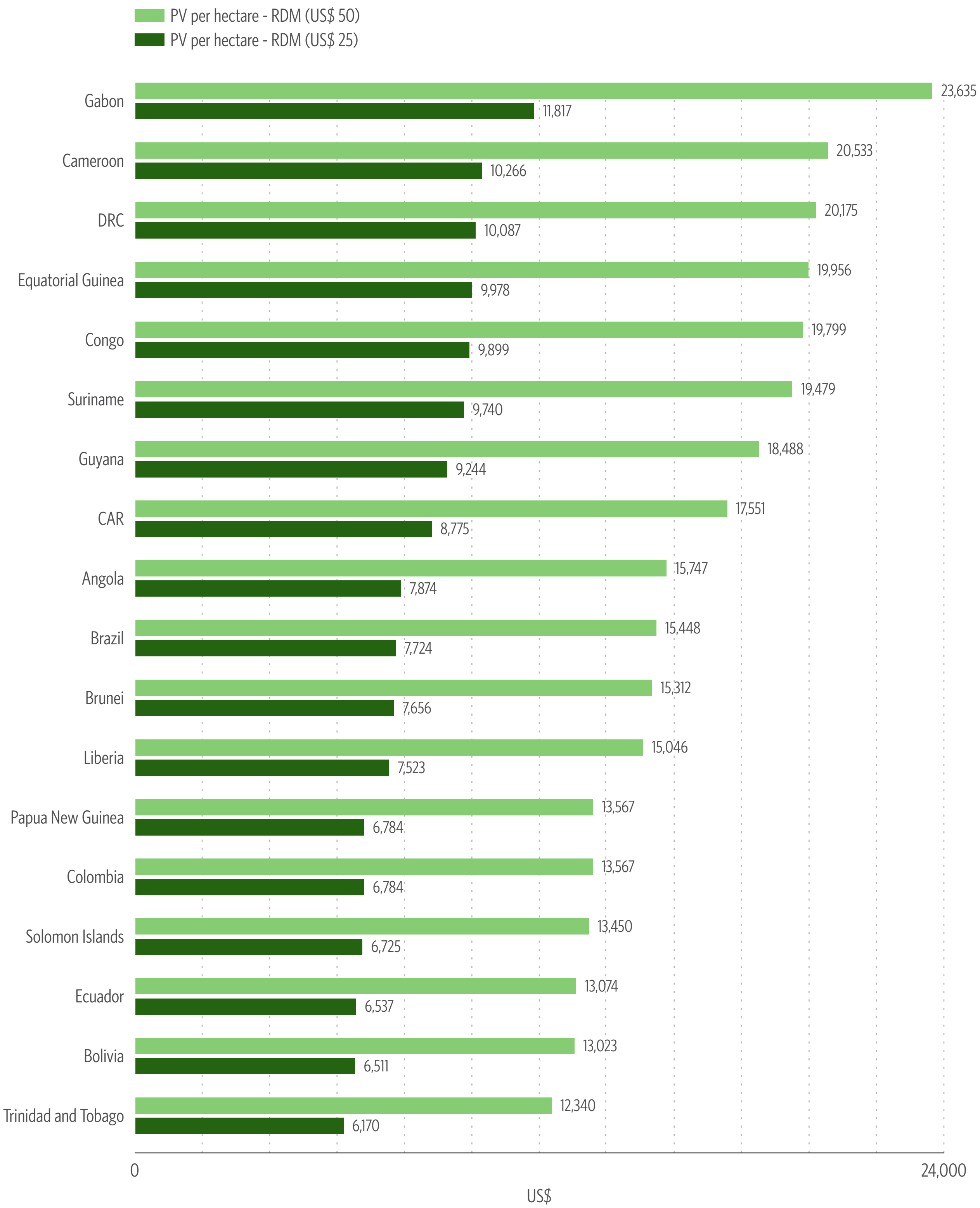
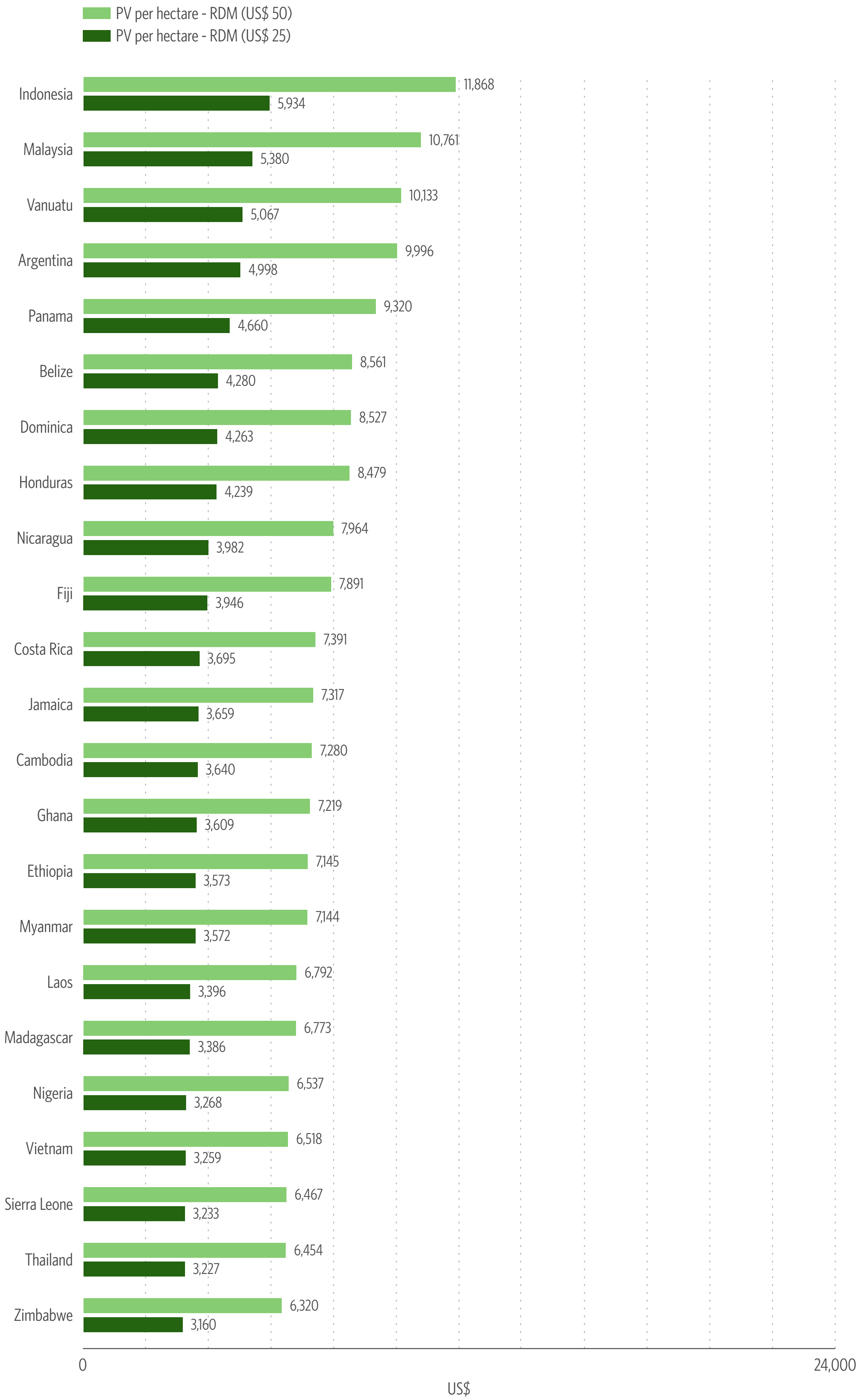


