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The role of green financing in forest management: A systematic review (2010–2025)

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Abstract
Forests provide essential ecosystem services but face chronic underfunding for sustainable management, with global needs in the tens of billions annually far outpacing current financial flows (FAO, 2020). Green financing instruments—such as carbon finance (REDD+), green and forest bonds, payments for ecosystem services (PES), blended finance, and emerging biodiversity credits—have evolved rapidly, yet significant challenges in measurement, governance, and equity persist (Qiao *et al*., 2025). This review synthesizes the current state of green financing in forest management (2010–2025), highlighting its novelty in integrating recent innovations such as outcome-based bonds and technology-enabled monitoring tools for measurement, reporting, and verification (MRV). Drawing on peer-reviewed literature, institutional reports, and case studies from Brazil, Costa Rica, China, and other forest-rich countries, the paper identifies key financing gaps, enabling conditions, and policy priorities. The findings demonstrate that green financing, when supported by robust safeguards and transparent governance, can transform forest management and align conservation objectives with long-term economic incentives.

Keywords: Green financing, forest management, REDD+, biodiversity credits, financing gaps, MRV technology, PES programs

Introduction

Forests cover about 31% of the Earth's land area and provide essential ecosystem services including carbon sequestration, water regulation, biodiversity habitat, soil stabilization, and cultural values (FAO, 2020) [6]. They are also critical for achieving the United Nations Sustainable Development Goals (SDGs) and the Paris Agreement on climate change (UNFCCC, 2015) [35]. However, global deforestation and forest degradation continue at alarming rates, largely driven by agricultural expansion, logging, and infrastructure development (Curtis *et al*., 2018) [7].

Conventional funding through national forestry budgets has proven inadequate to address the scale of investment required for forest conservation and restoration (Appanah *et al*., 2016) [3]. In response, green financing—financial flows aimed at supporting sustainable, low-carbon, and environmentally friendly activities—has gained momentum. The concept covers instruments such as green bonds, payments for ecosystem services (PES), carbon markets (REDD+), blended finance, and biodiversity offsets (Qiao *et al*., 2025) [26].

This paper reviews the role of green financing in sustainable forest management (SFM). Part I focuses on financing needs and major instruments, while Part II (to follow) addresses effectiveness, case studies, challenges, opportunities, and policy recommendations. "This review addresses a critical literature gap by providing the first forest-centric, post-Paris synthesis of green financing instruments, integrating 2024–2025[26] innovations with established mechanisms. Unlike prior work focused on general green finance (Qiao *et al*., 2025) [26] or early REDD+ evaluations (Angelsen *et al*., 2018) [2], it delivers actionable insights for scaling finance amid escalating climate and biodiversity crises, supported by systematic methodology and global case evidence. This review is novel because it focuses on recent developments (2020 [23]–2025) in green financing for forests.

Methodology

This study follows a structured review approach based on PRISMA guidelines. Literature was collected from Google Scholar, Scopus, and Web of Science for the period 2010–2025 [30]. Keywords such as "green finance", "forest management", and "REDD+" were used. Relevant studies were selected based on inclusion criteria, and irrelevant studies were excluded. Finally, selected studies were analyzed thematically. This review adopted a structured literature review approach to ensure transparency and reproducibility in assessing the role of green financing in forest management. Academic databases (Google Scholar, Scopus, Web of Science), institutional repositories (FAO, World Bank, UNFCCC, CBD), and reputable news outlets (Reuters, The Guardian) were searched for the period 2010–2025 [8, 30] using combinations of keywords such as "green finance", "forest management", "REDD+ financing", "forest bonds", "payments for ecosystem services", "blended finance forestry", and "biodiversity credits". Only English-language peer-reviewed articles, official reports, and verified news sources were considered. Inclusion criteria were: (i) direct relevance to green financing mechanisms applied to forests or forest landscapes; (ii) empirical studies, case studies, or policy analyses; and (iii) publications from 2010 onwards to capture post–Paris Agreement developments. Exclusion criteria were: (i) green finance focused solely on non-forest sectors (e.g., urban

infrastructure); and (ii) opinion pieces without substantive analytical content or data. An initial pool of studies was screened by title and abstract, followed by full-text assessment, yielding a final set of core references that underpin sections 3–9 of this paper. The selected literature was synthesized thematically. Key themes included: (a) the magnitude and structure of the forest finance gap; (b) design and performance of major green financing instruments (REDD+, green/forest bonds, PES, blended finance, biodiversity instruments); (c) effectiveness evidence from country case studies; and (d) cross-cutting challenges, opportunities, and policy recommendations. Where possible, information from global assessments (e.g., FAO, 2020; UN DESA, 2020) [9] was triangulated with country-level case studies to strengthen the robustness of conclusions.

