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ADVANCED REVIEW

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Negative emissions and the long history of carbon removal

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Abstract

Recent IPCC assessments highlight a key role for large-scale carbon removal in meeting the objectives of the Paris Agreement. This focus on removal, also referred to as negative emissions, is suggestive of novel opportunities, risks, and challenges in addressing climate change, but tends to build on the narrow techno-economic framings that characterize integrated assessment modeling. While the discussion on negative emissions bears important parallels to a wider and older literature on carbon sequestration and carbon sinks, this earlier scholarship—particularly from the critical social sciences—is seldom engaged with by the negative emissions research community. In this article, we survey this "long history" of carbon removal and seek to draw out lessons for ongoing research and the emerging public debate on negative emissions. We argue that research and policy on negative emissions should proceed not just from projections of the future, but also from an acknowledgement of past controversies, successes and failures. In particular, our review calls attention to the irreducibly political character of carbon removal imaginaries and accounting practices and urges acknowledgement of past experiences with the implementation of (small-scale) carbon sequestration projects. Our review in this way highlights the importance of seeing continuity in the carbon removal discussion and calls for more engagement with existing social science scholarship on the subject. Acknowledging continuity and embracing an interdisciplinary research agenda on carbon removal are important aspects in making climate change mitigation research more responsible, and a precondition to avoid repeating past mistakes and failures.

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carbon accounting, carbon removal, carbon sinks, climate change mitigation, negative emissions

1 | INTRODUCTION

Large-scale carbon removal, also referred to as negative emissions, has recently gained attention as a key component of climate change mitigation pathways that limit warming to 1.5 or 2°C (IPCC, 2014, 2018). First put forward in techno-economically focused integrated assessment models (IAMs) (Azar, Lindgren, Larson, & Möllersten, 2006; Kriegler et al., 2014; Kriegler, Edenhofer, Reuster, Luderer, & Klein, 2013; Van Vuuren et al., 2007), there is now an extensive literature that explores the potential opportunities, risks and trade-offs of relying on negative emissions (Buck, 2016; Dooley, Christoff, & Nicholas, 2018; Fuss et al., 2018; Gough et al., 2018; Heck, Gerten, Lucht, & Popp, 2018; McLaren, 2020; Williamson, 2016), maps the various feasibility concerns involved (Forster, Vaughan, Gough, Lorenzoni, & Chilvers, 2020; Hansson et al., 2019; Vaughan & Gough, 2016; Waller et al., 2020), or seeks to understand how IAMs came to rely so heavily on negative emissions in the first place (S. Beck & Mahony, 2017, 2018b; Geden, 2016; Haikola, Hansson, & Fridahl, 2019; Workman, Dooley, Lomax, Maltby, & Darch, 2020). Private sector actors have started taking an interest (Carbon Engineering, 2019; Shell, 2019; B. Smith, 2020), and a number of governments are moving to include negative emissions into climate and energy policies (Carbon Capture Coalition, 2019; Karlsson, 2020).

This emerging conversation is interesting not just for what it says, but also for what it remains silent on. In its current form, the negative emissions literature is distinctively forward-looking and hypothetical, defined by the outcomes of scenario analyses and therefore focused mainly on future risks and conditions. While this has informed a rich debate on the feasibility and desirability of different mitigation pathways—and on how and by whom these are constructed—there has been far less focus on stocktaking or efforts to learn from real-world experiences with carbon removal. This is despite the fact that many of the "technologies" now put forward under the guise of negative emissions—primarily bioenergy with carbon capture and storage (BECCS) and afforestation and reforestation (AR) (IPCC, 2018)—have been around for a considerable time, either in toto or, like BECCS, in their composite parts. More generally, the enhancement of carbon sinks has been a policy objective and a coveted offsetting strategy at least since the negotiation of the Kyoto Protocol (Boyd, Corbera, & Estrada, 2008; Lövbrand, 2004). It has given rise to extensive discussions and controversies, sparked various governance initiatives and led to the implementation of numerous projects, particularly in the global South.

The silence on these historical carbon removal experiences is remarkable, all the more so because scholarship on these subjects is extensive. The risks and trade-offs with carbon sequestration projects in the global South, for example, are well documented (Asiyanbi & Lund, 2020; Corbera & Friedli, 2012; Leach & Scoones, 2015), yet for the most part this literature is ignored in ongoing negative emissions research. Since most of this research is carried out in the (critical) social sciences, this translates into an underestimation of the social science research that is relevant to this conversation. A comprehensive survey of the negative emissions literature for example concludes that "[t]he social sciences and humanities are crucial for discussions on implementation, ethics and governance among other issues, but NET *[negative emissions technology]* discussions have not yet caught on in these fields" (Minx, Lamb, Callaghan, Bornmann, & Fuss, 2017, p. 4). Yet there *is* a long tradition of social science research on some of the questions that Minx et al. highlight, including the politics and governance of carbon sinks, the justice dimensions of implementing carbon sequestration projects, and the pitfalls of abstract carbon accounting and modeling tools for understanding complex social and ecological dynamics. This literature however does not employ the negative emissions and carbon removal vocabulary and does not (yet) directly speak to the (self-defined) negative emissions literature.

This review article aims to bring some of these social science insights into the negative emissions debate. We suggest that greater engagement with critical research on carbon sequestration and the politics of carbon sinks might help fill the knowledge gap identified by Minx et al. The lessons from earlier experiences with carbon removal directly speak to the present possibilities, limitations, barriers, and conditions for negative emissions and should inform current research and policy promises if we are to avoid repeating past mistakes. A historical perspective moreover helps us understand the continuities and discontinuities in the way negative emissions discourses and practices are unfolding and are an important tool for defining the future research and policy agenda on this topic.

In the next section, we briefly survey the negative emissions literature to illustrate different ways in which it does (not) engage with what we here define as the "long history" of research and societal debates on carbon removal. We then provide a succinct but comprehensive review of de facto carbon removal research within the critical social sciences, drawing out parallels with the negative emissions discussion and the various lessons these hold. Our review is primarily informed by literature in science and technology studies (STS), international relations, geography, critical political economy and political ecology. It is divided up in two main sections, in turn focusing on (a) imaginaries and

accounting practices pertaining to carbon removal; and (b) experiences with the implementation of (small-scale) carbon removal and closely related policies. Each of these sections brings to the fore insights regarding the politics, governance and justice dimensions of carbon removal. In the conclusion, we discuss why the themes and insights we have identified warrant more recognition in future negative emissions research. We end with some thoughts on the need to acknowledge continuities in the negative emissions debate, and the risks and biases that emerge when we face the future without drawing lessons from the past.

The main focus of our review is on land-based carbon removal by way of AR, where we see the largest contribution from the critical social sciences and also the most obvious gap with the negative emissions literature on the topic (Waller et al., 2020). As one of the two NETs that figure most prominently in Intergovernmental Panel on Climate Change (IPCC) assessments, it is also where significant policy and private sector interest on carbon removal is directed. While we do partly engage with insights from, for example, carbon capture and storage (CCS) debates as well, a comprehensive review is beyond the scope of this article (but see for example, Bäckstrand, Meadowcroft, & Oppenheimer, 2011; Bui et al., 2018; Dauvergne & Neville, 2010; Goetz, German, & Weigelt, 2017; Gough & Mander, 2019; Krüger, 2017; Lima & Gupta, 2013). This implies that our conclusions are in the first place applicable to conversations on land-based NETs, whose land-use requirements raise a number of distinctive social, political and ethical questions. That being said, despite the obvious differences between AR and technologies such as direct air capture (DAC) (Minx et al., 2018), many of the broader points raised in this review are relevant for the more industrial removal technologies now being proposed as well.

2 | FRAMING OUT THE PAST IN THE NEGATIVE EMISSIONS CONVERSATION

In the academic literature, the story of negative emissions tends to begin with integrated assessment modeling, that is, the use of coupled socioeconomic and bio-geophysical models to project a range of different mitigation pathways. Acknowledgement of historical experiences with carbon removal is rare in this literature, and when it does occur it is usually with reference to opportunities to learn about the pace of technological change (Nemet et al., 2018; Tavoni & Socolow, 2013) or opportunities to learn about organized opposition to new technologies (Meadowcroft, 2013). This puts the history of carbon removal in service of the aim of upscaling NETs and enabling societal acceptance, reflecting what others have argued is a predominantly instrumental focus in negative emissions research (Markusson, Balta-Ozkan, Chilvers, Healey, & McLaren, 2020; Waller et al., 2020). For example, the first of three review papers published in *Environmental Research Letters* starts with a short history of negative emissions but only briefly touches on proposals to remove CO_2 from the atmosphere during the 20th century (Minx et al., 2018). The review describes the mainstreaming of NETs discussions as a recent development, related to climate change mitigation scenarios from IAMs that feature BECCS (Minx et al., 2018). These scenarios were first summarized in the IPCC's Fourth Assessment Report in 2007, and became a key part of the Fifth Assessment Report. An earlier special issue on negative emissions, published in *Climatic Change*, also links the history of carbon dioxide removal (CDR) to developments in modeling in the Fourth Assessment Report (Tavoni & Socolow, 2013). The introduction piece to this collection does not address prior historical context except to note that "history can help by providing evidence bearing on the time required" for one energy alternative to displace another (Tavoni & Socolow, 2013), a perspective later echoed by Nemet et al. (2018). The exception in this special issue is the piece by Meadowcroft (2013), which observes that AR were already recognized under existing climate agreements, "[l]ong before they were re-conceptualized as forms of "CDR"" (p. 139). Generally, however, this insight is not well integrated into the companion papers or the wider literature on negative emissions, and the discussion on negative emissions tends to center on its representation in models.

There are some notable outliers, mostly in discussions of BECCS that bring up previous experience with both bioenergy and CCS (Buck, 2016; Geden, Scott, & Palmer, 2018; Gough & Mander, 2019; Honegger & Reiner, 2018). There are also a few recent papers which discuss accounting experiences under the clean development mechanism (CDM) (Torvanger, 2019) and accounting rules under land use, land-use change and forestry (LULUCF), reducing emissions from deforestation and forest degradation (REDD+), and CCS methodologies, as well as the political lessons from these struggles over the inclusion of biological carbon sinks (Moe, Røttereng, & J. K., 2018). Few of these papers however engage with or even acknowledge the extensive critical social science literature on these subjects. A recent review of the social and political dimensions of carbon removal for instance incorporates a survey of articles on CCS and flags the relevance of experiences with REDD+, but looks past most of the critical literature on forest-based mitigation, leading the authors to conclude that AR as a carbon removal strategy is under-researched (Waller et al., 2020). Hence, the broad

trend in the scholarly literature on negative emissions is to gloss over previous experiences in climate policy and carbon sequestration, particularly where this concerns critical perspectives and historical failures, and to fail to incorporate empirical work analyzing these experiences. The result is the construction of a seemingly novel research and policy agenda on carbon removal that downplays continuities with the past.

