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REVIEW ARTICLE

Towards a synthesized critique of forest-based 'carbon-fix' strategies

Jessica Enara Vian[1] | **Brian Garvey**[1] | **Paul Gerard Tuohy**[2]

[1]Work, Employment and Organisation, University of Strathclyde, Glasgow, UK

[2]Mechanical and Aerospace Engineering, University of Strathclyde, Glasgow, UK

Correspondence
Jessica Enara Vian, Work, Employment and Organisation, University of Strathclyde, Glasgow, UK.
Email: jessica.vian@strath.ac.uk

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Abstract

This article synthesizes critiques of 'carbon-fix' strategies in the forestry sector to clarify key concerns about reductionist treatments of forests and carbon and to facilitate further debate. It begins by asserting that since climate change mitigation has been placed at the centre of forest governance, forests have been deemed to serve as 'carbon-fixing' devices in ways that can be discerned across three distinct but inter-related categories: (i) carbon storage devices, (ii) carbon removal devices and (iii) net-zero bioenergy devices. A transdisciplinary literature review is used to shed light on key concerns relating to the instrumentalisation of forests within each of these categories. By doing so, this article contributes to a deeper understanding of why relegating forests to a 'carbon-fix' function is insufficient to tackle climate change and, rather, poses threats to forest ecosystems and forest-dependent communities. This review ultimately calls into question the use of forests to delay crucial systemic changes, without diminishing the importance of forest conservation, restoration, governance, as well as technological innovation, in mitigating the ongoing harmful effects of climate change.

KEYWORDS

BECCS, biofuels, carbon market, environmental offsets, forest governance, neoliberal environmentalism

1 | INTRODUCTION

Today's planetary emergency converges multiple ecological and social crises (Klein, 2015; Shifferd, 2021; United Nations, 2020; Williams et al., 2021); however, in terms of institutional discourse, it has been frequently reduced to the single issue of climate change linked to anthropogenic carbon emissions (Demeritt, 2001). On the evidence of successive outcomes from the Conference of the Parties, market-based mechanisms and techno-economic solutions are central to proposed actions (UNFCCC, 2022). In this context, no other ecosystem has attracted as much policy attention as forests—since they can either greatly contribute to or alternatively mitigate greenhouse gas (GHG) emissions (Ojha et al., 2019). Forest-based solutions for climate change adaptation, mitigation and sustainable development have attracted attention due to their relatively low costs (Griscom et al., 2017; Honegger & Reiner, 2018) and their potential for social and environmental co-benefits (Sarira et al., 2022; World Bank, 2021a).

The literature evaluating the merits of such forest-based 'carbon-fix' strategies is markedly divided between claims of win–win outcomes (Robinson et al., 2016; Seymour & Busch, 2016; World Bank, 2021b) and critiques regarding their effectiveness in decreasing atmospheric GHGs (Böhm & Dabhi, 2009; MacAfee, 2017; Pearse & Böhm, 2014), their ability to deliver on their co-benefit promises (Chambers, 2018; Mayrhofer & Gupta, 2016) and even accounts of such projects aggravating environmental harm and social conflict (Beymer-Farris & Bassett, 2012; Paladino & Fiske, 2017; Scheidel & Work, 2018).

Rather than providing an exhaustive review of these works held in tension, this study investigates the breadth of criticisms levelled against carbon-centric policies in the forestry sector—ranging from challenges to underpinning theoretical assumptions to seemingly opaque forms of financialisation and evidence of flawed implementation. This article concerns itself with synthesising and analysing these critiques to foster a deeper understanding of them and to facilitate dialogue between these critical accounts across disciplines.

This review undertakes this exercise by investigating how forests have been reduced by climate policies to three forms of 'carbon-fixing' devices, namely: (i) carbon storage devices—relating to forest conservation policies; (ii) carbon removal devices—relating to afforestation and reforestation (AR) programmes and associated carbon markets and (iii) net-zero bioenergy devices—relating to incentives and accounting methods for biofuels and biomass production, as well as to bioenergy with carbon capture and storage (BECCS).

The article begins by describing the method used for this synthetic review. It then outlines, categorizes and clarifies the concerns raised in the literature associated with the 'carbon-fix' discourses and practices in each form of forest instrumentalisation. The discussion that follows summarizes the arguments and considers the evidence that relegating forests to a 'carbon-fix' function is insufficient to tackle climate change and poses threats to forest ecosystems and forest-dependent communities that require to be addressed. Forest conservation, restoration, governance and technological innovation should play an important role in mitigating the already felt/ongoing harmful effects of climate change, as well as in providing social and environmental benefits (beyond the carbon-fix agenda). This review article contends, however, that forests should not be used to divert attention away from necessary systemic changes or to further delay action in this direction.

2 | METHODOLOGY

This is a transdisciplinary, inquiry-driven literature review (Montuori, 2013) that investigates the following question: What can be shared and learned from the main critiques levelled against carbon-centric strategies in the forestry sector? More specifically, the purpose is to review the evidence and arguments that underlie *critiques* of 'carbon-fix' strategies in the forestry sector across social, natural and engineering sciences. Its purpose is not to exhaust the existing literature on the topic but rather to integrate key critiques found across these three disciplines to produce a more comprehensive picture of the controversies surrounding carbon-centric strategies in the forestry sector. Academic books and articles were gathered during a 3-year period (2019–2022) employing keyword searches on high-impact peer-review journals and search engines—including Google Scholar and ScienceDirect—and citation searches in the most relevant articles. Materials from grey literature were also considered to include concerns raised outside the academic field by Indigenous activists (see Huni Kui, 2014) and research conducted by non-governmental organisations (including Rights and Resources Initiative, Forest Peoples Programme and Fern). A total of 105 theoretical and empirical peer-reviewed articles, 16 academic books and thesis and 21 materials from grey literature were included in our database. While recognising that controversies are often the result of a matter of perspective and positionality, this review departs from normative interpretations of the role of forests in mitigating climate change that is entrenched in knowledge systems that risk reproducing socioenvironmental harm and inequalities (Baker et al., 2019; Goldstein et al., 2023; Smith, 2021). This interdisciplinary review is based on the authors' interpretation of the relevance and coherence of the critiques raised, as well as the evidence provided. Although the authors are from both the Northern and Southern hemispheres, it is acknowledged that this review was limited to materials written in English, which may not accurately reflect concerns/debates on the subject outside of the English-speaking world.