Current status of green financing in forest management

Since the landmark 2015 Paris Agreement, green financing for forest management has undergone remarkable maturation, evolving into a robust ecosystem that funnelled approximately USD 84 billion annually by 2023—predominantly from government sources (91%)—to safeguard vital carbon sinks and biodiversity hotspots worldwide. Established instruments anchor this progress: REDD+ (Reducing Emissions from Deforestation and Degradation) now thrives across dozens of countries, amassing over USD 15.3 billion through jurisdictional programs spearheaded by powerhouses like Brazil's Amazon Fund (24% of total) and Indonesia, alongside key players such as the Forest Carbon Partnership Facility, which disburses results-based payments for verified emission reductions. Complementing these are Payments for Ecosystem Services (PES) successes, exemplified by Costa Rica's pioneering model—investing over USD 54 million to conserve more than 500,000 hectares via direct annual incentives to landowners—and China's colossal Conversion of Cropland to Forest Program, which has injected upwards of USD 80 billion since inception to restore degraded landscapes and bolster ecological resilience. Green bonds further amplify flows, with issuances like India's L&T Finance's USD 667 million for sustainable infrastructure channelling billions yearly, though often blending forests with broader ESG priorities. Despite this momentum, a yawning USD 216 billion annual financing chasm persists as we approach 2030 targets, starkly illustrated by 2023's meagre USD 18.2 billion for agriculture, forestry, and other land use (AFOLU) sectors against a USD 66.8 billion imperative for tropical forests alone. Private sector participation remains tepid, with blended finance vehicles and investors holding 57-88% of committed funds in limbo due to disbursement delays, while tropical nations allocate less than 1% of national budgets to forestry amid competing priorities. ESG investments surge with promise—forecasts for 2026 herald scaled forest bonds, corporate alliances, and nature-based solutions integration—but systemic frictions like opaque national spending and sluggish private mobilization hinder closure of the gap. Emerging tools inject fresh optimism into this landscape. Biodiversity credits are burgeoning in managed forests, as seen in Sweden and EU pilots, where landowners earn compensation for biodiversity upliftment (e.g., habitat enhancements) without curtailing timber yields, though global standardization remains elusive. The World Bank's trailblazing USD 225 million Amazon Reforestation-Linked Outcome Bond (launched 2024) [27] exemplifies innovation, tying investor returns to tangible milestones like tree survival rates and carbon sequestration, ultimately unlocking an extra USD 36 million through rigorous impact verification. Technological leaps, including AI-driven analytics, satellite monitoring, and blockchain-secured Measurement, Reporting, and Verification (MRV) systems—deployed in Brazil's Geonoma initiatives—enhance credibility, slashing fraud risks in carbon credit markets and paving the way for scalable, trust-based financing. Yet scaling these advances grapples with formidable barriers: fragmented standardization across credits and bonds, persistent verification bottlenecks, and the urgent need for de-risking mechanisms to lure private capital en masse, as evidenced by 30+ financial instruments totalling USD 25.9 billion where 31% languish unissued. Glimmers of resolution emerge, notably the Tropical Forests Forever Facility (TFFF), a proposed USD 4 billion-per-year endowment blending public endowments with private investments to reward enduring tropical conservation—allocating 20% directly to Indigenous peoples and local communities—poised for potential COP30 momentum in 2026. Ultimately, a diversified arsenal of biodiversity credits, concessional grants, results-based payments, and precision-targeted public funds could coalesce to triple investments by decade's end, fortifying forests as indispensable allies in the global climate and nature crises.