Figure A 1 continues in the next page.



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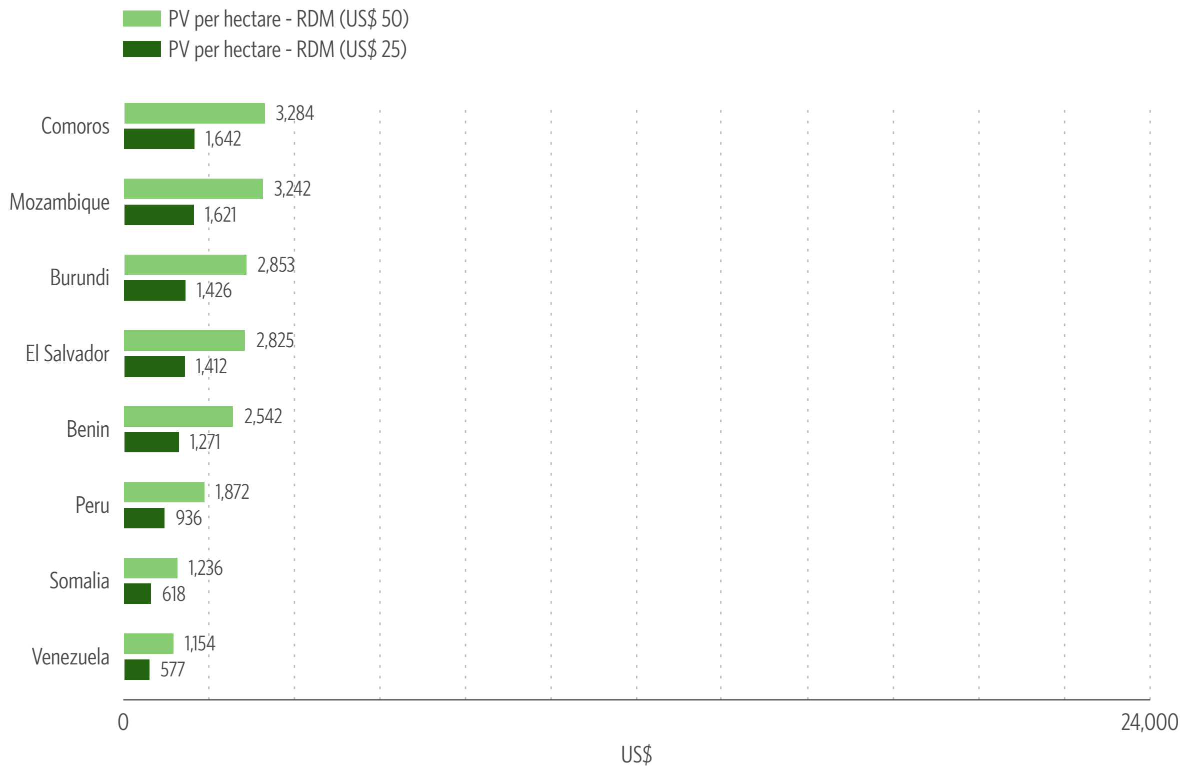