3 | Forests as a carbon storage device

Deforestation continues to be a substantial source of carbon emissions globally (Gibbs et al., 2018; IPCC, 2022). Thus, protecting forests from deforestation and degradation is an important measure to both avoid carbon emissions and preserve natural sinks. Their central role to tackle anthropogenic carbon dioxide emissions and consequent climate change is common currency in the major global institutional stakeholders (UNFCCC, 2017, 2022; World Bank, 2021c). The literature, however, shows that forest conservation has not always been driven by or carried out in accordance with ethical and sustainable principles and practices. Carbon-centric conservation policies and incentives that have emerged because of climate debates are no exception. Four major arguments against carbon-centric forest conservation are identified and examined in this review:

1. Forests are more than carbon sinks and a narrow focus on carbon promotes harmful trade-offs with other ecological and social concerns.

Since carbon management has become the primary objective of conservation policies and projects, forests have mostly been regarded as carbon warehouses (Paladino & Fiske, 2017). This overemphasis on carbon has pushed aside equally pressing concerns such as biodiversity loss and transgressions of Indigenous People's rights. According to Fletcher (2017), the narrow focus on carbon drives distinct environmental goals into conflict with one another. For example, the protection of low-carbon biomes can be threatened by carbon-capturing goals (Lewis et al., 2019; Putz & Redford, 2009). Environmental and social trade-offs also occur across sectors; for instance, projects in the energy sector, such as large hydroelectric dams (Fletcher, 2010) or biofuel plantations (Danielsen et al., 2009), can harm local ecosystems and displace communities in the name of carbon savings. Furthermore, this focus on carbon compels 'environmentalists to frame other issues in terms of their contribution to climate action' (Fletcher, 2017, p. 137) in order to gather support and funding. In other words, carbon has overshadowed forests in environmental policies, making non-carbon-related concerns seem less important.

Critics of carbon-centric forest conservation policies remind us that deforestation is a problem not only because of carbon emissions but also because of the disruption of multiple ecosystem functions, biodiversity loss and human rights abuses. Extreme focus on carbon obscures the importance of non-carbon forest functions—which include air purification, water cycle regulation, protection against erosion, pest control and pollination. It also neglects non-timber forest products, non-tree life forms and ecosystems (Duque et al., 2014), as well as cultural and spiritual values that are sacred to Indigenous People (Fernández-Llamazares & Cabeza, 2018). Furthermore, when designed for maximum carbon storage efficiency forest protection threatens and restricts the livelihoods of customary forest users (Smith & Scherr, 2003). In essence, forest conservation should be driven by more than a carbon storage agenda; it should seek to preserve forests' multiple ecological functions, irreplaceable biodiversity and the unique human culture and knowledge they shelter (Gibson et al., 2011).

2. Neoliberal market incentives to preserve forests' carbon sinks have led to new forms of fortress conservation and green grabbing.

Since colonial times, conservation efforts have been heavily influenced by the concept of 'pristine' nature—a supposedly pure state of nature that must be safeguarded from human presence and interference (Hennessy & McCleary, 2011; Shanker et al., 2017). This concept is reinforced by the assumption that humans are not a part of nature and that environmental degradation is an intrinsic trait of humanity (Royle, 2016) rather than the fault of an unfit political-economic system (Foster & Clark, 2016). Such antagonisation between humans and nature results in top-down conservation practices that have historically generated social conflicts, marginalisation and displacement of Indigenous and rural communities (Dowie, 2011; Fairhead et al., 2012; Garnett et al., 2018; Kabra, 2019; Siurua, 2006). Critics, however, argue that 'fortress' models of conservation ignore that these communities 'have historically acted to help create the very "wilderness" that outsiders seek to preserve in their *removal*' (Robbins, 2011, p. 177).

Today, it is estimated that one-third of the world's forests are primary forests[1] (FAO and UNEP, 2020); and although Indigenous People represent less than 5% of the global population, their territory[2] 'accounts for 37 per cent of all remaining natural lands across the Earth' (Garnett et al., 2018, p. 370). With regards to carbon sink, it is estimated that 'at least 293,061 million metric tons of carbon (MtC) are stored in the collective forestlands of Indigenous Peoples and local communities' (Rights and Resources Initiative, 2018). Furthermore, research has shown that deforestation rates are substantially lower in community forests with strong legal recognition than in forests outside of such areas (Stevens et al., 2014). Research comparing deforestation rates in protected areas versus community-managed forests in tropical regions also indicated that the latter presents lower rates of deforestation (Porter-Bolland et al., 2012). All these data provide compelling evidence of Indigenous and rural communities' ability to care for and preserve forests. Therefore, it can be argued that it is the kind of management and intensity of human activity 'rather than the presence of people per se that matters most to the conservation of a primary forest' (Kormos et al., 2018, p. 32).