We find something similar in scientific and policy reports, where there is a tendency to construct an open future, focused on the use and scalability of future technologies rather than assessing previous efforts to produce policy for carbon sink enhancement and management. Influential policy reports by the National Academies of Science (2019), the Royal Society (2018) and the European Academies Science Advisory Council (2018) all begin with the Paris Agreement as their framing, and its call to balance sources and sinks. Others, such as those recently published by the Lawrence Livermore National Laboratory (2020) and the World Resources Institute (Mulligan et al., 2020), refer instead to the IPCC's Special Report on 1.5°C and its finding that carbon removal will be required for meeting temperature goals. When previous attempts at sink enhancement are mentioned, they are often brought up in terms of "technology readiness" and the learning that has happened over the past decade, or "scalability and engineering challenges" (The Royal Society, 2018; see also Markusson et al., 2020). Such previous experiences are generally placed inside a "social box," in subsections separate from the assessment of negative emissions potential. This constructs a particular sequencing where technical potentials are reported as if the future is completely open, and then sociopolitical or economic factors are placed on later, as constraints that limit the horizon, or "factors affecting scale up." None of the reports view social processes as part of the enabling environment. Similarly, concerns that may well already be part of past experiences are presented as future hypotheticals. The Royal Society report, for example, notes that "indirect land-use change can involve spatial leakage—efforts to increase or protect forests in one location, without measures to meet demand for crops or ranching for meat, may push up crop and meat prices, increasing deforestation in another location" (2018, p. 82). It does not mention that leakage has been of considerable concern in carbon accounting discussions for more than two decades (Boyd et al., 2008).

A notable exception is the European Academies Science Advisory Council report (EASAC, 2018), which concludes that NETs "offer only limited realistic potential to remove carbon from the atmosphere and not at the scale envisaged in some climate scenarios" (p. 1). Unlike others, the EASAC report highlights specific examples of past challenges and cites a number of studies to point to learning experiences. It also has an appendix that "describes the current slow progress on developing and implementing large-scale CCS, and contrasts this with the scenarios of 5–10 years ago which envisaged rapid deployment post-2020 to remove substantial quantities of CO2 from fossil fuel power stations and energy-intensive industries" (p. 9). It is possible that the report is pessimistic in its outlook for negative emissions precisely because it did take into account the historical context.

This is not to say that other policy reports are entirely ahistorical. Engagement with the history of carbon removal differs across assessed technologies and depends on the particular social, economic or political issues that are discussed. Overall though, policy reports tend to approach history in an instrumental way and omit past experiences that appear relevant and important to inform decision-making. Historical context is primarily invoked to help understand technology cost curves and the general field of possibility for different NETs, which themselves are mostly presented as novel objects unfolding in a novel policy landscape.

3 | SOCIAL IMAGINARIES OF CARBON REMOVAL

In this section, we review some of the early discussions about carbon removal in scientific reports and different policy forums. We primarily draw on the substantial literature within international relations, STS and governmentality studies that has analyzed ideas and debates on carbon sinks and carbon sequestration. This literature brings to light the historical and political legacy of carbon removal and shows how practices of carbon accounting (in particular the choice of "net" accounting, that is, accounting for sources minus sinks) are not just technical or scientific in character, but have significant political economic and governance implications (Gifford, 2020; Lohmann, 2009; Lövbrand & Stripple, 2011; Lovell & Mackenzie, 2011; MacKenzie, 2009). Insights from this literature serve as a useful starting point to situate current debates on negative emissions and the contested role of IAMs as tools to inform climate policy (cf. S. Beck & Mahony, 2018a; Dooley, Christoff, & Nicholas, 2018; Ellenbeck & Lilliestam, 2019; Haikola et al., 2019).

3.1 | Carbon removal is political

Carbon removal has been on the political agenda at least since the start of the UNFCCC negotiations in the beginning of the 1990s. One of the key take-aways from this early history is that the concept of removal, the way it is framed and the purposes it serves are closely entwined with political interests and positionalities. The notion of net emissions accounting, for example, was introduced in the UNFCCC by a group of industrialized countries with significant forest interests (Kjellen, 1994; Lövbrand & Stripple, 2006). The inclusion of carbon sinks in the Kyoto Protocol too was not a chance development but the outcome of intense political negotiations (Lövbrand, 2009; Oberthür & Ott, 1999). It was aggressively promoted by countries in the so-called Umbrella Group (including the United States, Norway, Russia, and Canada) who, driven by the promise of cost-effective alternatives to emission reductions, made the inclusion of sinks a precondition for signing up to the agreement (Bernstein, 2002; Dooley & Gupta, 2017; Thompson, 2010). Opposition from the EU, NGOs and many developing countries meant that this quickly became one of the most contested aspects of the negotiations (Boyd et al., 2008; Fry, 2002; Lövbrand, 2004; Schlamadinger et al., 2007). Carbon sinks were eventually included in the Kyoto Protocol, but their scope was restricted to human-induced processes and to a focus on LULUCF activities, excluding avoided deforestation (Boyd et al., 2008; Lövbrand, 2009). As a result, the treaty text came to normalize carbon sequestration by AR as an accepted mitigation strategy (Bäckstrand & Lövbrand, 2006; Hajer & Versteeg, 2011).

Scientific expertise has always played an ambiguous role in these debates (Allan, 2017; Lahsen, 2009). Much of the political controversy about the use of sinks revolved around the significant uncertainties that pervade carbon uptake in terrestrial ecosystems (Oberthür & Ott, 1999), leading to disagreements about the kind of sequestration activities that should be allowed in the Kyoto Protocol and how they could be measured (Lövbrand, 2009). To break the impasse, the IPCC was tasked with preparing a Special Report on LULUCF that would establish a scientific basis for continued negotiations (IPCC, 2000). The writing of this report however quickly became politicized as countries sought to influence its findings and make use of the IPCC's scientific authority to help justify desired policy outcomes (Fogel, 2005; Fry, 2002; Lövbrand, 2004). The final text was seen by some European and developing countries to be advocating for the use of carbon sinks, while for example the United States felt it to be unwarrantedly conservative in its treatment of the complexities and uncertainties with carbon accounting (Fogel, 2005). Accusations of partiality were aggravated by the double role of some IPCC lead authors as UNFCCC country negotiators and by the overrepresentation among the authors of (predominantly natural) scientists from the United States and Europe (Fry, 2007; Lohmann, 2001). Thus, while the scientific authority of the IPCC was initially called upon to cool down some of the heated technical and political disagreements that had emerged in the negotiations, this did little more than displace the political contestation into the IPCC process itself. Scientific understanding of carbon sinks in this way evolved in direct response to politically motivated requests from policy makers. It came to play a key role in "legitimating and refining" a controversial policy agenda on biological carbon sequestration (Fogel, 2005), while also being shaped by that agenda (Allan, 2017).

Meanwhile, many of the issues that the IPCC was tasked to provide clarity on invoke questions in which science and politics cannot be meaningfully untangled. Continued disagreements about the definition of a "forest" and the delimitation of anthropogenic land-use change showed that a shared understanding of carbon sinks required not just accurate methods for measuring changes in carbon stocks but also political decisions about what and how to measure (Fry, 2007; Lövbrand, 2009). Some of the most enduring points of contention in the carbon sink discussion cannot be resolved by science and are fundamentally a matter of interpretation. These include what baselines to calculate carbon uptake against, how to assess the risk of carbon leakage, how to deal with the reversibility of forest sinks, and how to guarantee the additionality of carbon sequestration activities (Asiyanbi & Lund, 2020; Corbera & Jover, 2012; Lohmann, 2009; McAfee, 2016). Some of these questions are seen by critics as unknowable due to the indeterminate character of counterfactual or distant futures (FERN, 2001; Lohmann, 2001, 2009). Concerns about the impermanence of biological carbon sinks, for example, ultimately have to do with the contingency of future land-use change and broader social and political developments that cannot meaningfully be addressed through more research or the development of better methodologies. Instead, they call for more self-reflection on the social limits of scientific inquiry, "an acknowledgement of irreducible uncertainties and a thorough and public discussion about their potential consequences" (Lövbrand, 2004, p. 452).

Scientists have largely failed to recognize these limits to scientific inquiry. Focusing on the LULUCF report, Fogel (2005) for example has identified a form of "uncertainty management" in the practices of IPCC authors, that is, a tendency to downplay the complexities involved with the accounting and enhancement of carbon sinks, by presenting social and political uncertainties as tractable and governable. Scientists in this way effectively "manage[d] uncertainties

largely in conformance with policymakers' expectations about the ability of existing [...] institutions to address the environmental problem in question" (p. 206). Similarly, Lövbrand (2004) has argued that scientists tend to reduce social and political conditionalities to methodological and technical uncertainties that are calculable and thus manageable, therewith failing to acknowledge their indeterminate character. Such concerns about the representation of uncertainty in climate science, including in IAMs, go back to the 1990s (Shackley & Wynne, 1995, 1996). They illustrate that scientific choices about what knowledge is relevant and credible are not neutral, but have important implications for how policy makers perceive risks and the extent to which these can be managed (S. Beck & Mahony, 2018a; Demeritt, 2001; Lövbrand, 2011; Shackley, Risbey, Stone, & Wynne, 1999).

The carbon sinks debate poses a useful antecedent to recent contestations surrounding negative emissions, where the role of the IPCC, and the political character of scientific knowledge production and assessment (now in the form of IAMs) are again in focus (Anderson & Jewell, 2019; Anderson & Peters, 2016; S. Beck & Mahony, 2017; Haikola et al., 2019). Negative emissions too, emerged from mutual interactions between science and policy, where the demand from policy makers for policy-relevant solutions has motivated experts to produce pathways consistent with policy targets (S. Beck & Mahony, 2017, 2018b; Parson, 2017). And just as with the longer history of carbon removal, we can identify ways in which scientists creating negative emissions-dependent scenarios are making climate change governable in supposedly neutral, but ultimately value-laden and contested ways. One might thus reasonably ask—as scholars are doing in renewed calls for scientific reflexivity and a more responsible approach to negative emissions research (S. Beck & Mahony, 2017; Low & Buck, 2020)—what political perspectives and assumptions are represented in the "determinative" (Dooley, Christoff, & Nicholas, 2018) and "anticipatory" (S. Beck & Mahony, 2017, 2018b) scenario analyses that characterize IAMs. If NETs-dependent scenarios help shape the corridor of plausible policy actions, then contestable assumptions about, for example, what discount rate to apply in IAMs have potentially far-reaching implications for who or what is recognized in climate policy, and who or what is not (e.g., future generations) (M. Beck & Krueger, 2016). More, the long history of carbon removal underscores the need to ask what is knowable in research on negative emissions, and who gains from presenting uncertain futures as more knowable and perhaps more possible than they actually are. Together, this suggests a need for more scientific awareness about the political character of discourses on negative emissions. As with carbon sinks (Lohmann, 2011; Lövbrand & Stripple, 2011), negative emissions are used to shape and legitimize specific policy preferences, assign or evade political responsibilities and help to justify and/or contest proposed climate change solutions. The scope and definition of carbon removal is set to remain the substance of political contestation, demanding that researchers are attentive to how negative emissions are being framed, including by themselves, and how such framings position different actors in terms of political and economic possibilities.