Financing Needs and Priorities (Novelty of the Study)

1. The Magnitude of Forest Finance Gap

According to FAO (2020), global investment requirements for sustainable forest management are estimated in the tens of billions annually, far exceeding current flows. In many tropical countries, forestry budgets account for less than 1% of total national expenditures, despite forests supporting 1.6 billion people directly or indirectly (Appanah *et al*., 2016) [3]. This substantial gap underscores the urgency for increased funding to support conservation, restoration, and sustainable practices worldwide.

1.1 Investment Shortfalls

Sustainable forest management demands USD 70-160 billion yearly globally, yet current flows remain under USD 30 billion, including just USD 20 billion for developing countries from domestic and international sources (UNEP, 2025; FAO, 2020). Recent assessments show forest finance averaging only USD 2.2 billion annually for mitigation and adaptation, less than 1% of needs to meet 2030-2050 goals. Initiatives like the Tropical Forest Forever Facility have raised over USD 6.7 billion by late 2025[31], but this targets specific tropical protection rather than broad SFM.

1.2 Budg*et al*locations in Tropics

In many tropical nations, forestry receives under 1% of national budgets, limiting capacity for management despite forests' economic and ecological roles. This underfunding persists amid high deforestation pressures, with calls for redirecting private capital and innovative financing to bridge gaps estimated at USD 67 billion yearly for conservation alone (UNEP, 2025).

1.3 Human Dependence on Forests

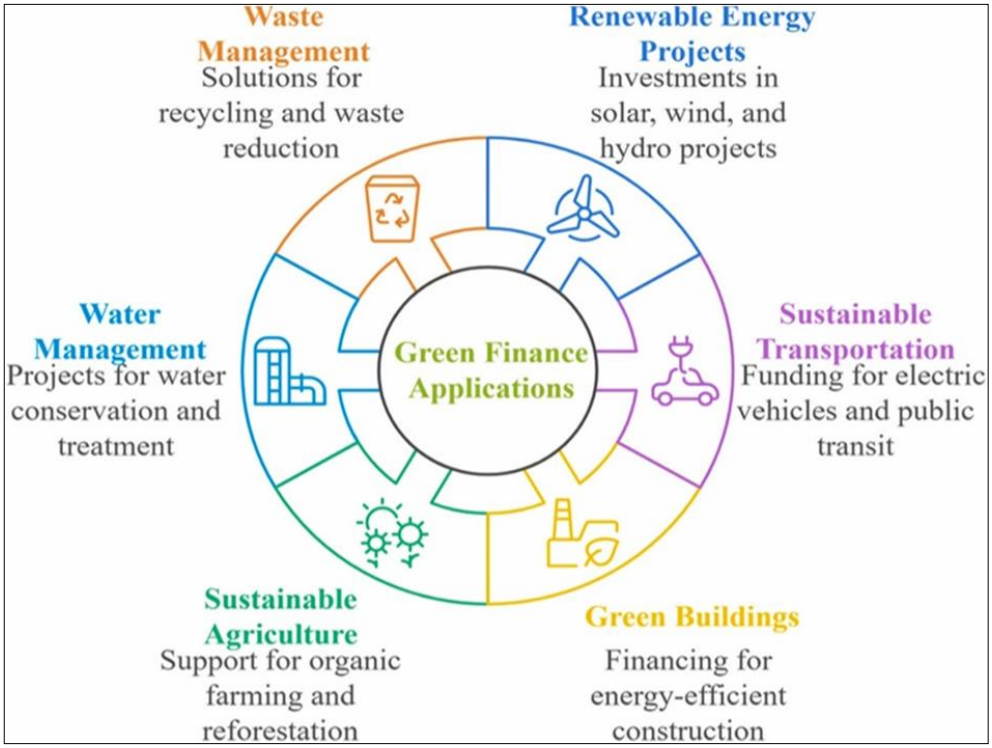
Forests sustain about 1.6 billion people directly or indirectly, with over 1 billion in extreme poverty relying on

them for livelihoods, food security, and ecosystem services like water regulation and carbon storage (FAO, 2020; IUCN, 2020). Around 60-240 million indigenous and tribal groups depend almost entirely on forest ecosystems, amplifying the stakes for adequate investment (IWGIA, 2019).

2. Priority Areas for Green Finance in Forests

- **Reducing deforestation and degradation:** Financing monitoring, enforcement, and incentive programs.
- **Forest restoration and afforestation:** Achieving global pledges such as the Bonn Challenge.
- **Sustainable value chains:** Promoting certified timber and non-timber forest products.
- **Biodiversity conservation:** Financing protected areas and wildlife corridors.
- **Community livelihoods:** Ensuring benefits for indigenous peoples and local communities.