Source: *CPI/PUC-RIO with data from Hansen et al. (2013), CHIRPS precipitation (2023), and TerraClimate temperature (2020), 2025*

Figure A 2. Simulating JREDD+, TFFF, and RDM Revenue Potential across Countries with Tropical Forests

Country	2023 Forest area (Million ha)	2001-2023 Deforested area (Million ha)	2023 Carbon stock ($GtCO_2$)	Potencial carbon capture ($GtCO_2$)	JREDD+ (US$ Million)	PV TFFF (US$ Million)	PV RDM US$ 50/tCO_2 (US$ Million)
Brazil	358.85	50.71	171.31	16.67	10,732	70,404	783,354
Indonesia	123.80	31.36	41.77	6.39	4,612	24,289	372,193
DRC	99.29	11.19	73.88	6.39	4,153	19,479	225,758
Malaysia	20.84	9.49	5.93	2.61	1,196	4,088	102,120
China	70.04	12.75	26.03	1.73	1,158	13,741	73,602
Colombia	69.31	4.63	28.02	2.59	887	13,598	62,817
Myanmar	35.82	5.34	8.19	0.48	696	7,028	38,151
Bolivia	27.46	2.75	16.37	0.84	520	5,387	35,813
Liberia	7.02	2.33	2.90	0.66	694	1,377	35,057
Cameroon	20.84	1.63	14.07	0.85	693	4,089	33,468
Laos	12.57	4.64	2.84	0.58	587	2,466	31,514
Madagascar	9.07	3.81	2.02	0.73	473	1,779	25,804
Papua New Guinea	38.43	1.85	15.51	0.64	427	7,539	25,100
Côte d'Ivore	8.73	3.49	1.79	0.60	246	1,713	21,142
Vietnam	10.14	3.00	2.39	0.19	370	1,989	19,553
Thailand	14.04	2.84	3.12	0.27	310	2,755	18,331
Mexico	12.92	3.22	5.48	0.20	245	2,534	14,490
Nicaragua	3.76	1.57	1.13	0.27	169	737	12,504
Congo	20.85	0.63	13.32	0.30	233	4,091	12,473
Ghana	4.84	1.72	1.04	0.21	232	949	12,416
Ecuador	16.12	0.90	6.27	0.44	156	3,163	11,766
Nigeria	5.77	1.58	1.63	0.24	227	1,133	10,329
Sierra Leone	2.24	1.59	0.60	0.14	218	440	10,283
Guatemala	4.01	1.59	1.01	0.17	120	787	9,921
Philippines	16.43	1.60	3.05	0.23	154	3,224	9,847
Gabon	20.24	0.38	15.89	0.24	147	3,970	8,981
India	21.99	2.37	3.39	0.08	155	4,315	8,839
Argentina	5.11	0.83	4.72	0.19	101	1,003	8,297
Peru	73.00	4.15	34.82	2.20	1,100	14,322	7,768
Paraguay	2.71	1.35	1.78	0.07	78	532	7,510
Honduras	2.61	0.76	1.21	0.11	113	511	6,444
Mozambique	5.71	1.70	2.26	0.06	88	1,121	5,511
Cambodia	2.58	0.71	1.16	0.27	60	506	5,169
Guinea	1.91	0.86	0.75	0.07	114	375	4,905
Guyana	18.49	0.26	9.98	0.14	82	3,628	4,807
Suriname	13.31	0.24	7.35	0.14	85	2,611	4,675
Panama	4.80	0.50	1.36	0.07	59	941	4,660
Tanzania	3.41	1.28	2.42	0.13	73	669	4,645
CAR	6.02	0.25	10.99	0.11	75	1,180	4,388

Figure A 2 continues in the next page.