3.2 | Carbon removal as tool to reproduce the status-quo

One particular manifestation of carbon removal's political character warrants more in-depth discussion. In the carbon sinks debate, a key concern has long been that a focus on carbon removal will provide the justification for business-as-usual and thereby risks undermining ambitious climate action (FERN, 2001; Lövbrand, 2009). In the negative emissions discussion as well, there is widespread concern that NETs serve to mask the lack of effective mitigation action (Geden, 2015; Pielke, 2018) or contribute to legitimate the status quo through fossil fuel lock-in, moral hazard or "mitigation deterrence," that is, the undue substitution or delay of necessary emission reductions (Carton, 2019; Lenzi, 2018; Markusson, McLaren, & Tyfield, 2018; McLaren, Tyfield, Willis, Szerszynski, & Markusson, 2019; Merk, Pönitzsch, & Rehdanz, 2019; Preston, 2013). That carbon sinks were inserted in international policy discussions in an explicit effort to provide flexibility and low-cost mitigation alternatives for carbon-intensive economies is perhaps the clearest indication that these are not idle concerns. Analysis of countries' negotiating positions shows that it is those governments that were most hostile to international climate policy who were also the strongest proponents of carbon sinks in the Kyoto Protocol, suggesting that sinks were widely seen as a way to circumvent the need for emission cuts (Jung, 2004). The OPEC countries were notably in favor of a broad inclusion of sinks, as were carbon-intensive and forest industries (Jung, Michaelowa, Nestle, Greiner, & Dutschke, 2005).

Other examples abound of how governments and businesses have over the years seized on the logic and technologies of removal to justify the compatibility of continued fossil fuel activities with ambitious climate action (Asiyanbi & Lund, 2020; Lovell, Bulkeley, & Liverman, 2009; Shell, 2018; Sheppard & Hook, 2019). Røttereng (2018a) for example analyzes international support for carbon sinks in the form of CCS and REDD+, and finds that in both cases it is

mainly affluent petroleum-producing countries that have been their most active proponents. A case study of Norway demonstrates that political support for CCS and REDD+ gained traction exactly because it allowed the government to reconcile its domestic interest in continued oil and gas extraction with international climate commitments (Røttereng, 2018b; Tjernshaugen, 2011). Meanwhile, the promise of CCS has proven fertile ground for fossil fuel producers, most notably the coal industry, which has seized on the technology in extensive "clean coal" campaigns as a way to fence off a crisis of legitimacy in the face of demands for climate action (Fitzgerald, 2012; Schneider, Schwarze, Bsumek, & Peeples, 2016; Tyree & Greenleaf, 2009). These historical experiences illustrate that the constructed commensurability between emission reductions and carbon removal (or carbon capture in the case of CCS) has played a justifying and enabling role in downplaying the need for a fossil fuel phase-out.

There are other ways in which removal has been tied to the perpetuation of status quo dynamics as well. For example, the prioritization of economic framings (favoring cost-effectiveness) in carbon accounting and governance advances a view of the world as constituted by rational, self-interested individuals and nations rather than a world in which structural inequalities and exploitation constitute blocks on global solidarity and cooperative climate governance (S. Beck, Forsyth, Kohler, Lahsen, & Mahony, 2016). Such dominant renderings of climate change and its impacts make certain worldviews and mitigation strategies seem rational or even natural, while silencing other perspectives and policy options (Gifford, 2020; A. Gupta, Lövbrand, Turnhout, & Vijge, 2012; Lövbrand & Stripple, 2011). They have repercussions not just for how we define the problem but also what weight is given to different drivers and solutions (Castree et al., 2014; Turnhout, Dewulf, & Hulme, 2016). These processes are epitomized most directly in the case of market-based policies, which have often accompanied carbon removal proposals. Market mechanisms such as carbon offsets have been extensively criticized for pushing an ideological commitment to neoliberal ideas as the inevitable logic of climate policy (Castree, 2010; Dempsey & Suarez, 2016; Gómez-Baggethun & Muradian, 2015; Lohmann, 2006), and have spurred ongoing debates within the critical social sciences about the desirability of valuing nature in economic terms and the vested political and corporate interests that such policies serve (Bailey, Gouldson, & Newell, 2011; Bumpus & Liverman, 2008; Dunlap & Sullivan, 2019; Hyams & Fawcett, 2013; McAfee, 2016; Paterson & P-Laberge, 2018; Stephan & Paterson, 2012).

Such economic framings are facilitated by the reductionist and technocratic character of much environmental knowledge production (Lave, 2012; Turnhout, 2018; Turnhout, Neves, & De Lijster, 2014). Knowledge of carbon removal is closely linked with advances in technological capacity which has brought about new methods and opportunities for satellite-based mapping of forest and land-use change, integrated modeling exercises and algorithmic analysis of large datasets (Edwards, 1996, 2010; Heymann & Dahan Dalmedico, 2019). This has given rise to new, distinctively global and politically powerful understandings of carbon flows and monitoring capacities, but has also tended to "render invisible complex on-the-ground forest realities" (A. Gupta et al., 2012, p. 728; see also Leach & Scoones, 2013). A key point therefore is that global knowledge of carbon removal is necessarily based on the simplification, abstraction, and standardization of local and regional processes. It reduces biodiverse and socioculturally rich landscapes to current and/or potential carbon sinks (Leach & Scoones, 2015; Turnhout et al., 2017), and reframes complex social and political processes as predominantly biophysical, economic, or technical ones, facilitating market-based logics and policies (McAfee, 2012; McDermott, 2014). The result is what Corry (2014) has called the "contraption fallacy," or the idea that a technique or a piece of technology works "on its own," that is, that its suitability for adoption can be understood in isolation from the social and political arrangements that its implementation requires. Critics have described the reductionist tendencies in environmental knowledge production, and the forms of policy making it serves, as a form of depoliticization, arguing that it confines the space of public deliberation on contested policies and gives priority to a managerial logic where decision-making is seen as the exclusive remit of experts and technocrats (Lövbrand et al., 2015; Swyngedouw, 2010, 2011). In so doing, it forecloses opportunities for more radical social, political and economic change and serves to uphold, and reproduce, dominant interests (Dunlap & Sullivan, 2019; Felli, 2015; Methmann, 2013; Swyngedouw, 2013).

In practical terms, a global perspective on carbon removal easily lends itself to broad-brushed, blueprint accounts and ultimately policies that fail to sufficiently take contextual dynamics into account (Hulme, 2010; Muradian et al., 2013). This can lead to an underestimation of complicating factors and barriers, and therefore an exaggeration of carbon removal potential. Recent scientific and public debate about the overblown potential of "natural climate solutions" (Griscom et al., 2017) are a case in point. The widely advertised conclusions of Bastin et al. (2019), that purport to show the vast, untapped mitigation potential of tree planting, look very different when more fine-grained and place-sensitive perspectives are applied (Allison, 2019; Lewis, Mitchard, Prentice, Maslin, & Poulter, 2019; Veldman et al., 2019). Similarly, studies have identified a propensity in carbon removal research and policy to render local

communities and perspectives invisible, by casting certain lands as underused and therefore suitable as carbon sinks, ignoring local and indigenous communities' complex land-use practices (Baldwin, 2009; Fogel, 2004; Leach & Scoones, 2015). In other cases, climate discourses draw on simplistic framings of deforestation and land degradation that single out poor smallholders' resource use while underplaying more systemic drivers of environmental change (Delabre et al., 2020; Hajdu & Fischer, 2017; Hajdu, Penje, & Fischer, 2016). These framings often serve to legitimize the use of violence so as to exclude local actors from landscapes on which they have historically relied (Asiyanbi, 2016; Duffy et al., 2019; Leach & Scoones, 2015), and partly build on a much longer history of pernicious colonial environmental representations and policies (Kashwan, 2017; Lohmann, 2008). Such examples illustrate how dominant, global understandings of social and ecological reality are not innocent. They tend to displace more diverse, place-based and nuanced forms of knowledge (Hulme, 2010), and might legitimize potentially counter-productive interventions. They underscore the need to be attentive of how scientific practices concerning negative emissions and "natural climate solutions" create conditions where people, ecosystems and environmental problems are presented in reductive ways, as well as the effects that this gives rise to.

Moreover, the expert quality of carbon sink knowledge and uneven capacities to access the technologies that underpin it give both an exclusive character. This creates barriers to participation in knowledge creation and/or interpretation for actors from the global South (Lövbrand, 2009), raising questions as to who or what is recognized—or not—in the creation of carbon removal knowledge, and under what conditions different actors are able to participate in it. Indigenous peoples and local communities are commonly portrayed as most impacted by climate change, yet their role in reshaping the frames guiding assessments and accounting systems remains limited (Fogel, 2004; Ford et al., 2016). That being said, such outcomes are tendential but by no means predetermined. A growing literature stresses that opportunities do exist for a variety of nonspecialist actors to make use of global accounting methods, and to appropriate, transform or repurpose scientific techniques and framings so as to advance their own interests (Devine & Baca, 2020; Forsyth, 2020; A. Gupta et al., 2012; McAfee & Shapiro, 2010; Shapiro-Garza, 2013).

Concerns about reductionist forms of knowledge production resonate with debates on the creation of mitigation scenarios and the role that integrated assessment modeling has come to play in IPCC assessments. In line with the depoliticization critique, IAMs too have been described as technocratic tools that give priority to technical and economic solutions, while sidelining behavioral change or direct regulatory interventions (Larkin, Kuriakose, Sharmina, & Anderson, 2017). As global-scale models, they have been found to underplay ecological complexities (Creutzig, 2016), socioeconomic barriers to deployment (Buck, 2016, 2019; Fridahl & Lehtveer, 2018), social justice concerns (Shue, 2017), and the ample other trade-offs involved with the large-scale implementation of concrete solutions such as BECCS and AR (Anderson & Peters, 2016; Dooley & Kartha, 2018; P. Smith, Davis, Creutzig, Fuss, & Minx, 2016; Williamson, 2016). In terms of representation, modeling studies, like IPCC working group III authorship and climate engineering research more generally, continue to be dominated by scientists from the global North (Biermann & Möller, 2019; Corbera, Calvet-Mir, Hughes, & Paterson, 2016; Laude, 2019), raising questions about *whose* scenarios and assumptions these models end up articulating.

A few key points emerge from this first part of our review. First, the social science literature on the history of scientific-political struggles over how to define and account for carbon sinks suggests that carbon accounting practices deserve much closer attention in the negative emissions debate. Negative emissions work as a discursive promise, and viewing them as such raises questions about the political and economic work that this promise performs for a range of actors, including but not limited to policy makers. Viewing negative emissions as a socially constructed object moreover puts in focus the important role that climate scientists, modelers and other experts play in the direction and substance of climate change governance. As a growing literature is now arguing, this is not just a matter of academic interest, but of democratic accountability and of making explicit assumptions and value judgments that are easily black-boxed within supposedly neutral modeling methodologies (M. Beck & Krueger, 2016; Waller et al., 2020). Related to this, the critical literature suggests that IAMs need to be understood as one particular approach to the creation of climate knowledge, which serves certain interests but marginalizes others. There are other ways of understanding, analyzing and representing both climate change and negative emissions, which are likely to be performative of different kinds of policies. This includes the social science understandings that we have reviewed here, the rights-based perspectives prioritized by environmental justice advocates (Dooley et al., 2018), or the kinds of knowledge and experiences articulated by different indigenous groups (Ford et al., 2016). Recognition of continuity in the carbon removal debate, in other words, adds to the critique and contextualization of IAM outputs and strengthens the call for alternative and complementary approaches to an almost exclusive reliance on techno-economic models for constructing future climate scenarios. It

cautions against relying on one particular form of knowledge and deriving from that the supposed "necessity" or "inevitability" of certain climate change solutions.