The central objective of forest-related green finance is therefore to align conservation goals with economic incentives while maintaining ecological integrity (UN DESA, 2020) [15].



Source: Ahmad *et al*. (2025) [1]

Fig 1: Detail illustration of GF applications in different sectors.

3. Green Financing Instruements

Table 1: Comparative Overview of Green Financing Instruments for Forests

Instrument	Mechanism	Example	Strengths	Limitations
REDD+	Results-based carbon payments	UNFCCC REDD+ (Brazil, Indonesia)	Climate-linked, large scale	MRV, permanence, equity issues
Green/Forest Bonds	Debt financing tied to forest outcomes	World Bank Amazon Bond (2024) [27]	Mobilizes institutional capital	Requires strong verification, risk of greenwashing
PES	Payments to landholders for services	Costa Rica National PES	Direct incentives, community engagement	Needs tenure clarity, sustainable funding
Blended Finance	Public funds de-risk private investment	FAO GF4SL initiative	Leverages private capital	Risk of poor subsidy targeting
Biodiversity Finance	Offsets, insurance, sustainability-linked loans	Corporate supply chain loans	Expanding tools, private sector engagement	Standards still evolving

4. Effectiveness of instruments

4.1 REDD+ and Carbon Finance Outcomes

REDD+ has been implemented in more than 65 developing countries, with billions committed by bilateral donors and multilateral funds (Angelsen *et al*., 2018) [2]. Several studies report measurable emission reductions, such as in Brazil's Amazon, where deforestation dropped by 80% between 2005–2012 due in part to results-based payments (Nepstad *et al*., 2014) [22]. However, these gains have proven fragile, with deforestation resurging after political and market changes (Silva *et al*., 2020) [29]. Key effectiveness drivers include strong governance, transparent benefit-sharing, and integration with national development policies. Countries with weak governance structures often struggle to convert REDD+ funding into sustained conservation outcomes (Karsenty *et al*., 2017) [18].

4.2 Payment for Ecosystem Services (PES) Effectiveness.

Costa Rica's PES program has been widely celebrated for expanding forest cover from 21% in the 1980s to more than 50% today (Porras *et al*., 2013) [25]. Similar initiatives in Mexico, China, and Vietnam also demonstrate substantial forest recovery and livelihood benefits (Wunder, 2015) [39]. Nevertheless, PES schemes can underperform if payments are too low, if tenure rights are unclear, or if monitoring systems are weak (Muradian *et al*., 2010) [21]. Their success depends heavily on long-term financing stability, which often requires public funding sources such as environmental taxes.

4.3 Blended Finance and PPPs Effectiveness.

Blended finance mechanisms, such as the Tropical Landscapes Finance Facility (Indonesia), have shown promise in attracting private investors to sustainable plantation and restoration projects (OECD, 2020) [34]. However, transparency issues remain, and critics warn against over-reliance on subsidies without clear exit strategies (Schmidt-Traub & Sachs, 2015) [28]. The effectiveness of blended finance hinges on risk-sharing arrangements and the capacity of governments and development banks to set rigorous environmental safeguards.

4.4 Emerging Biodiversity Finance Effectiveness.

Biodiversity offsets and sustainability-linked loans are still relatively new but expanding. For example, French and UK insurers have launched resilience bonds that finance ecosystem restoration as natural infrastructure against climate risks (Bishop *et al*., 2021) [5]. While promising, these instruments require stronger global standards to ensure they do not become a license to destroy ecosystems elsewhere (Kormos *et al*., 2017) [19]

Table 2: Overview of global policy frameworks relevant to forest finance and sustainable forest management.

