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OVERVIEW ARTICLE

Current constraints to reconcile tropical forest restoration and bioeconomy

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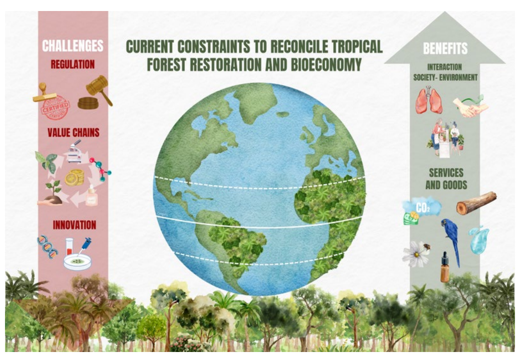
Abstract

Large-scale forest restoration is vital for delivering a broad array of ecosystem services benefits to society. However, it is often perceived as an economically noncompetitive land use choice. Integrating economic opportunities into restoration aligns socioeconomic and environmental goals, reducing conflicts between forest production and conservation-oriented management decisions. Supply chains focusing on high-value goods can enhance the reach of forest restoration efforts and unite ecological and economic benefits in a multifunctional manner. The bioeconomy has emerged as a potential but critical driver for attracting investments in restoration. We outline the challenges and solutions to reconcile forest restoration and bioeconomy, specifically about (i) native timber production, (ii) non-timber forest products, (iii) biotechnological products, and (iv) intangible ecosystem services. This requires collaborative and multidisciplinary efforts to improve investment in large-scale projects. The intricacies of these issues intersect with research development, market dynamics, legal frameworks, and regulatory paradigms, underscoring the necessity for nuanced and tailored public policy interventions. These integrated approaches should enable tropical countries to lead the global forest-based economy and usher in a new era of forest restoration.

Graphical abstract



Keywords Bioeconomy · Forest products · Large-scale restoration · Native species · Nature-based solutions · Cost-effective restoration

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Introduction: a bioeconomic perspective on tropical forest restoration

Recent history has revealed humanity's transformative power over the biosphere, reaching unprecedented levels of environmental degradation, biodiversity loss, and climate change, leading to ongoing global change emergencies. However, our transformative power may be redeployed to face the most urgent problems and to mitigate and adapt to the impacts of global change. In particular, the current global momentum toward forest restoration can effectively contribute to the recovery of ecosystem services for human well-being (Hua et al. 2022), extending the benefits to all beings. However, the outcomes concerning equity and livelihood that result from restoration programs have frequently been disregarded (Löfqvist et al. 2023). Moreover, the lack of financing has been identified as a major barrier to the recent international pledges toward forest restoration (Löfqvist and Ghazoul 2019; Löfqvist et al. 2023).

Making forest restoration economically viable and profitable for local people could help improve its equity and effectiveness while streamlining its expansion to meet global targets (Brancalion et al. 2012). However, despite the discussion surrounding the monetary value of biodiversity for goods and services provisioning, forest restoration is still perceived as an economically uncompetitive land use (Fagan et al. 2020). In this context, the bioeconomy concept (Bugge et al. 2016), which has recently been gaining much prominence, presents a compelling avenue for combining forest restoration endeavors with viable economic alternatives stemming from biodiversity-derived products and services (Gasparinetti et al. 2022).

Integrating tropical forest restoration and bioeconomy requires building the science and technical bases to use the vast diversity of tropical native species. Until today, the industrial use of a few species, such as the *Eucalyptus* genus, exotic outside Australia and a small portion of Asia, or *Pinus* species, has attracted major investments worldwide. Industrial monoculture plantations are among the most popular alternatives to obtain economic profit from reforestation investments, even though they can result in biodiversity loss (Pörtner et al. 2021) and the reduction of carbon storage over time (Hua et al. 2022), and contribute to exotic tree invasions (IPBES 2023).