Country	2023 Forest area (Million ha)	2001-2023 Deforested area (Million ha)	2023 Carbon stock ($GtCO_2$)	Potencial carbon capture ($GtCO_2$)	JREDD+ (US$ Million)	PV TFFF (US$ Million)	PV RDM US$ 50/tCO_2 (US$ Million)
Equatorial Guinea	2.43	0.15	1.46	0.08	54	477	2,993
Solomon Islands	2.25	0.21	0.90	0.07	51	442	2,825
Belize	1.18	0.26	0.34	0.03	34	232	2,226
Costa Rica	3.23	0.27	0.77	0.04	23	634	1,996
Kenya	2.26	0.40	0.34	0.01	23	443	1,719
Ethiopia	4.69	0.24	1.83	0.03	28	920	1,715
Dominican Republic	1.26	0.29	0.35	0.02	22	247	1,548
Uganda	1.83	0.32	0.65	0.03	26	358	1,544
Bangladesh	1.30	0.30	0.19	0.01	26	256	1,351
Venezuela	41.69	1.01	19.18	0.33	214	8,179	1,165
South Africa	0.76	0.22	0.63	0.01	14	150	1,057
Cuba	1.19	0.16	0.51	0.03	17	234	958
Brunei	0.50	0.03	0.20	0.01	6	98	459
Angola	0.23	0.02	7.13	0.01	7	45	315
Sri Lanka	1.23	0.06	0.35	0.01	5	241	299
Jamaica	0.59	0.04	0.14	0.01	3	116	293
Rwanda	0.35	0.06	0.05	0.00	6	69	263
Haiti	0.58	0.06	0.09	0.00	5	114	252
Trinidad and Tobago	0.34	0.02	0.11	0.01	2	66	247
Togo	0.31	0.05	0.05	0.00	5	60	199
Dominica	0.03	0.02	0.01	0.00	4	7	171
Fiji	0.96	0.02	0.33	0.00	3	189	158
Burundi	0.28	0.05	0.04	0.00	3	55	143
Zimbabwe	0.03	0.02	0.09	0.00	2	6	126
Vanuatu	1.05	0.01	0.21	0.00	2	206	101
Nepal	1.55	0.02	0.62	0.00	1	304	86
South Sudan	0.18	0.01	1.27	0.00	1	36	60
Japan	0.23	0.01	6.52	0.00	0	44	52
Bhutan	0.33	0.01	0.40	0.00	1	65	34
Comoros	0.12	0.01	0.02	0.00	1	24	33
El Salvador	0.08	0.01	0.12	0.00	1	16	28
Benin	0.00	0.01	0.01	0.00	1	0	25
Somalia	0.07	0.02	0.00	0.00	0	14	25
Singapore	0.01	0.00	0.00	0.00	0	3	25
Mauritius	0.06	0.00	0.01	0.00	0	11	13
Grenada	0.02	0.00	0.00	0.00	0	4	6
Swaziland	0.08	0.00	0.04	0.00	0	16	6
Palau	0.03	0.00	0.01	0.00	0	6	5
Saint Lucia	0.03	0.00	0.01	0.00	0	6	4
Malawi	0.01	0.00	0.15	0.00	0	0	2
Saint Vincent and the Grenadines	0.01	0.00	0.01	0.00	0	3	1

Figure A 2 continues in the next page.

Country	2023 Forest area (Million ha)	2001-2023 Deforested area (Million ha)	2023 Carbon stock ($GtCO_2$)	Potencial carbon capture ($GtCO_2$)	JREDD+ (US$ Million)	PV TFFF (US$ Million)	PV RDM US$ 50/tCO_2 (US$ Million)
São Tomé and Príncipe	0.01	0.00	0.00	0.00	0	2	1
Saint Kitts and Nevis	0.01	0.00	0.00	0.00	0	1	0
Antigua and Barbuda	0.01	0.00	0.00	0.00	0	0	0
Total	1,268	186	593	49	32,431	248,865	2,118,929

Source: *CPI/PUC-RIO with data from Hansen et al. (2013) - v1.11, CHIRPS precipitation (2023), and TerraClimate temperature (2020), 2025*

Note: *Of the 91 countries analyzed, only those with a combined value across all financial instruments greater than US$ 3,000 are included in the table. Mexico's forest-area figure is sourced from INEGI (2019) and refers to the year 2014. JREDD+ values represent the estimated cumulative amounts countries would have received over the last ten years under a counterfactual of zero deforestation in Tropical & Subtropical Moist Broadleaf Forests. TFFF and RDM figures represent the present value (PV) of all future payments under those instruments.*

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