Instrument	Mechanism	Example	Strengths	Limitations	Key References
REDD+	Results-based carbon payments	UNFCCC REDD+ (Brazil, Indonesia)	Climate-linked, large scale	MRV, permanence, equity issues	UNFCCC REDD+ Framework (2013); Correa *et al.* (2019); GCF Brazil REDD+ Programme (2019) [16]
Green/Forest Bonds	Debt financing tied to forest outcomes	World Bank Amazon Reforestation-Linked Bond (2024) [27]	Mobilizes institutional capital	Requires strong verification, risk of greenwashing	World Bank (2024); IBRD Outcome Bonds (2024) [27]
PES (Payments for Ecosystem Services)	Payments to landholders for ecosystem services	Costa Rica National PES	Direct incentives, community engagement	Needs tenure clarity, sustainable funding	Pagiola (2008); Wunder (2015) [39]
Blended Finance	Public funds de-risk private investment	FAO GF4SL initiative	Leverages private capital	Risk of poor subsidy targeting	FAO (2023/2024); OECD (2020)
Biodiversity Finance	Offsets, insurance, sustainability-linked loans	Corporate supply-chain sustainability-linked loans	Expanding tools, private sector engagement	Standards still evolving	Deutz *et al.* (2020); Fiegenbaum (2024)

Case Studies

1. **Costa Rica:** Costa Rica's National Payment for Ecosystem Services (PES) Program exemplifies successful green financing for sustainable forest management. Launched in 1997, it demonstrates how innovative fiscal mechanisms can reverse deforestation while delivering co-benefits.

Program Context

Initiated under the Forestry Law of 1996, the program finances payments to landowners for maintaining forests, reforestation, and sustainable practices through a dedicated national forest fund (FONAFIFO). Key revenue streams include a tax on fossil fuels, water tariffs, and international donor support, creating a diversified and stable funding base independent of volatile aid flows. This model shifted Costa Rica from a deforestation hotspot in the 1980s (losing 1.7% forest cover annually) to a net reforestation leader.

Key Achievements

The PES has doubled national forest cover from about 26% in 1987 to over 52% by the 2020s[9], protecting 710,000 hectares of existing forests, reforesting 50,000 hectares, and enabling sustainable management on 30,000 hectares. It strengthened indigenous land tenure by expanding eligibility to territories, incorporating up to 1,000 hectares per community with provisions for subsistence activities, and diversified rural incomes—participants report 11-17% increases in contracted forest area over eight years, alongside agroforestry gains. These outcomes reduced emissions, enhanced biodiversity, and boosted watershed services, per Porras *et al*. (2013) [25].

Critical Lessons

Clear legal frameworks, including property titling requirements for enrolment, ensured additionality and reduced leakage while legitimizing protected areas and evicting illegal squatters. Sustained political will across administrations—bolstered by cross-party consensus and economic incentives—prevented reversals, proving that long-term commitment trumps short-term fiscal pressures. For global replication in green financing, this underscores blending domestic taxes with international support under robust governance

2. **Brazil's AMAZON Funds:** It serves as a prominent REDD+ mechanism, illustrating both the promise and pitfalls of donor-dependent green financing in sustainable forest management. Established in 2008, it highlights the need for diversified, resilient funding models.

Fund Context: The Amazon Fund, managed by Brazil's National Development Bank (BNDES), receives results-based payments primarily from Norway ($1.2 billion) and Germany ($800 million+), totaling over $1.5 billion by 2023

for verified deforestation reductions in the Brazilian Amazon (FAO, 2020) [29]. Donations are tied to emission reductions, funding state-level projects in monitoring, enforcement, fire prevention, and sustainable development. This performance-based approach rewarded Brazil's 2005–2012 deforestation drop from 27,000 to 4,500 km² annually.

Key Achievements: The Fund supported 100+ projects, enhancing satellite monitoring (e.g., PRODES/DETER systems), IBAMA enforcement operations that curbed illegal logging, and sustainable livelihoods like agroforestry, community forest management, and eco-certification for smallholders. Between 2008–2017[38], it correlated with sustained low deforestation, protected indigenous territories, and boosted non-timber products (e.g., honey, Brazil nuts), generating co-benefits for 1,000+ producers in areas like Alta Floresta.

Critical lessons

Heavy reliance on voluntary donors exposed vulnerabilities to political shifts; post-2019 under Bolsonaro, Norway/Germany froze $400+ million amid rising deforestation (11,088 km² in 2019–2021), as governance weakened and anti-environmental rhetoric prevailed (Silva *et al*., 2020) [29]. Deforestation rebounded 50%+ before recent declines under Lula (down 34% 2023–2025) [12, 31]. Key takeaway: Donor dependency without domestic revenue mandates (e.g., taxes) risks reversals; hybrid models blending international results-based finance with national commitments ensure resilience in forest management financing.