Second, attention to the long history of carbon removal puts fears of moral hazard and mitigation deterrence in context. It shows that the use of sinks to substitute for more near-term mitigation actions is not incidental to the removal discussion, but a key reason for why carbon removal was put on the political agenda in the first place (McLaren & Markusson, 2020). The dynamics that underpin lock-in and mitigation deterrence are not hypothetical, but can be observed in how different countries and companies have historically utilized (the promise of) carbon removal technologies and net accounting methods (Hamilton, 2013; Jung, 2004; Røttereng, 2018a; Schneider et al., 2016). Moreover, the critical literature points to the assumption of equivalence across different geographical, biological, and sociotechnical settings as a key source of this dynamic. The constructed commensurability between emission reductions and carbon sinks—or indeed between emissions from fossil fuel combustion and land-use change—serves to obscure key differences (e.g., biological vs. geological sinks in terms of permanence) and enables the shifting around of mitigation responsibilities (Lohmann, 2011; Mackey et al., 2013). For instance, the unproblematized assumption that reductions in fossil fuel emissions and afforestation are functionally equivalent enables the fossil fuel industry's claim that investments in tree planting are a sound approach to offset emissions associated with its activities (Burkhardt & Albanese, 2019; Hook, 2019). Similarly, it is the obfuscation of crucial differences in the risk profiles, temporalities and "social lives" (Goodman & Boyd, 2011) of emission reductions versus removals through for example, BECCS that lie at the basis of why mitigation deterrence is problematic. This is implicitly acknowledged in McLaren et al.'s (2019) call for separate targets on emission reduction and carbon removal, but arguably such division needs to be part of a more general scrutiny of the value and pitfalls of a range of assumed commensurabilities, including in scientific knowledge production. To what extent, for example, can we reasonably expect synergies between climate action and biodiversity protection, when climate policy and standard carbon accounting is rendering the difference between natural forests and tree plantations invisible?

4 | HISTORICAL PRACTICES OF CARBON REMOVAL

Beyond the discursive politics of carbon removal, there is an abundance of social science scholarship on various international and national-level policies and (small-scale) projects that are of direct relevance to the negative emissions discussion. The literature on this is extensive and our review of it here is therefore necessarily selective. We focus mainly on experiences with AR, REDD+ and, to a lesser extent, CCS as documented and debated in the political ecology, critical political economy, and geography literatures. We also touch on the literature on market-based mechanisms as a long-preferred strategy for driving climate change mitigation (Boyd, Boykoff, & Newell, 2011; J. Gupta, 2014), particularly the use of carbon offsets, which are seeing a revival in the wake of net zero commitments and negative emissions discussions. Above all, this literature highlights significant political and economic barriers to the implementation of carbon removal, and underscores the need to bring justice concerns to the center of the conversation, rather than treating them as afterthoughts.

4.1 | The precarious political economy of carbon removal

Carbon sequestration policies, and forest policies in particular, have a long history in the carbon removal discussion. From the early inclusion of AR as carbon sinks in the UNFCCC negotiations, to the heated policy and academic debates on REDD+, to the recent rebranding of forestry as part of a broader promise of "natural climate solutions" (Griscom et al., 2017), tree planting and forest protection have enjoyed sustained attention in climate policy discussions. As the first part of this review already indicated, one of the key reasons for this is the allure of cost-effective mitigation that has long surrounded this sector. The literature however points to a number of problems with this framing. Casting forestry as cost-effective climate policy tends to underplay the complex political economic drivers of deforestation (Corbera, Estrada, & Brown, 2010; Lederer, 2012; Lund, 2015), and fails to do justice to the complexity of social and economic land-use relations in different geographical settings. As Corbera and Schroeder (2017) note for the case of REDD+, putting a halt to deforestation requires "long-term thinking and a profound change in national and international political economies" (p. 2), which belies the simplified understandings of social change embedded in, for example, policy tools such as payments for ecosystem services (McAfee, 2012; Muradian et al., 2013). Similarly, studies have

shown that guaranteeing the long-term success (and benefits) of tree planting projects is considerably more resource and time consuming than commonly recognized (Carton & Andersson, 2017; Corbera & Friedli, 2012; Osborne & Shapiro-Garza, 2018).

Historically, there has been little willingness by either governments or the private sector to commit these necessary resources. A lot of hope has been pinned on private funding for forest protection, for example through the creation of carbon markets and/or payments for environmental services, but significant investments in these have so far failed to materialize (Dempsey & Suarez, 2016; Gómez-Baggethun & Muradian, 2015). REDD+ for example was mainly expected to be financed through private, carbon market funding (Lederer, 2012), but in practice has become dependent on equally scarce public support. Moreover, funding often does not cover the opportunity costs of forest conservation, which means that REDD+ schemes are unable to compete with more profitable forms of land use and end up coexisting with the continued development of extractive industries and large-scale agriculture, which in many regions are the primary drivers of deforestation (Krause, 2020; McAfee, 2012; Turnhout et al., 2017). This is one example of structural tensions and contradictions between the prioritization of cost-minimization and the social and environmental outcomes of climate policy, which critics have argued are internal to the economizing logics of neoliberal environmentalism (Corson, MacDonald, & Neimark, 2013; Leach & Scoones, 2015; Lohmann, 2011; McAfee, 2012). Several analyses have evaluated the environmental impacts of REDD+ on carbon sequestration as limited, poor or even negative (Angelsen et al., 2018; Duchelle, Simonet, Sunderlin, & Wunder, 2018; Milne et al., 2019), though the exact lessons to draw from this are heavily disputed (Angelsen et al., 2017; Asiyanbi & Lund, 2020; Fischer, Hargita, & Günter, 2016; Fletcher, Dressler, Büscher, & Anderson, 2016).

AR projects meanwhile were included in the CDM, but failed to take off as a project category due in part to carbon accounting concerns and methodological issues (Thomas, Dargusch, Harrison, & Herbohn, 2010). The CDM as a whole, it is worth noting, also had limited—if any—climate benefits, and in many ways serves as a warning against overconfidence in the reliance on environmental markets (Cames et al., 2016; Drew & Drew, 2010). Forest projects on the voluntary carbon market have been more popular, but the supply of offsets on these markets has long outpaced their demand, resulting in low carbon prices and funding challenges for project organizers (Hamrick & Gallant, 2017; Hermwille & Kreibich, 2017; Otto, 2018). Recent attention to climate change in the public debate, following for example, the student climate strikes, has led to renewed interest and a surge in demand for voluntary offsets (Gross, Hook, & Powley, 2019), but it remains to be seen if this effect will be long-lived, particularly following the COVID-19 crisis. Given that the lack of strong climate policies and resulting regulatory uncertainty play an important role in how policies on REDD+ and AR have fared so far (Cadman, Maraseni, Ma, & Lopez-Casero, 2017), there is a clear risk that voluntary mechanisms will underperform in the future as well. As Dempsey and Suarez (2016) observe, quoting one of their sources, "Big capital" [...] will not flow freely into "high-risk, low-return investments" (p. 667). Beyond niche markets where consumers are willing to pay a premium for sustainability claims, forest conservation is simply "not a good investment" (Dempsey & Suarez, 2016, p. 667), and making it one will likely require much stronger climate policies than we have seen so far.

In fact, parallels between AR, REDD+ and the history of carbon capture and storage indicate that carbon removal as such is at present not a good investment. CCS, too, has long been promoted as a cost-effective "fix" for solving climate change (Hamilton, 2013; Markusson, Dahl Gjefsen, Stephens, & Tyfield, 2017). Despite enthusiasm from industrial actors and initial support from governments in both the EU and United States, the commercialization of the technology has fallen far short of expectations (Bui et al., 2018). CCS support programs have mostly failed to yield successful projects and numerous demonstration plants have ended up being canceled (Krüger, 2017). A key reason for this disappointing track record is the political economic conditions for the technology in the context of unambitious climate policy (Bäckstrand et al., 2011; V. Scott, Gilfillan, Markusson, Chalmers, & Haszeldine, 2013). CCS is expensive and has significant initial construction costs. Companies are therefore unlikely to commit to it unless unambiguous regulation makes continued emissions expensive or untenable (V. Scott et al., 2013). In other words, one might speak of a political economy of carbon removal that cuts across the many differences between biological and technological NETs. In the absence of strong regulation, there is no "business case" for taking CO_2 out of the atmosphere and permanently sequestering it in trees and soils, or storing it underground in geological formations. Economic value therefore needs to be sought elsewhere, explaining why AR often takes the form of timber plantations (Lewis, Wheeler, Mitchard, & Koch, 2019) and CCS quickly gives way to narratives about carbon capture and utilization (Bruhn, Naims, & Olfe-Kräutlein, 2016), where the captured carbon can be recycled into marketable products. Such solutions to the precarious economics of removal sit uneasily with the proclaimed need for permanent carbon storage. Meanwhile, the fact that

permanent removal is dependent on significant government regulation and/or support makes it vulnerable to the very same political economic dynamics as any other climate policy.

In the negative emissions literature as well, the discussion on finance seems to be stuck between the need for significant and sustained government support and/or intervention, and the lure of global-scale market mechanisms that provide offsetting opportunities for polluters (Bednar, Obersteiner, & Wagner, 2019; Coffman & Lockley, 2017). Honegger and Reiner (2018), for example, identify opportunities for including negative emissions under article 6 of the Paris Agreement, the rules of which remain unclear at the time of writing. Meanwhile, an increasing number of start-ups are reinventing voluntary carbon offsetting by selling credits that promise to "remove your carbon footprint" through for example soil conservation methods (Nori, 2020) and DAC (Climeworks, 2020). When reading these proposals and initiatives against the background of previous experiences with such markets, it might be tempting to call for more social and environmental safeguards, more careful design and closer regulatory oversight of carbon offset markets (Honegger & Reiner, 2018; Torvanger, 2019). A more pertinent lesson to draw, we would argue, is that providing flexibility for polluters, institutionalizing cost-minimization and relying on corporate goodwill are an unlikely recipe for achieving the "rapid and far-reaching transitions" (IPCC, 2018, p. 17) that will be necessary to mitigate climate change. The tensions and contradictions that permeate the long history of carbon removal suggest that *if* a rapid and significant scale-up of negative emissions is necessary, then markets are an ill-suited tool for that job. Similarly, there are good reasons to be skeptical of the slippage that is occurring from a focus on permanent carbon removal to attempts at turning carbon into a profitable commodity (Buck, 2019). The appeal of using captured carbon in, for example, synthetic fuels or enhanced oil recovery invoke important questions about how one moves from these efforts at commodifying carbon (and the interest groups they create) toward permanent storage of CO_2—rendering it economically inert? Resolving this dilemma will likely be of central importance to the relevance of negative emission promises as they currently exist in the scientific literature.