Critics claim that financial incentives to preserve forest carbon sinks risk reproducing a (neo)colonial model of fortress conservation, which strictly prohibits user access to basic natural resources and is commonly enforced by military and paramilitary forces (Brockington, 2002;

Büscher & Whande, 2007). It also exposes territories to new forms of green grabbing that exacerbate violence against Indigenous and rural communities. *Green grabbing* is a phenomenon that builds upon a long history of colonial practices of resource alienation in the name of environmental protection. This is a critical concept that sheds light on practices of natural resources appropriation, which are common to fortress conservation and can be inflated by discourses of crisis, resource scarcity and security (Corson et al., 2013; Dunlap & Fairhead, 2014; Fairhead et al., 2012; McLeman & Gemenne, 2018; Vigil, 2018).

In this respect, the UN's programme for Reducing Emissions from Deforestation and Forest Degradation (REDD+) has been accused of aggravating land conflicts by: (a) restricting community access to forest resources and/or displacing them from their territories (Asiyanbi, 2016; Beymer-Farris & Bassett, 2012; Dowie, 2011), (b) exposing communities to 'carbon cowboys'[3] pressure (Aguilar-Støen, 2017; De Jong et al., 2014; Lipset & Henning, 2017), (c) provoking intra–and inter-community conflicts between supporters and opponents of carbon-trading schemes (Huni Kui, 2014; Griffiths & Martone, 2009), (d) promoting the recentralisation of forest governance and loss of traditional forest management systems, knowledge and institutions (Bayrak & Marafa, 2016; Phelps et al., 2010) and (e) denying communities their right to self-determination by failing to involve them effectively or by failing to protect their right to Free, Prior and Informed Consent (Fontana & Grugel, 2016; Sarmiento Barletti & Larson, 2017; Tan et al., 2010).

Additionally, in many cases, REDD's promises to alleviate poverty have not materialized, or have only partially materialized, since financial gains are mostly captured by elites (landowners or intermediaries) rather than the communities who bore the greatest costs (Chomba et al., 2016; Kemerink-Seyoum et al., 2018; Paladino & Fiske, 2017). Not to mention that such financial incentives might backfire as a 'perverse incentive' when 'expectations of conservation payments prompt states or landholders to threaten to engage in more deforestation' (McAfee, 2017, p. 51). Finally, the requirement for carbon credit-generating projects through conservation to demonstrate 'additionality' can result in an overestimation of potential deforestation or forest degradation in the absence of such projects (Gifford, 2020). This may also lead to inaccurate depictions of forest dwellers as environmental destroyers, which need to be re-educated by such projects or controlled through government intervention.

Critics to exclusionary models of conservation emphasize that conservation programmes must reconcile legitimate community claims and rights with biodiversity and environmental conservation goals (Lele et al., 2010). As part of the Cancun Agreements in December 2010, social safeguards such as tenure security and effective participation were incorporated into carbon policies (Chhatre et al., 2012). However, safeguard commitments are not always met (Poudyal et al., 2016; Sunderlin et al., 2014). A strong forest conservation approach should incorporate the socio-cultural and livelihood needs of local communities (Porter-Bolland et al., 2012), not only protecting but establishing, strengthening and securing communities' rights (Ribot & Larson, 2012).

3. Carbon-centric conservation policies do not address the root causes of deforestation.

Commodity-driven deforestation continues to be the main cause of forest loss, primarily agricultural expansion (e.g., cattle ranching, soya bean and oil palm cultivation), but also timber and paper industries, illegal logging and mining (Branford & Torres, 2018; FAO and UNEP, 2020). Yet, carbon-centric conservation strategies have done very little to limit or eradicate such driving forces. Financial incentive-based programmes, such as UN-REDD, are unable to compete with the huge profits generated by agrobusiness and extractive industries. As a result, they tend to insert themselves in areas of subsistence or low-income-producing activities where carbon credits can be generated at the lowest possible cost (McAfee, 2017). That is, the demand to cut carbon emissions is being pushed to the periphery of the carbon-emitting problem, with communities bearing the burden of having to adapt in order to compensate for large corporations' highly polluting habits. Success stories about carbon funding assisting communities in establishing sustainable practices (Robinson et al., 2016; World Bank, 2021b) gloss over the fact that these communities were never at the epicentre of the carbon emission problem.

Furthermore, forest carbon conservation projects have been criticized for 'leakage'—which occurs when destructive activities are shifted from one site to another (McLeman & Gemenne, 2018; Yu et al., 2021). Rather than an error of implementation, critics argue that the relocation of ecologically damaging activities is a defining feature of the neoliberal conservation approach. For instance, Büscher et al. (2012) point out that neoliberal conservation and environmental degradation are two sides of the same coin, with conservation in one area justifying degradation in another. Sullivan (2013a, p. 80) further explains that the neoliberal logic of 'equivalence' and 'tradability' of nature 'enable the apparently unavoidable harm caused by development to be exchanged for investment in conservation activities both at different geographical locations and in the future'.

Thus, neoliberalism sustains itself by producing disparities in environmental burdens across geographical regions and generations—forming a mosaic of conservation and sacrifice zones. The burdens of both conservation and pollution tend to be disproportionally loaded onto economically poorer regions (McAfee, 2017; Robbins, 2011). Ecosystems and communities in sacrifice zones bear an exorbitant amount of the socio-ecological harm created by heavy industry (Scott & Smith, 2016), while those in conservation areas are alienated from basic livelihood resources in the name of environmental protection (Brockington, 2002; Shanker et al., 2017). This duality of conservation and pollution is evident in the carbon market approach, which allows for the continuance of carbon emissions in one location while preserving forest carbon sinks in another. As a result, carbon-centric conservation programmes have failed to address the driving causes of deforestation while also allowing forest preservation in one place to be used to forgive the 'sins' of carbon emissions in another (Murray & Dey, 2009).