3. **IFC'S Forest Bonds:** It is issued in Kenya in 2016, marked a pioneering step in green financing for sustainable forest management by securitizing carbon credits from REDD+ projects. It showcased market potential while revealing scalability constraints against massive global needs.

Launched by the International Finance Corporation (IFC) and listed on the London Stock Exchange, this first-of-its-kind forest bond raised $152 million from institutional investors, backed by carbon credits from the Kasigau Corridor REDD+ project spanning 200,000 hectares of dryland forest between Tsavo East and West National Parks (World Bank, 2017) [38]. Investors received either verified carbon units (VCUs) or cash coupons, with BHP Billiton managing credit purchases to support payments. The 5-year structure aimed to channel private capital into avoiding deforestation while generating returns. The bond financed protection of threatened forests, curbing poaching and illegal logging while creating over 1,000 jobs and delivering community benefits like water systems, education, health services, and women-led enterprises for 100,000+ locals. It generated ~1.4 million tonnes of CO_2 reductions annually, with over 5 million VCUs issued by 2021[13], alongside social gains such as 41% time savings for women in water collection and 12.5% income increases. This proved forest bonds could attract ESG investors to high-impact REDD+ without relying solely on grants.

The issuance demonstrated robust market appetite, drawing major institutions and paving the way for subsequent green bonds amid a market now exceeding $699 billion (2026 projection). However, its $152 million scale pales against the tens of billions needed yearly for global forest finance, highlighting structural barriers like credit illiquidity, verification complexities, and emerging market risks (World Bank, 2017) [38]. Success requires standardized MRV, larger issuances, and blended structures to bridge the gap from demonstration to mainstream financing for sustainable management.

4. **China's Ecological Compensation Programs**: Particularly the Sloping Land Conversion Program (SLCP, also known as Grain for Green), represent the world's largest payment for ecosystem services (PES) initiative in sustainable forest management. Launched in 1999, it showcases state-led green financing's power for massive ecological restoration alongside critical trade-offs.

Program Context

The SLCP pays farmers and rural households to retire marginal, erosion-prone cropland (typically on slopes >25°) and convert it to forests, grasslands, or terraces, targeting China's ecologically fragile Loess Plateau and upper Yangtze regions. Financed by central government subsidies—totaling over $50 billion USD by 2020—it provides grain, cash, and seedlings for 5–8 years, transitioning to long-term ecological contracts. This addressed severe soil erosion affecting 400 million people and massive floods like 1998's Yangtze disaster.

Key Achievements

By 2018, the program converted over 28 million hectares of farmland and barren land to forest/grassland—equivalent to the size of 42 Costa Rica's—boosting national forest cover from 16.6% to 23% (Liu *et al*., 2008) [20]. Ecosystem services improved dramatically: soil erosion dropped 60%, sediment loads in rivers fell 48%, and water retention rose, yielding $12 billion+ in annual environmental benefits. Rural poverty alleviation reached 124 million households, with participants gaining stable income equivalents to 2,400–5,000 kg grain/year.

Critical lessons

Large-scale PES succeeds with centralized state financing and top-down implementation across 25 provinces, proving governments can mobilize resources at unprecedented scale for green outcomes. However, balancing food security remains paramount: converting productive farmland risked grain shortages (China lost ~10% of arable land), necessitating compensatory policies like land reclamation elsewhere and improved yields on remaining fields. Long-term success demands monitoring contract compliance, diversifying subsidies beyond grain (prone to market fluctuations), and integrating biodiversity metrics to avoid monoculture plantations. This model offers replicable blueprint for developing nations, provided agricultural safeguards accompany ecological ambition.

Challenges

Green financing is vital for sustainable forest management, yet faces significant hurdles that limit its impact on conservation and restoration efforts.

1. Governance Risks

Weak institutions and corruption risks severely undermine green financing effectiveness, as funds intended for

sustainable forest management—such as REDD+ payments or green bonds—often face leakage through mismanagement or elite capture, as noted by Karsenty *et al*. (2017) [18]. In practice, this erodes investor confidence and diverts resources from on-ground activities like reforestation. Robust anti-corruption measures and transparent fund tracking are essential to ensure financing translates into verifiable forest outcomes.