4.2 | Justice and ethics in the uneven geographies of carbon removal

The promise of cost-effective carbon sequestration is part of a wider belief in "win-win" climate solutions, where projects can be implemented cheaply while also delivering a range of other sustainable development goals (Bäckstrand & Lövbrand, 2006; Boyd, 2009; Joyeeta Gupta, 2012; Leach & Scoones, 2015). A key theme in the critical literature has been to show that such narratives are simplistic, that benefits are often overstated and that important trade-offs and barriers are neglected or downplayed (Edstedt & Carton, 2018; Leach & Scoones, 2015; Nel & Hill, 2014; Osborne, 2011; Phelps, Friess, & Webb, 2012; Pokorny, Johnson, Medina, & Hoch, 2012). Research on the implementation of carbon forestry initiatives in different geographical settings has identified trade-offs between climate and biodiversity goals (Phelps et al., 2012), between public and private costs and benefits (Dyer, Matthews, & Meyfroidt, 2012), between carbon and noncarbon benefits (Duchelle et al., 2017) and between equity and efficiency objectives (Karsenty, Vogel, & Castell, 2014; McAfee, 2016; Osborne, 2015). The economic logics of carbon removal mean that such trade-offs often play out in the global South. While there is real potential for poor communities to benefit from well-designed and inclusive carbon removal projects (Jindal, Swallow, & Kerr, 2008; Thomas et al., 2010), the impacts on local well-being and local resource governance are in practice often disappointing or even negative (Asiyanbi & Lund, 2020; Milne et al., 2019). Numerous carbon forestry schemes have been shown to interrupt and limit local resource use, entrench existing local inequalities, or destabilize local economies, while promised local incentives commonly fail to materialize in any significant way (Chomba, Kariuki, Lund, & Sinclair, 2016; Leach & Scoones, 2015; Milne et al., 2019). In market-based schemes in particular, the promise of efficiency drives the pursuit of economies of scale, which often manifest in biases against smallholders and attempts to cluster up local communities in ways that privilege dominant groups and divert benefits away from the poorest (Benjaminsen & Kaarhus, 2018; Isyaku, Arhin, & Asiyanbi, 2017).

Experiences with how investments in REDD+ and similar carbon forestry initiatives shape land tenure and rural livelihoods reveal some of the potentially dire ramifications of land-based negative emissions projects envisaged on a global scale. Research for example shows that opportunities to access green finance and international investments through carbon forestry schemes often drive states and private actors to assert greater control over forests and lands (Chomba et al., 2016; Fairhead, Leach, & Scoones, 2012; Nel, 2015), reflecting a long forewarned trend toward recentralization under REDD+ (Phelps, Webb, & Agrawal, 2010). This trend is amplified by measures aimed at stabilizing property rights and securing value, for example by enforcing stiff forest protection laws and through the use of moratoria. Studies that frame REDD+ in terms of discrete policy and a form of payment for ecosystem services consider

these so-called "interim solutions" to tenure problems necessary in principle (Duchelle et al., 2014; Bolin et al, 2013). Such measures however sit uneasily with claims of voluntary incentivization of forest conservation, and appear to drive a resurgence of "fortress conservation" that leads to local exclusion, conflict, and violence (Asiyanbi, 2016; Cavanagh & Benjaminsen, 2014; Fairhead et al., 2012; Vedeld et al., 2016). These tendencies have spurred widespread demand for the development of social and environmental safeguards within the global forestry and REDD+ community (Rutt, 2013). However, their implementation has so far been limited, while in some countries and REDD+ communities safeguards remain completely absent (Jagger, Luckert, Duchelle, Lund, & Sunderlin, 2014; Saeed, McDermott, & Boyd, 2017; Saito-Jensen, Rutt, & Chhetri, 2014). This may partly explain the evidence of marginalization and rights abuses across many carbon forestry projects (Cavanagh & Benjaminsen, 2014; Edstedt & Carton, 2018; Lyons & Westoby, 2014; Milne et al., 2019; Nel & Hill, 2014; Sarmiento Barletti & Larson, 2017).

Taken together, this suggests that the search for land-based negative emissions, be they in biofuel production for BECCS or for forest conservation and other "natural climate solutions," risks deepening economic inequality if lessons from past experiences are not taken seriously. First, land-based removal might allow for continued resource exploitation, fossil fuel-based production and wanton consumption in the global North, while creating exclusions and restricting development opportunities in some of the poorest areas of the global South (Bigger et al., 2018; Lohmann, 2008). Second, if ineffective, the likely mitigation deterrence (Carton, 2019; Markusson et al., 2018) of negative emission promises would lead to a global carbon budget overshoot and higher global warming that will have disproportionate negative impacts on the poorest regions of the world. Third, experiences from carbon offsetting and REDD+ indicate that most economic gains from such projects are likely funneled back to the global North through international consultancy, administrative costs for intermediary organizations, payments to certifying organizations, returns on investment for private investors, grants to international NGOs and even illegal proceeds by carbon fraudsters (Asiyanbi & Lund, 2020; Bumpus & Liverman, 2008). For instance, REDD+ administrative cost for the World Bank's Forest Carbon Partnership Facility was more than 50% of the total annual REDD+ disbursement for each year of the 6-year period between 2009 and 2015 (FCPF, 2016). With this in mind, it is not surprising that studies are finding that some governments in the global South are putting more into REDD+ financially than they are getting out of it (Luttrell, Sills, Aryani, Ekaputri, & Evinke, 2018). In short, land-based negative emissions, of which small-scale carbon forestry initiatives provide important antecedents, risk entrenching socioeconomic inequities, sustaining, and reproducing an uneven geography of economic destitution and prosperity.

Further, the boundaries of what is acceptable in terms of social and environmental impacts look very different from the perspective of policy makers versus that of local communities and other actors. Even when projects stall or fail—a real possibility as many biofuel and REDD+ projects have shown—they often have already set in motion wide ranging social and ecological impacts (Engström & Hajdu, 2019; Harnesk & Brogaard, 2017; Lund, Sungusia, Mabele, & Scheba, 2017). While consultants and many international partners can easily move on to other projects, host localities must deal with the fall-out of such failures. From an ethical point of view, this is deeply concerning. Projects may also stall or fail exactly because they are locally unacceptable. Research on carbon forestry and REDD+ has demonstrated how local resistance shapes interventions and can defy carbon sequestration ambitions (Asiyanbi, Ogar, & Akintoye, 2019; Benjaminsen, 2014; McAfee & Shapiro, 2010). And, of course, the use of arson and the burning of forests as an effective form of local resistance to unfair forms of rule dates back much further (Agrawal, 2005; J. Scott, 1990).

In addition to notes of caution and pessimism concerning the potential of NETs, the social science literature on carbon forestry also offers important lessons for how to create enabling environments for large-scale carbon removal. Studies have demonstrated, for instance, how formal land tenure systems often interact with bureaucratic conservation norms to disincentivize forest conservation (Larson & Ribot, 2007; Sungusia & Lund, 2016), including in participatory forestry systems (Baral et al., 2018; Lund, 2015). Similarly, studies have shown how bureaucracies and institutions of higher education become sites where universalizing and in some cases counterproductive norms of "proper" forestry are reproduced (Fleischman, 2014; Mathews, 2011; Ojha, 2006; Sungusia, 2018; Temu, Okali, & Bishaw, 2006). Such studies provide clear lessons for policy reforms that could create a more enabling environment for leveraging land-based negative emission policies that are seen as just by the people who live in the landscapes that such policies set out to transform.

In sum, the experiences with carbon forestry schemes such as REDD+ point to important lessons for negative emissions research and policy. First, assumptions about the availability of suitable conditions for large-scale land-based NETs in the global South need to be carefully scrutinized. Not only might actual realities on the ground look very different, these assumptions have material effects and will set in motion a reordering of social and environmental conditions

in the global South, with potentially far-reaching consequences for impacted communities. Second, while attempts at reducing specific unequal economic impacts skewed against the South must be pursued, this should proceed in the awareness of how implementing carbon removal, per default, rests on, and is poised to entrench, existing structural inequities. An entirely new form of political solidarity with poor regions of the world must be conjured to direct financing and project design for negative emissions in ways that alleviate global inequalities. Third, as is now increasingly recognized, negative emissions will involve difficult trade-offs, for instance between land requirements for AR or BECCS, food production, and biodiversity conservation. How such trade-offs are negotiated and addressed will be crucial to the local and global societal legitimacy of negative emission policies, on which, ultimately, their ecological efficacy rests.

5 | NEGATIVE EMISSIONS: WE HAVE BEEN HERE BEFORE

Our review reveals important yet largely ignored continuities between the ongoing conversation on negative emissions and earlier scientific and policy discussions on carbon sinks and carbon sequestration. This is not to deny the important differences that do exist. Negative emissions are now being imagined at scales that completely eclipse past proposals on carbon sinks, and the increasing political infeasibility of sufficiently rapid emission reductions are giving the conversation an unprecedented sense of urgency. Similarly, we are seeing research and investment in a range of removal technologies—DAC, enhanced weathering, ocean fertilization, and so on—that was not there 20 years ago. Nevertheless, the point remains that the negative emissions conversation extends from a much longer and multidisciplinary conversation on carbon removal, the legacy of which is going largely unacknowledged. The neglect of this longer history means that established insights now resurface as novel concerns and hypotheticals under the negative emissions framing. This holds true especially for the social science literature, where an extensive and empirical body of scholarship is going all but ignored, rendered irrelevant, perhaps, by a dominant research focus on future promises, novel policy agendas, and techno-economic potentials.

This is not the first time that the creation of exclusive epistemic communities is leading to knowledge discontinuities and foreseeable problems in how environmental policy is being framed or implemented. Wilson Rowe (2015) for example describes how the negotiation and design of REDD+ was initially driven primarily by economists and remote sensing specialists, at the exclusion of forestry and development experts. This led to a significant underestimation of social and political obstacles to implementation and to simplifications and abstractions similar to the ones discussed in this paper. In one notable interview that Wilson Rowe draws on, a country negotiator for the UNFCCC laments how "[i]n the past 5 years, the climate community has learned what the forest community knew already" (p. 69).

The stakes and risks with NETs are high and we do not have the luxury to waste 5 years rediscovering what we already know about the obstacles and limits to carbon removal. To avoid repeating past mistakes scientists and policy makers have the responsibility to engage with, and learn from the past, which in turn involves a commitment to interdisciplinary exchange and an openness to receiving and engaging with critique. In this review, we have summarized some of the key insights that can be garnered from previous social science scholarship on land-based carbon removal, even if this literature does not self-identify as such. These include, first, a need to recognize the irreducibly political character of the negative emissions concept, and its already politicized history. From the intricacies of net accounting to the choices and assumptions that modelers are making, through to the implementation and governance of specific carbon removal policies, the long history of carbon removal shows that there are no neutral positions in this conversation. A key reason for this is the way that global knowledge production operates, and the ongoing work of scientific abstraction and reductionism that allows carbon to be rendered commensurable across the specific geological, biological and sociotechnical settings in which it exists, obscuring crucial differences in the risk profiles, temporalities and (in) justices of different mitigation and removal approaches.