Combining the high technology industry, political stewardship, indigenous peoples, local communities, civil society, and academia is essential to building innovative bioeconomy-based forest restoration models. This perspective holds promise for a forest-based economy, surpassing conventional rural activities in job creation and income generation through the establishment and maintenance of forest restoration (Brancalion et al. 2022). In these models, effective societal benefits must be ensured, including human well-being and the positive impacts of biodiversity maintenance on multiple ecosystem services provisioning (Cohen-Shacham et al. 2016). We propose that this bioeconomic perspective on forest restoration is an efficient pathway to make the adaptive movement (IPCC 2022) to reverse the current degradation trend and guarantee a healthy future for our planet. This vision has been promoted by pioneer scientific contributions a decade ago (Brancalion et al. 2012). Now, we assess current barriers and solutions to reconcile forest restoration and bioeconomy by presenting examples from forest restoration and conservation hotspot areas in the Amazon rainforest and the Brazilian Atlantic Forest.

The market for products derived from standing native forest species, such as timber, nuts, resins, vegetable butter, oils, and molecules, has been recognized as an important opportunity to benefit local communities and national economies (Löfqvist and Ghazoul 2019; Antunes et al. 2021; Carvalho Ribeiro et al. 2024; Clement et al. 2024) since the beginning of the discussions about sustainable forest management to curb deforestation in developing countries, which emerged from the Earth Summit in 1992 (Sist et al. 2021; IPCC 2022). Additionally, intangible ecosystem services are essential for life. While some services, such as carbon stock and water and climate regulation, are already being priced, other services, such as the spiritual, cultural, identity and capabilities-related, ethnic and social benefits of forests, are poorly understood by capitalist societies but extremely important for indigenous peoples and local communities (Coelho-Junior et al. 2021; Normyle et al. 2023).

The opportunity to enhance the value of standing forests has increased as forest restoration has been incorporated into the forest conservation agenda. Additionally, the for-profit private sector's commitment to sustainability and engagement in green supply chain initiatives has expanded, particularly among companies seeking competitive advantages in the market (Schimetka et al. 2024). However, to move towards practical application and successfully implement bioeconomic forest restoration, it is necessary to identify potential opportunities and determine how to execute sustainable ecosystem use.

It is imperative to make significant progress in enhancing practical knowledge regarding the establishment of viable value chains, surpassing the prevailing emphasis on theoretical potential alone and integrating the multiple uses and benefits of the whole array of ecosystem services produced by forests while developing bioproduct innovations (Maximo et al. 2022; Pascual et al. 2023) and avoiding forest cover homogenization (Clement et al. 2024). This implies taking risks and challenges toward a multi-faceted interdisciplinary effort to structure new and innovative value chains and to promote new pathways to aggregate value to forest restoration.

Barriers and solutions to reconcile forest restoration and bioeconomy

Native timber production

The production of native species timber is a critical outcome of forest restoration since recent results suggest that sustainable management of mature tropical forests will not be able to supply the timber demand and is hardly compatible with economically viable forestry practices (Piponiot et al. 2019; Sist et al. 2021). Promoting the use of native species for timber production in restored tropical forests is critical to curbing deforestation and enhancing technical/technological capability. This involves fostering the entire value chain of forest restoration, from seed collection and species selection to silvicultural practices and encouraging the industry to utilize native species. Focusing on the native species under proper management schemes can yield better economic returns than low-productivity livestock on low-quality lands (Hua et al. 2022).

However, the lack of knowledge of native tree species management and market potential in biomes where tree species exhibit very contrasting growth dynamics and multiple and thin boles has so far hampered the integration of clear silvicultural objectives into most ecological restoration projects (Krainovic et al. 2023a, b). The scientific debate about the impacts and opportunities of forest restoration in mitigating climate change indicates that major wood demand centers can reduce imports from ecologically sensitive regions like the Amazon by gradually replacing these sources with productive restoration models, thereby easing pressure on these ecosystems (Metzger et al. 2024). To succeed in timber production through forest restoration, it is essential to develop technical criteria, embrace scientific advancements (e.g., timber improvement and processing technology), and implement silvicultural treatments for native species to enhance their productivity and attractiveness (Krainovic et al. 2023a, b).

In contrast to species domesticated in conventional agriculture, which benefit from high-tech equipment and consolidated knowledge that satisfy technical management criteria and market needs (Shackleton and Pandey 2014), tropical forest restoration projects often rely on wild native tree species (i.e., which were never bred in genetic improvement programs) exhibiting very high intra-species variability in their morphology and growth potential. This results in high uncertainty in the production of forest products and contributes to the low attractiveness of productive forest restoration, given the challenges in making precise projections about the success of a forest restoration-based business. Developing large-scale breeding programs of native tree species for wood production is an essential target for expanding productive forest restoration.