2. Measurement Difficulties

Forest carbon stocks and biodiversity metrics are inherently complex to monitor due to ecosystem variability, making verification a persistent barrier for green finance instruments, per Harris *et al*. (2021) [14]. Unlike static assets, forests involve dynamic processes like growth, decay, and species interactions, inflating MRV costs and delaying payouts. Standardized protocols integrating remote sensing could bridge this gap, enabling reliable performance-based funding.

3. Equity Safeguards

Green financing risks exacerbating inequities by excluding or undercompensating indigenous peoples, who steward vast forest areas yet often receive minimal benefits from payments for ecosystem services, according to Dahal *et al*. (2010) [8]. This can lead to displacement or lost livelihoods, undermining project legitimacy. Inclusive models with free, prior, and informed consent (FPIC) are crucial to align financing with social justice and long-term stewardship.

4. Political Instability

Shifts in national leadership, exemplified by Brazil's policy reversals under different administrations, can abruptly halt or redirect green forest financing, exposing investments to high volatility. Such instability disrupts multi-year projects like sustainable timber certification or protected area funding. International safeguards and multi-stakeholder agreements help mitigate these risks, fostering policy continuity.

5. Financing Gaps

Green financing currently mobilizes only a small fraction of the tens of billions needed annually for global forest management, leaving massive shortfalls in restoration and protection efforts, as highlighted by FAO (2020). Public funds alone fall short, while private capital hesitates due to perceived risks. Innovative mechanisms like blended finance are key to closing this divide and scaling impact.

Opportunities

Green financing unlocks transformative potential for sustainable forest management by leveraging market mechanisms, policy alignments, and innovations to scale conservation investments.

1. Investor's ESG (Environmental, Social and Governance) Demand

Growing demand for ESG assets drives rapid expansion of green bonds and sustainable forest funds, channelling billions into management practices like reforestation and sustainable timber certification. Investors seek stable returns from verifiable environmental impacts, boosting financing for forest carbon projects. This trend aligns corporate portfolios with net-zero goals, accelerating private capital flows.

2. Climate Commitments

Integration with NDCs under the Paris Agreement embeds forest finance into national climate strategies, unlocking funds from Article 6 carbon markets and adaptation budgets for enhanced management. Countries increasingly prioritize forests in updated NDCs, linking green financing to global pledges. This creates predictable revenue streams for long-term stewardship.

3. Technological Innovations

Remote sensing, blockchain for transparent tracking, and AI streamline MRV systems in forest projects, as noted by Harris *et al*. (2021) [14], slashing costs and enhancing green finance credibility. Satellite data enables real-time deforestation alerts, while blockchain ensures tamper-proof credit issuance. These tools make performance-based funding scalable and investor-friendly.

4. Public Private Partnerships (PPPs)

PPPs mobilize agribusinesses, insurers, and banks for zero-deforestation supply chains, blending public de-risking with private expertise in sustainable forest management. Initiatives like sustainable soy financing exemplify how insurers cover restoration risks and banks fund agroforestry transitions. This amplifies impact beyond public budgets.

5. Biodiversity Credits

Emerging standardized biodiversity credit markets, building on Bishop *et al*. (2021) [5], parallel carbon mechanisms to reward holistic forest outcomes like species diversity and ecosystem resilience. Pilots integrate these into green portfolios, diversifying revenue for management beyond carbon. Widespread adoption could fill financing gaps for comprehensive conservation.

Policy Recommendations

1. Strengthen Governance

Robust governance ensures green finance delivers on forest sustainability by embedding transparency, indigenous rights, and anti-corruption safeguards into funding mechanisms. This includes mandatory grievance systems, secure land tenure recognition, and national safeguard information systems (SIS) to build investor trust and prevent elite capture in REDD+ or biodiversity projects. Effective enforcement reduces risks, enabling scaled public-private partnerships for long-term forest health.

2. Diversify Funding

Diversifying sources through environmental taxes, sovereign green bonds, and corporate ESG commitments expands the $216 billion annual forest finance gap. Green bonds, for instance, have funded sustainable forestry via carbon credits and watershed protection, while taxes on timber extraction can redirect revenues to reforestation. Corporate pledges align supply chains with zero-deforestation goals, blending philanthropy with commercial returns for broader impact.