Second, the political character of carbon removal implies a need to ask what kind of "work" promises of negative emissions actually perform, and for whom. While it is now well acknowledged that the prioritization in models of negative emission technologies is characterized by lock-ins and the closing-off of alternative pathways (Bellamy, 2016; Dooley & Kartha, 2018; Larkin et al., 2017), far less attention has been paid to the kind of political-economic dynamics and interests that such pathways serve (though see Carton, 2019; Geden, 2016). The pursuit, promotion or indeed research on negative emissions is about more than removing carbon from the atmosphere. Just as REDD+ has served to deepen state control over forests and a continued flow of resources to environment-development professionals (Lund et al., 2017; Nel, 2015; Phelps et al., 2010), and CCS has been invoked to legitimate continued fossil fuel use (Røttereng, 2018a; Schneider et al., 2016), so too the promise of negative emissions serves a range of different motives

and interests. These are integral to how carbon removal plays out in practice and what particular outcomes it is likely to have in environmental and socioeconomic terms. The risk that negative emissions will in some way help to shore up the socioeconomic status-quo, or indeed undermine ambitious climate action, is in this sense not a hypothetical one, but a historical observation of how carbon removal has been, and continues to be framed and utilized by policy makers and corporations invested in the status quo. Similarly, scientific knowledge on carbon removal serves technocratic policy ambitions by adopting global scale perspectives that gloss over ecological and socioeconomic diversity. Rather than just describe it, scientific projections of negative emissions continuously contribute to producing our world—including pointing to that which must change (e.g., poor peoples' land uses), and that which apparently cannot (e.g., growing global energy demand).

Third, our review illustrates that the long history of carbon removal has been characterized by successive scientific and policy "innovations" or "fads" (Lund et al., 2017; see also Redford, Padoch, & Sunderland, 2013) that were surrounded by initial hype and excitement but that so far have all failed to live up to expectations. This poses challenging questions to negative emissions scenarios: what makes NETs different, and why would they succeed where for example, CCS and REDD+ have not? The absence of government regulatory support or a carbon price high enough to force through investments emerge from earlier experiences as key (and well-known) factors limiting the widespread take-off of carbon removal. In the end, then, the missing ingredient in the mix has been, and remains, the political will to mitigate climate change. While we certainly do not want to suggest that NETs are bound to fail (the increasing urgency of climate change might well push governments in unprecedented directions), the lessons from earlier carbon removal failures must to be acknowledged and should, in our opinion, inspire circumspection, not in the least when it comes to the role that market mechanisms can and should play in negative emissions governance.

Fourth and finally, our review illustrates that continued experiments along well-trodden paths, particularly where these involve a prioritization of cost-effective and market-based solutions over more inclusive carbon removal approaches, are likely to further entrench local and global inequalities and reproduce current patterns of uneven development. Unless researchers and policy makers start taking the lessons from for example, REDD+ seriously, it is the global South that is set to bear the brunt of the burden of land-based negative emissions and/or that will reap the least of its benefits. Past experiences suggest that this is likely to result in local resentment and resistance, which will contribute toward the undermining of global carbon removal ambitions. The social science literature on this topic points to ample opportunities for legislative and institutional reforms to help unleash much greater citizen-based, inclusive carbon removal action across the global South and beyond.

What should researchers in particular take away from this? Fundamentally, the long history of carbon removal underscores calls for more self-reflexivity on the underlying modalities and assumptions of negative emissions research (cf. Low & Schäfer, 2020; Waller et al., 2020), and signals the need to acknowledge the limitations of scientific inquiry when it comes to projecting an increasingly uncertain future (Lövbrand, 2004). Instead of being insulated from critical scrutiny, scientific and methodological choices, such as what counts as negative emissions and what assumptions underlie the choice of particular technologies and carbon accounting techniques, need to be made accountable to public debate. Calls for "institutional reflexivity" (Wynne, 1993) are highly relevant in this context and highlight a need to render the "internal processes (and not just the products)" of negative emissions research into "a legitimate subject of public evaluation" (Wynne, 1984). There is an emerging literature that aims to do this for BECCS, by making visible the often-hidden networks of collaboration, funding and problem-definition involved in emerging areas of science and technology, and to provide a transparent evidence base that can inform assessment and democratic deliberation (Cointe, Cassen, & Nadaï, 2019; Hughes & Paterson, 2017; Laude, 2019). There are also ongoing efforts to "open up" the conversation on NETs (and solar geoengineering) through deliberative methodologies, involving a broad group of actors, which can help to promote reflexivity by exposing the societal limits of scientific assumptions (S. Beck & Mahony, 2018a; Bellamy, 2016; Bellamy, Chilvers, & Vaughan, 2014; Blue, 2018).

Crucially though, self-reflexivity also needs to extend to the hidden politics of the negative emissions conversation. Recognition of the irreducibly political character of carbon removal requires that researchers are attentive to whose interests are served and whose are marginalized in the pursuit (or indeed rejection) of negative emissions and specific NETs. They articulate a choice that scientists have: to not (just) speak for, and to those in power with their research, but (also) to and for those most marginalized and most likely to bear the brunt of climate change; to refuse to uphold an unsustainable and exploitative status-quo, by envisaging scenarios, policy tools and regulatory arrangements that actively "close down" opportunities for business-as-usual. The critical social sciences have much to offer here in terms of tools and theories for understanding and questioning the actor-specific interests, ideologies and worldviews that underpin proposed climate solutions. A wealth of concrete proposals already exist that may help open up the political

imagination: calls for degrowth (Kallis et al., 2018), a transformative Green New Deal (Aronoff, Battistoni, Cohen, & Riofrancos, 2019), supply-side policies such as fossil fuel bans and moratoria (Newell & Simms, 2019), restrictions on excessive consumption by global elites (Wiedmann, Lenzen, Keyßer, & Steinberger, 2020), or a rights-based approach to mitigation research (Dooley, Stabinsky, et al., 2018), to name just a few. Giving more voice to these alternatives in climate change research and assessments puts calls for large-scale NETs in context, by pointing out that the future of social, economic and political systems can always be different.

It has long been observed that the social sciences and the humanities are included in the scientific conversation on climate change in limited and selective ways (Castree et al., 2014; Hulme, 2011; Overland & Sovacool, 2020). Recent studies highlight that research on negative emissions is no exception, and that social science on the topic tends to be "marginalized, constrained and depoliticized" (Markusson et al., 2020, p. 2; see also Waller et al., 2020). The selective silence on previous carbon removal experiences in the negative emissions literature is one particular manifestation of this pattern. This silencing plays into the hands of those who would rather forget previous policy failures, and entrenches disciplinary divisions between the social, the natural and the applied/policy-oriented sciences. A more inclusive and interdisciplinary conversation on negative emissions is necessary in order to maximize the diversity of perspectives and present a fuller range of possible climate solutions for public debate, also those that presently appear politically naïve or present a poor fit with dominant epistemological frameworks. A broader recognition of the continuities in the carbon removal conversation, and of the knowledge that already exists on this topic, provides an essential starting point for this.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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Wim Carton: Conceptualization; writing-original draft; writing-review and editing. **Adeniyi Asiyanbi:** Writing-original draft; writing-review and editing. **Silke Beck:** Conceptualization; writing-original draft; writing-review and editing. **Holly Buck:** Conceptualization; writing-original draft; writing-review and editing. **Jens Friis Lund:** Writing-original draft; writing-review and editing.

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REFERENCES

Agrawal, A. (2005). Introduction: The politics of nature and the making of environmental subjects. *Environmentality: Technologies of Government and the Making of Subjects*, *11*, 858–859. https://doi.org/10.1093/envhis/11.4.858

Allan, B. B. (2017). Producing the climate: States, scientists, and the constitution of global governance objects. *International Organization*, *71* (1), 131–162. https://doi.org/10.1017/S0020818316000321

Allison, S. (2019). The trouble with indiscriminate tree-planting in Africa. *Mail and Guardian*. Retrieved from https://mg.co.za/article/2019-10-31-00-the-trouble-with-indiscriminate-tree-planting-in-africa/

Anderson, K., & Jewell, J. (2019). Debating the bedrock of climate-change mitigation scenarios. *Nature*, *573*(7774), 348–349. https://doi.org/10.1038/d41586-019-02744-9

Anderson, K., & Peters, G. (2016). The trouble with negative emissions. *Science*, *354*(6309), 182–183. https://doi.org/10.1126/science.aah4567

Angelsen, A., Brockhaus, M., Duchelle, A. E., Larson, A., Martius, C., Sunderlin, W. D., … Wunder, S. (2017). Learning from REDD+ : A response to Fletcher et al. *Conservation Biology*, *31*(3), 718–720. https://doi.org/10.1111/cobi.12933

Angelsen, A., Martius, C., De Sy, V., Duchelle, A. E., Larson, A. M., & Thu Thuy, P. (2018). *Transforming REDD+: Lessons and new directions*. Bogor, Indonesia: CIFOR.

Aronoff, K., Battistoni, A., Cohen, D. A., & Riofrancos, T. (2019). *A planet to win: Why we need a green new Deal*. London, England: Verso.

Asiyanbi, A. P. (2016). A political ecology of REDD+: Property rights, militarised protectionism, and carbonised exclusion in Cross River. *Geoforum*, *77*, 146–156. https://doi.org/10.1016/j.geoforum.2016.10.016

Asiyanbi, A. P., & Lund, J. F. (2020). Policy persistence: REDD+ between stabilization and contestation. *Journal of Political Ecology*, *27*(1), 378–400. https://doi.org/10.2458/v27i1.23493

Asiyanbi, A. P., Ogar, E., & Akintoye, O. A. (2019). Complexities and surprises in local resistance to neoliberal conservation: Multiple environmentalities, technologies of the self and the poststructural geography of local engagement with REDD+. *Political Geography*, *69*, 128–138. https://doi.org/10.1016/j.polgeo.2018.12.008

Azar, C., Lindgren, K., Larson, E., & Möllersten, K. (2006). Carbon capture and storage from fossil fuels and biomass—Costs and potential role in stabilizing the atmosphere. *Climatic Change*, *74*(1–3), 47–79. https://doi.org/10.1007/s10584-005-3484-7

Bäckstrand, K., & Lövbrand, E. (2006). Planting trees to mitigate climate change: Contested discourses of ecological modernization, green governmentality and civic environmentalism. *Global Environmental Politics*, *6*(1), 50–75. https://doi.org/10.1162/glep.2006.6.1.50

Bäckstrand, K., Meadowcroft, J., & Oppenheimer, M. (2011). The politics and policy of carbon capture and storage: Framing an emergent technology. *Global Environmental Change*, *21*(2), 275–281. https://doi.org/10.1016/j.gloenvcha.2011.03.008

Bailey, I., Gouldson, A., & Newell, P. (2011). Ecological modernisation and the governance of carbon: A critical analysis. *Antipode*, *43*(3), 682–703. https://doi.org/10.1111/j.1467-8330.2011.00880.x

Baldwin, A. (2009). Carbon nullius and racial rule: Race, nature and the cultural politics of forest carbon in Canada. *Antipode*, *41*(2), 231–255. https://doi.org/10.1111/j.1467-8330.2009.00671.x

Baral, S., Meilby, H., Khanal Chettri, B. B., Basnyat, B., Rayamajhi, S., & Awale, S. (2018). Politics of getting the numbers right: Community forest inventory of Nepal. *Forest Policy and Economics*, *91*, 19–26. https://doi.org/10.1016/j.forpol.2017.10.007

Bastin, J. F., Finegold, Y., Garcia, C., Mollicone, D., Rezende, M., Routh, D., … Crowther, T. W. (2019). The global tree restoration potential. *Science*, *364*(6448), 76–79. https://doi.org/10.1126/science.aax0848

Beck, M., & Krueger, T. (2016). The epistemic, ethical, and political dimensions of uncertainty in integrated assessment modeling. *WIREs Climate Change*, *7*(5), 627–645. https://doi.org/10.1002/wcc.415

Beck, S., Forsyth, T., Kohler, P. M., Lahsen, M., & Mahony, M. (2016). The making of global environmental science and politics. In U. Felt, R. Fouché, C. A. Miller, & L. Smith-Doerr (Eds.), *The handbook of science and technology studies* (4th ed., pp. 1059–1086). Cambridge, MA: MIT Press.