However, successful examples of joint tropical forest restoration and timber production have been reported. Guanandi wood (*Calophyllum brasiliense* Cambess.) has gained popularity in the market and finds successful use in reforestation of areas historically used as pastures for cattle and intensive agriculture, such as soybeans (Pereira et al. 2021). Other native species with potential timber production have been used in forest restoration in the Brazilian northeast and southeast, such as jequitibá-rosa (*Cariniana legalis* (Mart.) Kuntze) and araribá (*Centrolobium tomentosum* Guillem. ex Benth), among others. Agroforestry systems also offer economic benefits when considering investments in timber resource management. Selected Amazonian species like Brazil nut (*Bertholletia excelsa* Bonpl.), andiroba (*Carapa guianensis* Aubl.), paricá (*Schizolobium parahyba amazonicum* (Huber ex Ducke) Barneby, and taxi-branco (*Tachigali vulgaris* L.G.Silva & H.C.Lima) yield favorable cost/benefit ratios and Internal Rates of Return (IRRs) of 21.7% per hectare over 30-year cycles (Brienza-Júnior et al. 2008).

Non-timber forest products: raw material

Non-timber forest products (NTFP) are crucial in global forest restoration (Huber et al. 2023), generating income in an intermediate time frame while timber extraction is unavailable, which leads to mixed species and multiple-use model/management plans that integrate various income sources over different periods for landowners (de Mello et al. 2020; de-Miguel et al. 2014; Shackleton and Pandey 2014). In the Brazilian, Peruvian, and French Guinean Amazon, rosewood (*Aniba rosaeodora* Ducke) essential oil offers a sustainable economic option, generating jobs and income while reducing the strain on threatened populations. Ten-year-old trees, managed by pruning, yield approximately 35 kg of biomass per tree, producing 220 kg of essential oil from branches and leaves per hectare, leading to returns of around US$87,000 per hectare in the first harvest (assuming a 1.5% oil yield at US$400 per kg; 833 trees per hectare and 50% water content in the biomass). This approach allows for the regrowth of approximately 40% of the initial biomass within a year after 100% crown removal (Krainovic et al. 2018).

Studies have shown that agroforestry systems are more profitable in certain parts of the Brazilian Amazon than livestock farming or soybean cultivation. In terms of profit comparisons, a hectare of pasture generates between US$60 and US$120 per year (Barbosa et al. 2015), while soybean cultivation faces high fluctuations, sometimes becoming negative, with peaks ranging between US$104 and US$135 (Oliveira et al. 2013). Meanwhile, the use of forests as a source of income through the harvest or the management of non-timber forest products (NTFP) in agroforestry systems in the Amazon has the potential to generate an annual profit ranging from US$300 to US$650 per hectare (Peters et al. 1989; WWF 2020). The typical investment to restore degraded lands with agroforests ranged between US$2500 and US$7000 per hectare in the Amazon (Brandão et al. 2022), with an average yearly operating cost between US$863 and US$1229 per hectare (Gasparinetti et al. 2022). Payback periods varied from 2 to 13 years, with internal rates of return ranging from 10 to 111% (Brandão et al. 2022).

The economic and environmental benefits of NTFP and its integration into forest restoration income flows provide a means of replacing the current land use model based on monoculture expansion over tropical forests (Clement et al. 2024) with a bioeconomic model based on biodiverse forest restoration (Metzger et al. 2024). In addition to making forest restoration more profitable, the use of native species contributes even more effectively to mitigating global changes by regulating hydrological and energy cycles, increasing the carbon stock on the earth's surface, preventing soil erosion, and serving as food and shelter for flora and fauna compared to agricultural monocultures (IPCC 2022).

Several other forestry systems in tropical regions have shown potential for restoring degraded areas and creating income from NTFPs. These include the native ginkgo (*Ginkgo biloba* L.) agroforestry system in Chinese tropical and subtropical forests (Sun et al. 2017), mixed plantings and agroforestry practices in Indonesia, Tanzania, Laos, and Cameroon (Pfund et al. 2011), and the production of diverse NTFP in Cambodia and Peru (Gasparinetti et al. 2022). Box 1 contains examples of the use and management of native timber and NTFP in various regions and systems mentioned above.