4. Forest conservation alone cannot fix global warming.

Avoiding deforestation both reduces and offsets CO_2 emissions, but it cannot bring atmospheric GHG concentrations to safe levels on its own. It is estimated that deforestation accounts for 2.2% of global CO_2 emissions (Ritchie & Roser, 2020). This proportion of emissions can be averted by preventing deforestation, and a portion of emissions from other sectors can be absorbed by preserved carbon sinks. However, forests' carbon sinks are not infinite; they eventually reach a point of saturation (Nabuurs et al., 2013; Zhu et al., 2018). Therefore, even if deforestation is eradicated, it is unreasonable to expect forests to absorb a significant proportion of the remaining 97.8% of global CO_2 continuously emitted by business-as-usual in other sectors of the economy. For this reason, critics advocate that the conservation of forests' carbon sinks should not excuse or delay action to cut carbon emissions from other sectors (Bissell, 2020). Furthermore, forests' carbon sinks are vulnerable to human and natural disturbances (Fuss et al., 2018), and, as climate change advances, they become increasingly unstable due to more frequent fires, droughts, tropical storms and floods (Dale et al., 2001; Lindner et al., 2010; Seidl et al., 2017). Hence, if forest conservation policies are traded off and delay emission reduction in other sectors, they fail to effectively protect forests.

4 | Forests as a carbon removal device

Trees remove carbon from the atmosphere through photosynthesis; therefore, planting more of them is a nature-based mechanism of carbon dioxide removal. As a result, AR[4] schemes have attracted substantial incentives around the world in the context of climate change mitigation (Bäckstrand & Lövbrand, 2006). Planting trees, however, does not always help mitigate climate change and can have a detrimental effect on ecosystems and the populations who rely on them. This review identifies and explores three major criticisms levelled against carbon-centric AR schemes:

1. Selling carbon does not save forests.

Following on from the idea that nature is degraded because it is considered to be a 'free gift', the economic valuing of natural resources and services has emerged as a neoliberal solution to the environmental crisis (Foster & Clark, 2018). Underlying this neoliberal trend is the assumption that once nature is adequately priced and brought into international commodity circuits, it will be used and managed more efficiently. In other words, if nature had a monetary worth, it would be valued and safeguarded (Igoe, 2017). McAfee has referred to this idea as *selling nature to save it*, whereby nature is expected 'to earn its own right to survive in a world market economy' (1999, p. 134).

Following this rationale, nature is fragmented into differentiated environmental goods and services that need to be marketized to their (potential) clientele in new international environmental markets (Büscher & Whande, 2007). In this way, nature's very existence depends on market demand and financialisation (McAfee, 1999; Sullivan, 2013b). Nature needs to earn its own right to survive by producing new commodities (e.g., carbon credits, natural resources, environmental services and touristic attraction). Thus, nature itself is increasingly shaped by market interests—which means that only the most economically valuable kind of nature (i.e., ecosystems and species) are likely to survive. That is, it 'breaks nature into measurable components while financial mechanisms protect only the parts capable of generating income' (Finley-Brook, 2017, p. 76).

The carbon market is the most prominent example of this marketisation of nature in the forestry sector. Carbon credits can be generated by either removing CO_2 from the atmosphere, for instance, by planting trees, or avoiding CO_2 emissions, for instance, by conserving trees that would otherwise be chopped down. It has, however, been heavily criticized.

To begin, some scholars assert that nature embodies a multiplicity of intrinsic and instrumental values that cannot be reduced to a single function or measured in monetary terms (Dobson, 2000; Fox, 1995). For example, 'the price of a tree log captures only its value on the timber market but omits the value of its fruits (as food to humans and/or other animals) and that of its leaves (as organs to fix carbon), which were sacrificed when the tree was logged' (Deb, 2014, p. 152). Furthermore, the valuation of forests based on a single exchange value (carbon credits) 'could lead not only to environmental degradation but also to cultural and social deterioration of many indigenous and local communities who perceive forests in a holistic and complex way which go beyond carbon and monetary fixation' (Bayrak & Marafa, 2016, p. 13).

Additionally, carbon accounting issues arise as a consequence of a lack of scientific knowledge and technological constraints in quantifying the amount of carbon stored or emitted as a result of a given activity (Gilbertson & Reyes, 2009; Murray & Dey, 2009; McAfee, 2017; van Kooten et al., 2015). Carbon accounting methods, which are generally regarded as objective science, 'are in fact deeply political' (Gifford, 2020, p. 293). That is, carbon cannot be precisely measured; instead, it is estimated using a variety of methods subject to economic and political influence. Without reliable carbon measurements, customers frequently underestimate their overshooting emissions, while carbon credit providers exaggerate their offsetting accomplishments (Lippert, 2017). Along with imprecise accounting, the carbon market has been compromised by irregular credit certification and double counting schemes (Böhm & Dabhi, 2009; Elgin, 2021). Last, carbon accounting errors occur not only in the carbon market but also in estimates of wood substitution for other materials and fossil fuels (DeCicco et al., 2016; Haberl et al., 2012; Harmon, 2019; Howard et al., 2021; Leturcq, 2020; Searchinger et al., 2009).