Beck, S., & Mahony, M. (2017). The IPCC and the politics of anticipation. *Nature Climate Change*, *7*(5), 311–313. https://doi.org/10.1038/nclimate3264

Beck, S., & Mahony, M. (2018a). The IPCC and the new map of science and politics. *WIREs Climate Change*, *9*, 1–16. https://doi.org/10.1002/wcc.547

Beck, S., & Mahony, M. (2018b). The politics of anticipation: The IPCC and the negative emissions technologies experience. *Global Sustainability*, *1*, 1–8, e8. https://doi.org/10.1017/sus.2018.7

Bednar, J., Obersteiner, M., & Wagner, F. (2019). On the financial viability of negative emissions. *Nature Communications*, *10*(1), 8–11. https://doi.org/10.1038/s41467-019-09782-x

Bellamy, R. (2016). A sociotechnical framework for governing climate engineering. *Science, Technology & Human Values*, *41*(2), 135–162. https://doi.org/10.1177/0162243915591855

Bellamy, R., Chilvers, J., & Vaughan, N. E. (2014). Deliberative mapping of options for tackling climate change: Citizens and specialists 'open up' appraisal of geoengineering. *Public Understanding of Science*, *25*(3), 269–286. https://doi.org/10.1177/0963662514548628

Benjaminsen, G. (2014). Between resistance and consent: Project-village relationships when introducing REDD+ in zanzibar. *Forum for Development Studies*, *41*(3), 377–398. https://doi.org/10.1080/08039410.2014.961953

Benjaminsen, G., & Kaarhus, R. (2018). Commodification of forest carbon: REDD+ and socially embedded forest practices in Zanzibar. *Geoforum*, *93*, 25–75. https://doi.org/10.1016/j.geoforum.2018.04.021

Bernstein, S. (2002). International institutions and the framing of domestic policies : The Kyoto protocol and Canada' s response to Climate Change. *Policy Sciences*, *35*(2), 203–236.

Biermann, F., & Möller, I. (2019). Rich man's solution? Climate engineering discourses and the marginalization of the global south. *International Environmental Agreements: Politics, Law and Economics*, *19*(2), 151–167. https://doi.org/10.1007/s10784-019-09431-0

Bigger, P., Dempsey, J., Asiyanbi, A. P., Kay, K., Lave, R., Mansfield, B., … Simon, G. L. (2018). Reflecting on neoliberal natures: An exchange. *Environment and Planning E: Nature and Space*, *1*(1–2), 25–75. https://doi.org/10.1177/2514848618776864

Blue, G. (2018). Scientism: A problem at the heart of formal public engagement with climate change. *Acme*, *17*(2), 544–560.

Bolin, A., Lawrence, L., Leggett, M. (2013). Land tenure and fast-tracking REDD+: time to reframe the debate? Analytical Paper, Global Canopy Program.

Boyd, E. (2009). Governing the clean development mechanism: Global rhetoric versus local realities in carbon sequestration projects. *Environment and Planning A*, *41*(10), 2380–2395. https://doi.org/10.1068/a41341

Boyd, E., Boykoff, M., & Newell, P. (2011). The "new" carbon economy: What's new? *Antipode*, *43*(3), 601–611. https://doi.org/10.1111/j.1467-8330.2011.00882.x

Boyd, E., Corbera, E., & Estrada, M. (2008). UNFCCC negotiations (pre-Kyoto to COP-9): What the process says about the politics of CDM-sinks. *International Environmental Agreements: Politics, Law and Economics*, *8*(2), 95–112. https://doi.org/10.1007/s10784-008-9070-x

Bruhn, T., Naims, H., & Olfe-Kräutlein, B. (2016). Separating the debate on CO2 utilisation from carbon capture and storage. *Environmental Science and Policy*, *60*, 38–43. https://doi.org/10.1016/j.envsci.2016.03.001

Buck, H. J. (2016). Rapid scale-up of negative emissions technologies: Social barriers and social implications. *Climatic Change*, *139*(2), 155–167. https://doi.org/10.1007/s10584-016-1770-6

Buck, H. J. (2019). *After geoengineering: Climate tragedy, repair and restoration*. Verso: London, England; New York, NY.

Bui, M., Adjiman, C. S., Bardow, A., Anthony, E. J., Boston, A., Brown, S., … Mac Dowell, N. (2018). Carbon capture and storage (CCS): The way forward. *Energy and Environmental Science*, *11*(5), 1062–1176. https://doi.org/10.1039/c7ee02342a

Bumpus, A. G., & Liverman, D. (2008). Accumulation by decarbonization and the governance of carbon offsets. *Economic Geography*, *84*(2), 127–155.

Burkhardt, P., & Albanese, C. (2019). Oil Giant Eni will help protect African forests to offset its carbon footprint. *Bloomberg*. Retrieved from https://www.bloomberg.com/news/articles/2019-05-03/eni-to-focus-on-saving-african-forests-to-offset-co2-emissions

Cadman, T., Maraseni, T., Ma, H. O., & Lopez-Casero, F. (2017). Five years of REDD+ governance: The use of market mechanisms as a response to anthropogenic climate change. *Forest Policy and Economics*, *79*, 8–16. https://doi.org/10.1016/j.forpol.2016.03.008

Cames, M., Harthan, R. O., Füssler, J., Lazarus, M., Lee, C. M., Erickson, P., & Spalding-Fecher, R. (2016). How additional is the clean development mechanism ? Retrieved from https://ec.europa.eu/clima/sites/clima/files/ets/docs/clean_dev_mechanism_en.pdf

Carbon Capture Coalition. (2019). Carbon Capture Coalition Commends Senate Introduction of the EFFECT Act. carboncapturecoalition.org. Retrieved June 3, 2019, from https://carboncapturecoalition.org/carbon-capture-coalition-commends-senate-introduction-of-the-effect-act/

Carbon Engineering. (2019). Carbon Engineering Announces Investment from Oxy Low Carbon Ventures and Chevron Technology Ventures to Advance Innovative Low-Carbon Technology. Retrieved April 5, 2019, from https://carbonengineering.com/carbon-engineering-announces-investment/

Carton, W. (2019). "Fixing" climate change by mortgaging the future: Negative emissions, spatiotemporal fixes, and the political economy of delay. *Antipode*, *51*(3), 750–769. https://doi.org/10.1111/anti.12532

Carton, W., & Andersson, E. (2017). Where Forest carbon meets its maker: Forestry-based offsetting as the Subsumption of nature. *Society and Natural Resources*, *30*(7), 829–843. https://doi.org/10.1080/08941920.2017.1284291

Castree, N. (2010). Neoliberalism and the biophysical environment: A synthesis and evaluation of the research. *Environment and Society: Advances in Research*, *1*(1), 5–45. https://doi.org/10.3167/ares.2010.010102

Castree, N., Adams, W. M., Barry, J., Brockington, D., Buscher, B., Corbera, E., … Wynne, B. (2014). Changing the intellectual climate. *Nature Climate Change*, *4*(9), 763–768. https://doi.org/10.1038/nclimate2339

Cavanagh, C., & Benjaminsen, T. A. (2014). Virtual nature, violent accumulation: The "spectacular failure" of carbon offsetting at a Ugandan National Park. *Geoforum*, *56*, 55–65. https://doi.org/10.1016/j.geoforum.2014.06.013

Chomba, S., Kariuki, J., Lund, J. F., & Sinclair, F. (2016). Roots of inequity: How the implementation of REDD+ reinforces past injustices. *Land Use Policy*, *50*, 202–213. https://doi.org/10.1016/j.landusepol.2015.09.021

Climeworks. (2020). Climeworks Carbon Dioxide Removal. Retrieved March 18, 2020, from https://climeworks.shop/?utm_source=climeworks&utm_medium=CO2 removal service&utm_campaign=1

Coffman, D., & Lockley, A. (2017). Carbon dioxide removal and the futures market. *Environmental Research Letters*, *12*(1), 1–9. https://doi.org/10.1088/1748-9326/aa54e8

Cointe, B., Cassen, C., & Nadaï, A. (2019). Organising policy-relevant knowledge for climate action: Integrated assessment modelling, the IPCC, and the emergence of a collective expertise on socioeconomic emission scenarios. *Science and Technology Studies*, *32*(4), 36–57. https://doi.org/10.23987/sts.65031

Corbera, E., Calvet-Mir, L., Hughes, H., & Paterson, M. (2016). Patterns of authorship in the IPCC working group III report. *Nature Climate Change*, *6*(1), 94–99. https://doi.org/10.1038/nclimate2782

Corbera, E., Estrada, M., & Brown, K. (2010). Reducing greenhouse gas emissions from deforestation and forest degradation in developing countries: Revisiting the assumptions. *Climatic Change*, *100*(3), 355–388. https://doi.org/10.1007/s10584-009-9773-1

Corbera, E., & Friedli, C. (2012). Planting trees through the clean development mechanism: A critical assessment. *Ephemera*, *12*(1/2), 206–241.