A key factor in boosting a bioeconomic forest restoration related to NTFP is the application of technology to transform primary raw materials into high-value products (Barata 2012). Machinery for extracting fruit pulp and fixed and essential oils from different plant parts and decantation, filtration, pasteurisation, and refrigeration are crucial to ensure a feasible value chain. The simple transformation of fruits and seeds into marketable pulp and vegetable oil may increase five times the final price of a product, which already happens with assai pulp that has its fruit sold at US$0.40 to US$0.50 per kilo while its pulp can reach US$3 per kilo. Andiroba seeds (*Carapa guianensis*) are sold between US$ 0.40 and US$ 2.30 per kilo, while andiroba oil may reach US$ 12 (Brandão 2023) through a simple extraction process. These examples reinforce the importance of adapted and functional technologies for NTFP production chains. In many cases, these value chains have already become the primary source of income for local families, representing an annual average of US$3392, equivalent to 42% of their income (Antunes et al. 2021).

Currently, a constant constraint is the low number of facilities equipped with technologies to add value to NTFP. In the Brazilian Amazon, an assessment identified a lack of NTFP processing technology in 80% of the 532 municipalities, revealing a technological gap that could compromise productive forest restoration projects (Brandão et al. 2021). To move towards a biodiversity-based economy in the tropics, investments are needed to implement industrial raw material processing infrastructure from restoration projects. Although there are no scientific studies on the costs of installing such factories, a well-known case in the Brazilian Amazon indicated that US$100,000 is required to establish infrastructure capable of receiving production from 300 local families (Idesam 2020).

As more investment is applied toward technologies that add value to NTFP, output from forest restoration can become more diverse and valuable. For example, in addition to NTFPs used as foods or raw materials, forest restoration would benefit from yielding plant parts with active substances capable of curing diseases, moisturizing skin, or controlling pests. This approach, known as biotechnological products, is related to a market with a high potential to increase the income of forest restoration projects, showing high growth potential (Nobre and Nobre 2019).

High-value non-timber forest products: biotechnological products

The biotechnological potential of native forest plants is likely the most recent and promising bioeconomic prospect for forest restoration, where species composition can be (at least partly) determined by managers. To gain insight into the biotechnological potential of native species and to understand the market patterns in a case study, we built a database using data from Oliveira and Nogueira (2023) to identify patents from the top thirty companies with the most patent registrations for biodiversity-derived products at the Brazilian National Institute of Industrial Property (INPI) in the pharmaceuticals, cosmetics, and crop care segments (Krainovic et al. 2023b). We wanted to assess whether companies registered patents on native trees from the Atlantic rainforest. According to our survey, that group of companies held a total of 738 different patents for raw materials, ingredients, chemical formulations, or processes. Only 11% of these patents describe formulations, processes, or products that include the use of native species from the Atlantic Forest biome. Companies continue to favor already existing, well-established value chains, and the products or processes registered in patents are derived from plant species considered exotic species (89%), with 45% being commodities such as soybean (*Glycine max* (L) Merr.), sunflower (*Helianthus*

Box 1 Illustrative examples showcasing the diverse utilization of timber and non-timber forest products across various geographic regions and under a spectrum of landscape management strategies. Credits: Pedro Medrado Krainovic, Zenaide Telles, Diego Oliveira Brandão, André Naves and Ricardo R. Rodrigues

annuus L.), and grape (*Vitis vinifera* L.). Around 55% of registered patents are derived from herbaceous plants, while only 22% come from trees. The most registered plant parts are leaves, fruits, and seeds (Fig. 1). Our assessment of patent registration trends aligns with specialized literature, such as Santos et al. (2023), who found that patents in various Brazilian biomes primarily cover the agriculture, livestock, pharmaceutical, and cosmetic sectors, with most registrations associated with non-endemic species. Regarding the patent registration of native species, the literature also reveals that the biodiversity business in Brazil remains largely untapped (Carvalho Ribeiro et al. 2024) reinforcing the need for research and entrepreneurial efforts concentrated on native tree species.