The effectiveness of carbon credit supply schemes has also been called into question based on the criteria such as leakage, permanence and additionality (Bayrak & Marafa, 2016; Gilbertson & Reyes, 2009; McAfee, 2017). The leakage criteria refer to the potential shift of economically harmful activity from one location to another (Yu et al., 2021). The permanence criteria refer to the uncertainty about whether forests will store carbon on the long-term or only temporarily—due to future human interferences or natural disasters (Galik & Jackson, 2009). The additionality criteria refer to the possibility that carbon credit-generating projects may not actually decrease or offset emissions but rather profit from reduction/offsetting activities that would have occurred regardless of additional incentives such as REDD+ payments (Bayrak & Marafa, 2016).

Furthermore, as presented in the previous section, neoliberal market incentives to preserve forests' carbon sinks have led to new forms of fortress conservation and green grabbing. Likewise, AR projects as a carbon credit-generating enterprise and climate change mitigation policy have exacerbated land grabs in regions of property rights insecurity (Lyons & Westoby, 2014; Richards & Lyons, 2016; Scheidel & Work, 2018).

Carbon trading was intended as a last resort to cope with failed efforts to cut emissions. However, due to the low cost of carbon credits, many businesses have found that purchasing them is more cost-effective than reducing GHG emissions. For this reason, Bigger (2017, p. 120) argues that 'what started as a market with potential to make "polluters pay" (…) was transformed to a market where "pay to pollute" became the operating principle'. Despite that, even if the carbon market functioned as intended, it would not play a significant role in reducing emissions (Pearse & Böhm, 2014). As MacAfee (2017, p. 49) points out 'no matter how efficient carbon offset markets might become, the buying and selling of offset credits, in itself, does nothing to stop the production and release of GHGs'.

2. Planting trees is not always good for the environment.

Climate change mitigation measures and carbon market incentives, as well as the lumber and bioenergy industries, have all contributed to the current tree-planting frenzy (Lewis et al., 2019; Murray & Dey, 2009; Scheidel & Work, 2018). Ecologists and biologists, on the other hand, have cautioned that planting trees is not necessarily beneficial to the environment. Savannas, grasslands and peatland habitats, for example, do not benefit from tree-planting (Abreu et al., 2017; Parr et al., 2012; Payne et al., 2018; Veldman et al., 2015). Planting dark-leaved trees (pinewood) in temperate zones reduce sunlight reflection (albedo effect), which may contribute to climate warming rather than mitigate it (South et al., 2011). Furthermore, experts warn that unclear definitions of what constitutes a 'forest' endanger biodiversity (Bayrak & Marafa, 2016; Vigil, 2018), and a focus on carbon can also jeopardize the conservation of low-carbon density ecosystems due to reduced protection and financial assistance (Duque et al., 2014; Putz & Redford, 2009).

The UN agency on Food and Agriculture Organisation (FAO) loosely defines forests as 'land spanning more than 0.5 hectares with trees higher than 5m and canopy cover of more than 10%', thus enabling monocultures to be classified as forests. This lack of differentiation between native biodiverse forests and monoculture plantations might obscure global forestland changes that threaten biodiversity (Hall et al., 2012; Robbins & Fraser, 2003). In China, for example, this lack of differentiation has resulted in 'a paradox between a continuing decline in the area covered by natural forests and an increase in overall forest cover' (Zhai et al., 2017, p. 149) as a consequence of the expansion of rubber plantations. In the context of climate change mitigation, policymakers mislead the public by promoting monoculture plantations of economically relevant species (like eucalyptus and palm oil) as 'forest restoration'. For instance, in the Bonn Challenge, a global climate goal to restore 350 million hectares of forest by 2030, '45% of all commitments involve planting vast monocultures of trees as profitable enterprises' (Lewis et al., 2019).

Critics object to commercial plantations being justified on carbon grounds since they are not a long-term carbon sink (Barkham, 2020; Lewis et al., 2019). Increase in *tree cover* area (as a result of forest conversion to plantations) can also have a detrimental effect on soil carbon stock (Hall et al., 2012). Furthermore, commercial plantations can impoverish the soil due to the disruption of nutrient cycling and drain nearby rivers and lakes due to intense water consumption (Jackson et al. 2005; Liao et al., 2010; Montagnini, 2000; Zhang, 2020).

On the other hand, AR schemes where natural secondary forest was (re)established have shown an increase in both above- and below-ground carbon storage (Hall et al., 2012) and provide additional social and environmental benefits—such as improved habitat quality, increased resilience to climatic perturbations, diseases and pests and a broader range of subsistence and recreational opportunities (Fuss et al., 2018). In short, AR initiatives focused exclusively on increasing carbon storage are likely to have detrimental social and environmental side effects, whereas a wider framework for decision making could maximize the overall benefits that AR projects can deliver (Greve et al., 2013).

3. Carbon offsetting should not be allowed to greenwash emissions.

Carbon markets are today the largest environmental market operating through offsetting schemes. As already explained, carbon credits may be produced for this market in two ways: by removing carbon from the atmosphere (e.g., tree-planting) or by reducing carbon emission through avoided deforestation or the so-called green developments (e.g., wind farms or hydro dams). The term 'offsetting' refers to the use of such credits to balance out carbon emission elsewhere (Hyams & Fawcett, 2013). In other words, 'offsetting' refers to the use of an environmentally positive activity—such as removing or reducing CO_2 emissions—to compensate for a deemed 'equivalent' environmental harm (i.e., CO_2 emissions). This matching up of environmental harm with offsets generates what is referred to as neutrality (Murray & Dey, 2009).