3. Improve Monitoring

Satellite technology and independent verification enhance green finance accountability by providing real-time data on forest cover, carbon stocks, and biodiversity metrics. Tools like AI-integrated remote sensing, paired with third-party audits, address leakage and additionality concerns in

financed projects. This scalability supports compliance with regulations like the EU Deforestation Regulation, boosting credibility for investors.

4. Scale Blended Finance

Blended finance de-risks private capital for forestry by layering concessional public/philanthropic funds with commercial investments, phasing out subsidies as projects mature. Initiatives like Unlocking Forest Finance demonstrate how first-loss equity absorbs risks, unlocking billions for landscape-scale restoration in regions like the Amazon. Over time, this transitions to self-sustaining models, enhancing impacts in sustainable land use.

5. Integrate in to National Systems

Linking forests to national finance via climate adaptation, rural development, and infrastructure policies mainstreams green investments beyond siloed forestry budgets. For example, sovereign bonds can co-finance agroforestry with rural roads, while adaptation funds integrate forests into resilience planning. This holistic approach mobilizes private sector resources, aligning SFM with SDGs for equitable, multi-benefit outcomes.

Future Research Directions

More research and advanced methods are essential to strengthen biodiversity credit markets and related conservation efforts.

1. Biodiversity Credit Markets

More research is needed to address methodological flaws and uncertainties in biodiversity credit markets, such as inconsistent baselines and validation protocols, which currently limit investor confidence and ecological integrity. Studies should prioritize longitudinal analyses of pilot projects to quantify additionality and permanence, drawing lessons from carbon markets' early pitfalls. Global frameworks like the Kunming-Montreal Global Biodiversity Framework underscore the urgency, projecting market growth from $8 million today to billions by 2050 if rigorous standards emerge.

2. AI for Forest Monitoring

Advanced technologies like AI should be deployed to enable near real-time, scalable forest monitoring, surpassing traditional manual methods in accuracy and cost-efficiency. Integrating AI with satellite imagery, LiDAR, and tools like Open Foris Whisp can automate deforestation risk assessments and species tracking across vast areas. Future work must focus on interoperability standards and capacity-building in regions like India to operationalize these for national biodiversity strategies.

3. Blended Finance Effectiveness

More studies are required to evaluate blended finance's causal impact on conservation outcomes, beyond correlational evidence from $3.1 billion in tracked transactions. Research should employ randomized controlled trials to isolate concessional funding's role in de-risking private investments for forestry and restoration projects. This would clarify scalability barriers, particularly in emerging markets, supporting the mobilization of $200 billion annually as targeted by global biodiversity goals. Community participation should be studied in detail to optimize its role in project success, from forest regeneration to livelihood integration. In-depth ethnobotanical and economic analyses can reveal how benefit-sharing schemes empower locals, fostering social cohesion and reducing conflicts over resources. Case studies, such as Amur falcon roosting initiatives, demonstrate dual biodiversity and income gains, warranting participatory models in credit-funded efforts.

4. Standard Impact Measurement

Standard methods for impact measurement should be developed to ensure transparency and comparability across biodiversity projects, incorporating dynamic baselines, multi-species monitoring, and independent validation. Protocols must balance cost-effective metrics (e.g., remote sensing indices) with comprehensive indicators like population dynamics and ecosystem services. International collaboration, as in recent government-led nature credit mappings, is essential to harmonize these and close the $942 billion annual financing gap.

Conclusion

Forests are indispensable to climate stability, biodiversity, and livelihoods, yet they face chronic underfunding. Green financing offers innovative pathways to bridge the gap, from REDD+ and PES to green bonds, blended finance, and biodiversity credits. Evidence from Costa Rica, Brazil, China, and global bond initiatives shows that well-designed financing mechanisms can achieve both conservation and economic goals.

However, effectiveness depends on robust governance, credible verification, equitable benefit-sharing, and sustained political commitment. As climate change intensifies and demand for nature-based solutions grows, scaling green finance for forest management is not just an option but an imperative. If implemented responsibly, green financing can reimagine forests as global assets—securing ecological integrity while fostering inclusive green growth.

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Conflict of Interests

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