Pursuing a balanced market for goods and services, focusing on forest restoration, offers promising opportunities through biotechnology (Calixto 2019). This approach involves scaling up forest restoration and promoting growth in the bioproducts sector, counting on the crucial private-sector investments (Löfqvist and Ghazoul 2019; Smith et al. 2020). Forest products have a long history of human use, particularly in healthcare, and today, approximately 35% of medicines are sourced from natural origins, including plants (Markets & Markets 2022; Natural Extracts Market Size and Industry Report 2022). However, the literature on biodiversity use is too concentrated on the screening stages (i.e., in vitro and in vivo phases or analytical chemistry description phase). There is a need for more studies on how to manage species to allow their use (Krainovic et al. 2023b), enhancing the connection with bioproduct industries. In terms of potential, a literature review done by us on the biotechnological potential of native species from the Atlantic Forest highlights such notable examples as the subtropical conifer, Araucaria (*Araucaria angustifolia* (Bertol.) Kuntze), which presents anti-herpes, antioxidant, antibacterial, and anti-fungi properties, including *Listeria monocytogene*, responsible for cases of listeriosis in humans. Araucaria is also an essential source of pine nuts, a food appreciated for its nutritional value and taste. Copaiba oil/resin (*Copaifera langsdorffii* (Desf.) Kuntze) has demonstrated wound healing, anti-inflammatory effects, and applications in dentistry for treating periodontal diseases (Souza et al. 2011). It also serves as a larvicide for agricultural and tropical disease vectors, achieving 100% larval mortality for *Aedes aegypti* (de Mendonça et al. 2005). *Hymenaea courbaril* L., a canopy tree with potential for timber production used in forest restoration projects (Krainovic et al. 2023a, b), can also have its bark used as an antioxidant, myorelaxant, and natural anti-inflammatory besides having antifungal activity and low toxicity on animal cells (Bezerra et al. 2013).

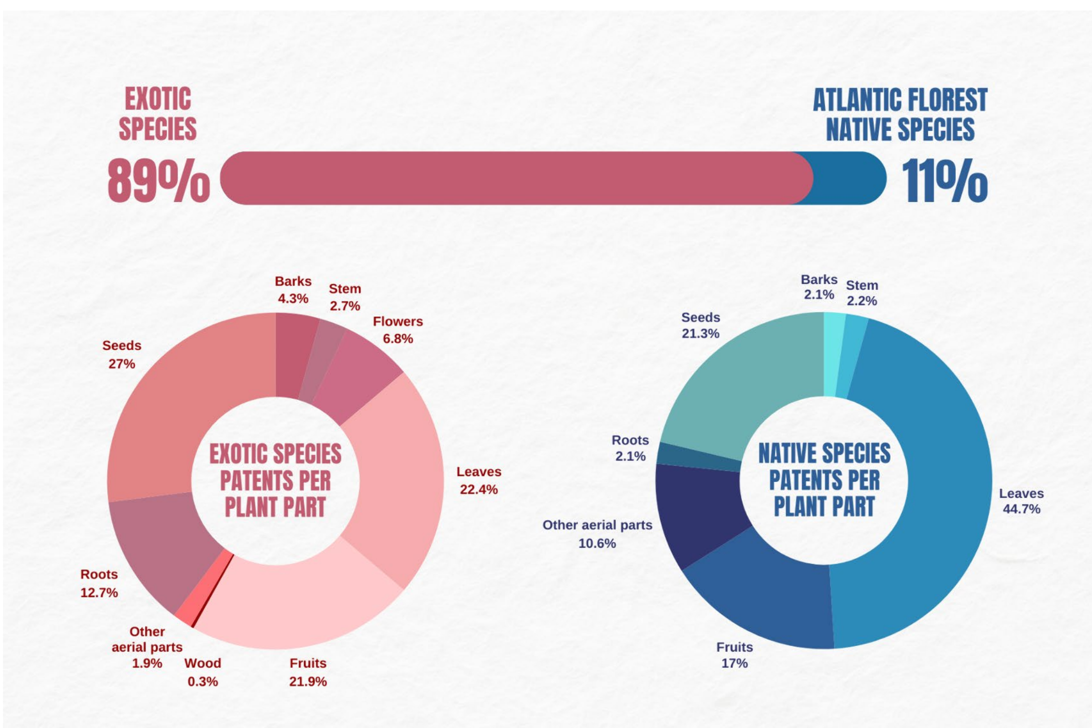

Fig. 1 Proportion between native and exotic species and plant parts used by the top 30 companies that have patented biodiversity-derived products with the National Institute of Industrial Property (INPI–Brazil) in the pharmaceuticals, cosmetics, and crop care segments in 2022–2023. Database in: https://zenodo.org/records/7837248