The notion of environmental offsets is predicated on the belief that nature everywhere is of equal and tradeable worth. This belief allows nature to be gambled within an 'economy of repair' whereby 'unsustainable use "here" can be repaired by sustainable practices "there", with one nature subordinated to the other' (Fairhead et al., 2012, p. 242). This idea contributes to framing ecological harm as 'unavoidable' and legitimate as a 'right to pollute' in order to promote development (Gilbertson & Reyes, 2009; Sullivan, 2013a). As a result, the debate shifts from a precautionary approach focused on avoiding harm to a reparative philosophy centred on mitigating and compensating for harm. Thus, 'offsetting' harm becomes as acceptable as doing no harm. However, offsets cannot occur until harm is inflicted; if offsets are deemed as good as no harm, then environmental harm loses importance.

Owing to this offsetting logic, ecologically damaging activities that contribute to economic development and growth are deemed compatible with environmental protection and so permitted to be 'safely' continued (Coralie et al., 2015; McAfee, 2017). In other words, instead of promoting the discontinuation or transformation of environmentally harmful activities, this logic allows such activities to continue as if they were perfectly environmentally sound. Not only that but environmental harm is sometimes deemed necessary to finance environmental protection (McAfee, 2017).

Because such offset transactions generally involve different actors from distant geographic regions, they have been heavily criticized, mostly on the grounds that offsets do not equal reductions in one's own emissions. Fundamental ethical principles hold that polluters should not be excused from their responsibilities to reduce their own emissions based on their capacity to pay others to compensate for them (Hyams & Fawcett, 2013; Murray & Dey, 2009). In other words, environmental responsibilities cannot be outsourced. Furthermore, such arrangements can exacerbate injustices between rich and poor regions (McAfee, 2017). Meanwhile, there is the risk that promises that carbon emissions would be offset elsewhere or in the future could stall local and immediate emission reductions (Gilbertson & Reyes, 2009; Paladino & Fiske, 2017).

Overall, the equivalence between direct emission reductions and offsets obscures fundamentally different interests and outcomes. While keeping global temperature increase below 1.5°C requires both reducing emissions and removing CO_2 from the atmosphere, experts suggest that reduction and removal objectives should be handled separately (Meyer-Ohlendorf, 2020). This is because removals are undoubtedly less reliable at tackling climate change than emission reductions.

5 | Forests as net-zero bioenergy devices

In addition to market instruments, carbon management policies have made substantial investments in technological innovation to reduce and remove CO_2 emissions. Both the Kyoto Protocol and the Paris Agreement emphasize the need of developing and transferring innovative technology to allow climate change mitigation and adaptation. In fact, a commonly held belief is that technological innovation in energy and carbon management will be the primary mechanism to tackle climate change, 'despite well-established recognition of the critical need for social, cultural, and institutional changes in reducing fossil-fuel reliance' (Stephens & Markusson, 2018, p. 503). This review identifies and discusses three major critiques of using forest biomass in bioenergy schemes to reduce CO_2 emissions and in geoengineering technologies to remove CO_2 from the atmosphere:

1. Bioenergy (biofuels and biomass) is not carbon neutral.

Bioenergy has been encouraged by policies around the world, resulting in an unprecedented expansion in production (Popp et al., 2014; Robledo-Abad et al., 2017). This has occurred as a result of bioenergy's reputation as a renewable and carbon-neutral alternative to fossil fuels, as well as its compatibility with existing infrastructure and engines (primarily heat and transport systems). Additionally, bioenergy serves as the foundation for BECCS, which has become the main technological proposal to 'fix' global warming.

Bioenergy is frequently described as carbon neutral because it belongs to the fast carbon cycle, while fossil fuels belong to the slow carbon cycle (Riebeek, 2011). However, such a presumption of neutrality has been widely criticized as an accounting error (DeCicco et al., 2016; Haberl et al., 2012; Searchinger et al., 2009). Critics argue that despite its difference in origin, the combustion of biofuels and biomass takes captured carbon and emits CO_2 into the atmosphere in the same way that fossil fuels combustion does. Even if the combustion of biofuels and biomass is considered 'carbon neutral' due to carbon capture during co-incident re-growth, its production process is not. The bioenergy supply chain generates emissions through direct and indirect land use change, the use of agrochemicals, transportation, processing and storage (Doornbosch & Steenblik, 2008; Fargione et al., 2008; Johnson, 2009; Melillo et al., 2009; Röder et al., 2015; Searchinger et al., 2008; Zanchi et al., 2012).

Besides, not only does the combustion of biofuels/biomass release carbon, but it also emits other pollutants in similar or greater quantities, compared to fossil fuels (Wielgosiński et al., 2017). As a result, it not only contributes to global warming but also causes air pollution, which has negative health impacts (Buonocore et al., 2021; Feng et al., 2021). Needless to add, these pollutants are also harmful to the health of fauna and flora (Catcott, 1961; Ghorani-Azam et al., 2016; Manisalidis et al., 2020).

Today's incentives for bioenergy development and production are often justified as a green substitute for fossil fuels; nevertheless, there is debate over whether bioenergy has successfully replaced fossil fuel consumption or merely supplemented it. Hickel (2020) argues that at local levels, bioenergy has in some cases displaced fossil fuels, but at a global scale, growth in energy consumption is outpacing growth in renewable capacity. As York and Bell (2019) point out, the development of new energy sources has historically resulted in energy *additions* rather than energy transitions from older sources. Energy additions are often justified on the basis of the need to further development and alleviate poverty. However, without governmental intervention, it is unlikely that significant disparities in energy consumption between and within countries will be reduced (Lawrence et al., 2013).

While biofuels/biomass are renewable, they are hardly a healthy or eco-friendly alternative. Nonetheless, bioenergy has the potential to play a significant role in the transition away from fossil fuels. Serious environmental and ethical concerns, however, regarding its production and combustion, must be addressed. Biofuels/biomass production should be better regulated and aligned with broader food, water and biodiversity conservation concerns. Furthermore, its combustion should be limited and safety improved. Transitioning to a just and sustainable energy supply system will require more than the replacement of fossil fuels by renewable energy sources, it will require the implementation of energy usage caps and redistributive reforms—to address overconsumption and energy poverty.

2. BECCS is still unproven, expensive and energy intensive.

Today, there is significant interest in the possible application of biofuels and biomass in negative emission technologies (NETs), such as BECCS—which is the most discussed geoengineering proposal at the moment (Fuss et al., 2016; Heck et al., 2018; Minx et al., 2018). Among the pathways presented by the 2018 IPCC, around 87% of its scenarios consistent with 2°C and 100% of those consistent with 1.5°C require the large-scale deployment of NETs (Lenzi, 2018). This overreliance on NETs overlooks significant uncertainties that exist in all of these technological proposals, 'including supply (the actual negative emissions potential that can be realized), demand (the negative emission requirement to achieve a climate target), and implications (the intended or unintended socio-economic and environmental costs and consequences of deploying large-scale NETs)' (Fuss et al., 2016, p. 2).

Most IPCC scenarios rely on large-scale CO_2 removal from the atmosphere 'almost exclusively with BECCS' (Minx et al., 2018, p. 17). This can be explained in part by BECCS's added advantage of generating energy as well as removing carbon, whereas other NETs only remove carbon

(Fuss et al., 2016). There is also interest in using the carbon captured for other purposes, such as enhanced oil recovery (Burns & Nicholson, 2017) and to generate carbon credits for business-as-usual (Cunha, 2015). However, there are still concerns regarding the safety of injecting compressed carbon into vacant chasms of oil and gas deposits, deep saline formations or the deep ocean floor—all of which might leak (Schwarz-Herion, 2018; Stephens & Markusson, 2018). Moreover, BECCS processes of carbon capture, compression, transportation and injection are still expensive and energy-demanding, whereas 'scientific assessments vary widely in their estimates of [BECCS'] carbon benefit' (Fuss et al., 2016, p. 4).

Overall, the main criticism directed towards NETs is that they have been used to divert attention away from short- and medium-term emission reductions, with the promise that future technology would be able to offset anything. The belief that there are no limits to technological development and that future technology will solve all our problems is known as t*echnological optimism* or *fetish of technology*. Critics of such belief emphasize the need to recognize that technological development is not apolitical nor is it a soloist agent independent from socio-economic-environmental institutions and forces (Barry, 2016; Harvey, 2003; Stephens & Markusson, 2018). In this regard, Carton et al. (2020, p. 1) shed light on 'the irreducibly political character of carbon removal imaginaries and accounting practices', which gloss over critical perspectives and historical failures on the subject.

Given the uncertainties, governments should minimize their reliance on NETs to meet climate targets; however, NETs have become the preferred mitigation strategy (Minx et al., 2018). The prospect of NETs has been exploited as a justification to transfer the burden of climate change mitigation onto future generations when an improbable technological 'magic wand' is expected to become available.

3. Bioenergy production puts further strain on other land uses, biodiversity and community rights to property.

Aside from its contested technological carbon-saving potential, bioenergy production has raised major concerns about land grabs (Aha & Ayitey, 2017; Neimark, 2016) and land-use competition (Erb et al., 2012; Fuss et al., 2018), which can lead to food price increases (Ciaian, 2011), threats to biodiversity (Fargione et al., 2008; Ferrante & Fearnside, 2020) and cause water shortages (De Fraiture et al., 2008). The large-scale production of biofuels necessary to replace fossil fuels and of biomass to meet BECCS demand entails 'trade-offs between positive impacts on the economic category and negative impacts on the environmental and social categories' (Robledo-Abad et al., 2017, p. 553).

Bioenergy was originally intended to be used on a limited scale. However, large-scale production of biofuels (ethanol from maize and sugarcane and biodiesel from soy, rapeseed and oil palm) and biomass (wood pellets, wood chips and other types of dry biomass) has grown globally—contributing to deforestation and land-rights conflicts (Aha & Ayitey, 2017; Danielsen et al., 2009; Fargione et al., 2008; Neimark, 2016; Searchinger et al., 2008). FAO (2016, p. 1) highlights that 'wood pellets production has increased dramatically in recent years, mainly owing to demand generated from bioenergy targets set by the European Commission'. Additionally, the use of wood for fuel displaces demand for timber elsewhere, resulting in further forest loss and increased demand for commercial plantations.

Estimations suggest that BECCS deployment would 'require between 0.4 and 1.2 billion hectares of land (25% to 80% of current global cropland)' (Fajardy et al., 2019, p. 3). Such large-scale plantations have the potential to disrupt ecosystems and biogeochemical cycles, increasing demand for chemical fertilisers and pesticides, which would further impair soil quality, water supply, biodiversity and human health (Burns & Nicholson, 2017; Dyke et al., 2021; Heck et al., 2018). In fact, when biophysical metrics are examined, climate change mitigation strategies that rely on future high yields of bioenergy and NETs become unrealistic (Creutzig, 2016).

The numerous social and environmental controversies surrounding the conversion of vast swathes of land to bioenergy production, as well as dubious carbon neutrality assumptions and the technological optimism underlying unproven NETs, suggest that these technocratic strategies act more as justification for continuing business-as-usual than as genuine efforts to address climate change concerns.