Intangible ecosystem services

A variety of ecosystem services are not related to a physical or tangible good that is manufactured or produced to meet the material needs of consumers but are equally essential for our survival and well-being. Amidst the ongoing economic debate about forest restoration, it is crucial to emphasize that its success hinges on promoting habitat for carbon uptake, biodiversity conservation (Despot-Belmonte et al. 2017), soil protection (Krainovic et al. 2020), hydrological services (Jones et al. 2022), and pollination of crops and forest species (Kaiser-Bunbury et al. 2017), among other ecosystem services. Regarding generating diverse co-benefits for nature and humans, forest restoration is one of the most efficient strategies for carbon uptake in the tropics (Heinrich et al. 2021). Meanwhile, the payment mechanisms for ecosystem services are being regulated and certified, boosting rural property landowners' adoption of ecological restoration associated with the ecosystem services market. This is already happening through the creation of carbon market regulation (e.g., the National Policy on Climate Change in Brazil) and discussions on pricing water provisioning (Viani et al. 2019). Agroforestry systems, for example, can compose a restoration strategy and store more carbon than secondary forests succeeding land degradation (Cardozo et al. 2022).

The carbon market, economic gains, public policies, and social pressure on companies drive the business and research on payment for ecosystem services (PES). Technology is crucial for accurate carbon measurement and cost reduction (Almeida et al. 2021), reducing transactional costs in carbon trading, improving reporting on companies' emissions, compliance status, and carbon pricing, and meeting additional obligations for regulated trade through precise local carbon baselines. On a larger scale, a global system for coordinating carbon emissions and markets will emerge, stratifying countries and companies by emission levels and sectors, allowing transfers between countries with distinct economic growth and human development worldwide. Other ecosystem services, like biodiversity recovery and conservation, pollination, soil protection, and water regulation and provisioning (also linked to agriculture), will gain market value continuously. This 'biomarket' is expected to gain visibility and be operated initially by national-level PES programs that follow a standardized global methodology. Simultaneously, an international policy combination will be implemented, offering incentives for research and development alongside global PES.

Fostering tropical forest restoration outcomes

Demonstrating tropical forest restoration financial feasibility is still limited to a few academic studies and the grey literature (Molin et al. 2018). Because data on potential financial benefits from the restoration are scarce and uncertain, studies focus on opportunity and avoided costs rather than potential benefits (Schimetka et al. 2024). This tendency obscures the fact that restoration can indeed be economically viable. Clear demonstration of the trade-offs and economic viability of forest restoration is crucial to persuade landowners, policymakers, and investors that the integration of restored forests into crop production, pastures, or rural landscapes can yield multiple socio-environmental "co-benefits" in addition to generating income (Hua et al. 2022), even if indirectly. The current scarcity of information diminishes stakeholder interest in investing in forest restoration due to the high risk stemming from the uncertainty related to market access (Edwards et al. 2021), species performance (Krainovic et al. 2023a, b), and understanding of the incentives for forest restoration (Tedesco et al. 2023).

More economic data tailored for forest-based enterprises can aid in improving forest restoration outcomes and enhance the effectiveness of forest restoration efforts while accounting for multifunctionality criteria. This approach transcends the mere costs linked to planting saplings. Ideally, species selection for restoration projects should consider multiple criteria beyond local species distribution. Accurate prediction of beneficial species at local and regional levels can contribute to increasing socio-ecological and economic returns on restoration investments, and each time more tools are being developed to allow these actions (e.g., ecological niche to predict species occurrence at large scales; Diversity for Restoration (D4R), to identify suitable tree species for climate resilience (Fremout et al. 2022); InVEST model tool, to integrate considerations of socioeconomic functionality (Natural Capital Project 2023); MARXAN tool to determine the target species niche and optimize decision making in areas to be conserved, and others (Ball et al. 2009). For bioeconomic forest restoration, information such as native wood and NTFP production, long-term carbon assimilation (Brancalion et al. 2018), local key species, genetic selection for survival and productivity in degraded areas, and climate adaptability (Butterfield et al. 2017; Fremout et al. 2022) and the creation of habitat for endemic species, large mammals, insects and other living beings must be considered together, which is vital for integrating environmental information into economic analysis.

Political systems must recognise and learn from past failures in implementing policy laws and regulations to make bioeconomic forest restoration effective, given the persistent threat to multiple ecosystems. An iconic example is the Brazilian Atlantic Forest, a biodiversity conservation hotspot, where approximately 30% of the forest cover regrowth is cleared again after eight years to avoid mandatory conservation based on successional classes (Piffer et al. 2022) as foreseen in the Biome protection Law (Resende et al. 2023). Meanwhile, innovative land use through multifunctional landscapes that could increase the attractiveness of forest restoration remains uncertain without a definition of the appropriate duration for funding programs (Crouzeilles et al. 2020) since ecological time scales are often much longer than private investment time horizons and political cycles.

A favorable market for forest restoration-origin products can encourage the implementation of multifunctional native forests, creating an appropriate net of local cases to be monitored and serving as a source of data for econometric models from bioeconomic forest restoration. Policy instruments can promote fair competition between forest restoration products and those from traditional production routes (e.g., extensive monoculture). They can establish a responsible certification seal for forest restoration products, accompanied by incentives linked to production methods and taxation. Additionally, these instruments can favor access to financing sources, such as those from the private sector or in a blended finance arrangement, identified as feasible mechanisms for enabling forest restoration (Metzger et al. 2024). In the list of market-related priorities to further bolster the attractiveness of forest restoration products, policy measures should aim to boost demand for restoration-derived products used by public entities like hospitals, schools, police stations, public infrastructure works, and other public procurement thereby favoring demand and scaling up. In this way, regulation should prevent capital concentration, ensure the sharing of benefits and genetic heritage access, and involve local communities and cooperatives of small landowners while controlling overharvesting and biopiracy. The package to promote multifunctional restoration involves training restoration professionals to apply scientific advancements and bridge interdisciplinary research with practical implementation. This approach catalyzes the generation of multiple revenue streams, appealing to a wide range of stakeholders, particularly landowners.

Importantly, forest restoration needs to be envisioned and planned at the landscape scale, where different parcels achieve multiple objectives through diverse land management strategies, while still considering a reference ecosystem to reach ecological goals (Toma et al. 2023). Certain parcels of the landscape may be intensively managed to yield high-value products, while others can provide intangible ecosystem services such as water regulation, microclimate enhancement, carbon stock, biodiversity conservation, and pleasing views. Forest restoration allocation often focuses on marginal areas (low-aptitude agricultural and pastureland) and regions with greater significance for connectivity (Metzger et al. 2017; Tedesco et al. 2023), ensuring food security by not affecting important productive areas. A forest restoration pathway for a forest-based economy will use an adapted cost–benefit analysis. Here, we are referring not only to financial cost–benefit analysis, essential for gaining attractiveness to landowners and entrepreneurs but also to economic-social cost–benefit analysis, given the need for interconnection with the various externalities related to ecological restoration, which impact multiple actors beyond the governance limits of a forest restoration project. These positive externalities—ecosystem services, jobs, income generation, and others—are significant in forest restoration projects and are currently not added to the cost-and-benefit equation because they are not easily quantified (Lamb et al. 2021). The restorative bio-economic land use model represents a range of possibilities for transforming resources into goods and services usable by society, generating economic value. This approach ushers in a new era of global forest restoration, providing an excellent opportunity for tropical countries to actively participate and take a leading role in the sustainable management of their forests and global ecosystem provisioning.

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Data availability The data on patented biodiversity-derived products published by the top 30 companies can be accessed at https://zenodo.org/records/7837248 upon request.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. PMK, AFR and NCSN report that the State of Sao Paulo Research Foundation provided financial support. Additionally, PMK reports that The Nature Conservancy and World Resources Institute provided financial support. PHSB and RRR are partners of the Re.green company.

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