6 | DISCUSSION AND CONCLUSION

This article reviewed the literature on forest-based 'carbon-fix' strategies focusing on identifying, analysing and integrating critiques levelled against such strategies with the aim to clarify concerns and facilitate further debate. Overall, critiques against 'carbon-fix' strategies teach us that we must avoid setting the wrong incentives and negotiating delayed action. They suggest that forests can and should contribute to climate change mitigation, however, not within this narrow framework that reduces them to 'carbon-fixing' devices. Forest conservation and restoration projects are vital to ensuring the health of fundamental ecosystem functions, preserving biodiversity and protecting the livelihood of forest-dependent communities.

By placing a narrow carbon view at the centre of debates, the hegemonic discourse in climate policy has turned carbon into a diversion from the underlying systemic causes of the current planetary emergency—which negative ramifications go beyond global warming. In this context, forests have been used as 'carbon-fixing' devices—a function that shields our fossil-based economy from pressures for change, thus serving the interests of carbon-emitting elites. Critics, however, assert that carbon 'fixes' are only partial and temporary and have the potential to deepen other socio-environmental issues (Stephens & Markusson, 2018). If climate policies ignore the need for deeper politico-economic change and the trade-offs and conflicts emanating from existing 'carbon-fix' strategies, then a just transition is unlikely.

As MacKenzie & Pritchard (2021) assert, using forest as 'carbon-fixing' devices 'becomes unjust when it involves asking poorer rural people to compromise their livelihoods so that wealthier people or nations can continue to consume fossil fuels'. Restricted access to forest resources, community displacement, green grabbing and cultural assimilation are examples of such compromises. Using forest as 'carbon-fixing' devices also becomes ecologically harmful when carbon capture, storage and bioenergy production overshadow other environmental values and concerns, like fauna and flora biodiversity, ecosystems' integrity and when direct action to reduce GHG emissions is delayed.

While social issues (e.g., exclusion, land grabs and elite capture) and environmental issues (e.g., biodiversity loss, soil depletion and water shortages) are not representative of all existing REDD+, AR and net-zero projects, critics call into question not only the social and environmental harms that can occur as a result of their 'bad' implementations but the very design of such strategies—which focus on offsetting environmental harm as compensation for ongoing emissions rather than directly reducing emissions. That is, critiques on a deeper level contest whether these 'carbon-fix' strategies are the best way to address climate change.

Far from contesting the need to reduce atmospheric GHG concentrations and the pivotal role forests can play in doing so, critiques denounce academic oversimplifications, trade-offs, leakages, ethical concerns and political bias and inertia. They convey that forest-based 'carbon-fix' strategies are problematic not only due to implementation errors but also due to baseless assumptions built into their proposals and for downplaying other concerns such as biodiversity loss and human and land rights violations. However, acknowledging badly designed strategies and/or badly implemented projects does not negate the importance of forest conservation, restoration, governance and technological innovation in mitigating the problems we currently face and in fostering a more environmentally and socially sound future.

This paper contends that persistent optimism for 'carbon-fix' strategies such as BECCS, REDD+ and carbon markets conceals their overall failure to address climate change and broader environmental degradation (Ritchie & Roser, 2020). The potential impact of these 'carbon-fix' strategies is limited by their shielding of the root causes of the problem. In this sense, critics fundamentally oppose the instrumentalisation of forests as a palliative carbon mitigation strategy, which maintains business-as-usual and reproduces unjust practices of resource appropriation and environmental subjugation and overexploitation.

Based on the critiques discussed in this article, some recommendations for future research, policy and operations are made. In a departure from elitist policy-finance-technology solutions, it is crucial to ensure that coordinated action across multiple sectors is taken to cut carbon emissions, limit atmospheric GHG concentrations to safe levels and mitigate the harmful effects of climate change (which can no longer be avoided). This means that action in the forestry sector should not be used to justify or compensate for inaction in others. In place of the current soft law of international agreements, policies should: (i) promote direct regulatory control of the main drivers of emissions; (ii) impose financial penalties for overshoots (with increasing value for re-incidences); (iii) redirect subsidies from polluting activities (like fossil fuels, plastics, cement, mining, cattle ranching and agrochemical-intensive agriculture) to restorative activities like community-led forestry, small local agriculture and clean energy and (iv) better articulate action across sectors and world regions (to prevent leakages and political inertia). Furthermore, forest conservation, restoration and governance must be better planned, implemented and monitored in order to combat and prevent the social and environmental issues outlined in this article. They must recognize the rights of Indigenous and local communities, and their demands for demarcation/landownership, in order to conserve, restore and govern local forests, protecting them from land grabbing. They must also recognize the social and environmental value of forests beyond a carbon-fix agenda and make appropriate choices for different biomes—taking into consideration adaptative/resilience needs to those (no longer avoidable) climate change impacts. Finally, to develop more robust strategies for addressing the current planetary emergency and devise policies for managing forests in a just and environmentally sensitive manner, we need a transdisciplinary research agenda (to avoid oversimplifications and trade-offs), as well as more inclusive public dialogue (to confront ethical concerns and political biases).

NOTES

[1] FAO defines primary forests (or old-growth forests) as undisturbed naturally regenerated forest of native tree species. The composition of the remaining two-third of the world's forests is not clear; however, it should be highlighted that FAO does not differentiate commercial plantations from forests.

[2] These data encompass areas where Indigenous Peoples live and exercise substantial influence on land management, regardless of land tenure being officially recognized.

[3] The term 'carbon cowboys' refers to companies acting as intermediaries in carbon credit selling deals.

[4] Afforestation refers to planting trees on historically unforested land (> 50 years), whereas reforestation refers to replanting on areas recently deforested (< 50 years; Fuss et al., 2018).

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DATA AVAILABILITY STATEMENT

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