Corbera, E., & Jover, N. (2012). The undelivered promises of the clean development mechanism: Insights from three projects in Mexico. *Carbon Management*, *3*(1), 39–54. https://doi.org/10.4155/cmt.11.74

Corbera, E., & Schroeder, H. (2017). REDD+ crossroads post Paris: Politics, lessons and interplays. *Forests*, *8*(12), 1–11. https://doi.org/10.3390/f8120508

Corry, O. (2014). Climate engineering and the contraption fallacy. *The Washington Geoengineering Consortium*. Retrieved April 17, 2020, from http://ceassessment.org/guest-post-olaf-corry-open-university-climate-engineering-and-the-contraption-fallacy/

Corson, C., MacDonald, K. I., & Neimark, B. (2013). Grabbing green: Markets, environmental governance and the materialization of natural capital. *Human Geography*, *6*(1), 1–15. Retrieved from. http://eprints.lancs.ac.uk/69262/

Creutzig, F. (2016). Economic and ecological views on climate change mitigation with bioenergy and negative emissions. *GCB Bioenergy*, *8* (1), 4–10. https://doi.org/10.1111/gcbb.12235

Dauvergne, P., & Neville, K. J. (2010). Forests, food, and fuel in the tropics: The uneven social and ecological consequences of the emerging political economy of biofuels. *Journal of Peasant Studies*, *37*(4), 631–660. https://doi.org/10.1080/03066150.2010.512451

Delabre, I., Boyd, E., Brockhaus, M., Carton, W., Krause, T., Newell, P., … Zelli, F. (2020). Unearthing the myths of global sustainable forest governance. *Global Sustainability*, *3*(e16), 1–10. https://doi.org/10.1017/sus.2020.11

Demeritt, D. (2001). The construction of global warming and the politics of science. *Annals of the Association of American Geographers*, *91* (2), 307–337. https://doi.org/10.1111/0004-5608.00245/abstract

Dempsey, J., & Suarez, D. C. (2016). Arrested development? The promises and paradoxes of "selling nature to save it". *Annals of the American Association of Geographers*, *106*(3), 1–19. https://doi.org/10.1080/24694452.2016.1140018

Devine, J. A., & Baca, J. A. (2020). The political Forest in the era of green neoliberalism. *Antipode*, *52*(4), 911–927. https://doi.org/10.1111/anti.12624

Dooley, K., Christoff, P., & Nicholas, K. A. (2018). Co-producing climate policy and negative emissions: Trade-offs for sustainable land-use. *Global Sustainability*, *1*, 1–10. https://doi.org/10.1017/sus.2018.6

Dooley, K., & Gupta, A. (2017). Governing by expertise: The contested politics of (accounting for) land-based mitigation in a new climate agreement. *International Environmental Agreements: Politics, Law and Economics*, *17*(4), 483–500. https://doi.org/10.1007/s10784-016-9331-z

Dooley, K., & Kartha, S. (2018). Land-based negative emissions: Risks for climate mitigation and impacts on sustainable development. *International Environmental Agreements: Politics, Law and Economics*, *18*(1), 79–98. https://doi.org/10.1007/s10784-017-9382-9

Dooley, K., Stabinsky, D., Stone, K., Sharma, S., Anderson, T., Gurian-Sherman, D., & Riggs, P. (2018). *Missing pathways to 1.5°C. The role of the land sector in ambitious climate action*. Retrieved from https://static1.squarespace.com/static/5b22a4b170e802e32273e68c/t/5bef947f4fa51adec11bfa69/1542427787745/MissingPathwaysCLARAreport_2018r2.pdf

Drew, J. M., & Drew, M. E. (2010). Establishing additionality: Fraud vulnerabilities in the clean development mechanism. *Accounting Research Journal*, *23*(3), 243–253. https://doi.org/10.1108/10309611011092574

Duchelle, A. E., Cromberg, M., Gebara, M. F., Guerra, R., Melo, T., Larson, A., … Sunderlin, W. D. (2014). Linking forest tenure reform, environmental compliance, and incentives: Lessons from REDD+ initiatives in the Brazilian amazon. *World Development*, *55*, 53–67. https://doi.org/10.1016/j.worlddev.2013.01.014

Duchelle, A. E., de Sassi, C., Jagger, P., Cromberg, M., Larson, A. M., Sunderlin, W. D., … Pratama, C. D. (2017). Balancing carrots and sticks in REDD+: Implications for social safeguards. *Ecology and Society*, *22*, 1–13. https://doi.org/10.5751/ES-09334-220302

Duchelle, A. E., Simonet, G., Sunderlin, W. D., & Wunder, S. (2018). What is REDD+ achieving on the ground? *Current Opinion in Environment Sustainability*, *32*, 134–140. https://doi.org/10.1016/j.cosust.2018.07.001

Duffy, R., Massé, F., Smidt, E., Marijnen, E., Büscher, B., Verweijen, J., … Lunstrum, E. (2019). Why we must question the militarisation of conservation. *Biological Conservation*, *232*, 66–73. https://doi.org/10.1016/j.biocon.2019.01.013

Dunlap, A., & Sullivan, S. (2019). A faultline in neoliberal environmental governance scholarship? Or, why accumulation-by-alienation matters. *Environment and Planning E: Nature and Space*, *3*(2), 552–579. https://doi.org/10.1177/2514848619874691

Dyer, G. A., Matthews, R., & Meyfroidt, P. (2012). Is there an ideal REDD+ program? An analysis of policy trade-offs at the local level. *PLoS ONE*, *7*, 1–12. https://doi.org/10.1371/journal.pone.0052478

Edstedt, K., & Carton, W. (2018). The benefits that (only) capital can see? Resource access and degradation in industrial carbon forestry, lessons from the CDM in Uganda. *Geoforum*, *97*, 315–323. https://doi.org/10.1016/j.geoforum.2018.09.030

Edwards, P. N. (1996). Global comprehensive models in politics and policymaking. *Climatic Change*, *32*(2), 149–161. https://doi.org/10.1007/BF00143706

Edwards, P. N. (2010). *A vast machine: Computer models, climate data, and the politics of global warming*. Cambridge, MA: MIT Press.

Ellenbeck, S., & Lilliestam, J. (2019). How modelers construct energy costs: Discursive elements in energy system and integrated assessment models. *Energy Research and Social Science*, *47*, 69–77. https://doi.org/10.1016/j.erss.2018.08.021

Engström, L., & Hajdu, F. (2019). Conjuring 'win-world'—Resilient development narratives in a large-scale agro-Investment in Tanzania. *Journal of Development Studies*, *55*, 1201–1220. https://doi.org/10.1080/00220388.2018.1438599

European Academies Science Advisory Council (EASAC). (2018). *Negative emission technologies: What role in meeting Paris Agreement targets? EASAC Policy Report*. Retrieved from https://easac.eu/fileadmin/PDF_s/reports_statements/Negative_Carbon/EASAC_Report_on_Negative_Emission_Technologies.pdf

Fairhead, J., Leach, M., & Scoones, I. (2012). Green grabbing: A new appropriation of nature? *The Journal of Peasant Studies*, *39*(2), 237–261. https://doi.org/10.1080/03066150.2012.671770

Felli, R. (2015). Environment, not planning: The neoliberal depoliticisation of environmental policy by means of emissions trading. *Environmental Politics*, *24*(5), 641–660. https://doi.org/10.1080/09644016.2015.1051323

FERN. (2001). *Sinks in the Kyoto Protocol: A Dirty Deal for Forests, Forest Peoples and the Climate*. Retrieved from https://www.fern.org/fileadmin/uploads/fern/Documents/2001.07_-_Sinks_in_the_Kyoto_protocol.pdf

Fischer, R., Hargita, Y., & Günter, S. (2016). Insights from the ground level? A content analysis review of multi-national REDD+ studies since 2010. *Forest Policy and Economics*, *66*, 47–58. https://doi.org/10.1016/j.forpol.2015.11.003

Fitzgerald, J. (2012). The messy politics of "Clean Coal": The shaping of a contested term in Appalachia's energy debate. *Organization and Environment*, *25*(4), 437–451. https://doi.org/10.1177/1086026612466091

Fleischman, F. D. (2014). Why do foresters plant trees? Testing theories of bureaucratic decision-making in Central India. *World Development*, *62*, 62–74. https://doi.org/10.1016/j.worlddev.2014.05.008

Fletcher, R., Dressler, W., Büscher, B., & Anderson, Z. R. (2016). Questioning REDD+ and the future of market-based conservation. *Conservation Biology*, *30*(3), 673–675. https://doi.org/10.1111/cobi.12680

Fogel, C. (2004). The local, the global and the Kyoto protocol. In S. Jasanoff, M. L. Martello, P. M. Haas, & G. I. Rochlin (Eds.), *Earthly politics: Local and global in environmental governance* (pp. 103–125). Cambridge, Massachusetts: MIT Press.

Fogel, C. (2005). Biotic carbon sequestration and the Kyoto protocol: The construction of global knowledge by the intergovernmental panel on climate change. *International Environmental Agreements: Politics, Law and Economics*, *5*(2), 191–210. https://doi.org/10.1007/s10784-005-1749-7

Ford, J. D., Cameron, L., Rubis, J., Maillet, M., Nakashima, D., Willox, A. C., & Pearce, T. (2016). Including indigenous knowledge and experience in IPCC assessment reports. *Nature Climate Change*, *6*(4), 349–353. https://doi.org/10.1038/nclimate2954

Forest Carbon Partnership Facility (FCPF). (2016). *Annual Report 2016*. Retrieved from https://www.forestcarbonpartnership.org/system/files/documents/FCFP Annual Report FY16_1.pdf

Forster, J., Vaughan, N. E., Gough, C., Lorenzoni, I., & Chilvers, J. (2020). Mapping feasibilities of greenhouse gas removal: Key issues, gaps and opening up assessments. *Global Environmental Change*, *63*, 102073. https://doi.org/10.1016/j.gloenvcha.2020.102073

Forsyth, T. (2020). Who shapes the politics of expertise? Co-production and authoritative knowledge in Thailand's political forests. *Antipode*, *52*(4), 1039–1059. https://doi.org/10.1111/anti.12545

Fridahl, M., & Lehtveer, M. (2018). Bioenergy with carbon capture and storage (BECCS): Global potential, investment preferences, and deployment barriers. *Energy Research and Social Science*, *42*, 155–165. https://doi.org/10.1016/j.erss.2018.03.019

Fry, I. (2002). Twists and turns in the jungle: Exploring the evolution of land use, land-use change and forestry decisions within the Kyoto protocol. *Review of European Community and International Environmental Law*, *11*(2), 159–168. https://doi.org/10.1111/1467-9388.t01-1-00314

Fry, I. (2007). More twists, turns and stumbles in the jungle: A further exploration of land use, land-use change and forestry decisions within the Kyoto protocol. *Review of European Community and International Environmental Law*, *16*(3), 341–355. https://doi.org/10.1111/j.1467-9388.2007.00571.x

Fuss, S., Lamb, W. F., Callaghan, M. W., Hilaire, J., Creutzig, F., Amann, T., ... Minx, J. C. (2018). Negative emissions—Part 2: Costs, potentials and side effects. *Environmental Research Letters*, *13*(6), 2–4. https://doi.org/10.1088/1748-9326/aabf9f

Geden, O. (2015). Policy: Climate advisers must maintain integrity. *Nature*, *521*(7550), 27–28. https://doi.org/10.1038/521027a

Geden, O. (2016). The Paris agreement and the inherent inconsistency of climate policymaking. *WIREs Climate Change*, *7*(6), 790–797. https://doi.org/10.1002/wcc.427

Geden, O., Scott, V., & Palmer, J. (2018). Integrating carbon dioxide removal into EU climate policy: Prospects for a paradigm shift. *WIREs Climate Change*, *9*(4), 1–10. https://doi.org/10.1002/wcc.521

Gifford, L. (2020). "You can't value what you can't measure": A critical look at forest carbon accounting. *Climatic Change*. 1–16. https://doi.org/10.1007/s10584-020-02653-1

Goetz, A., German, L., & Weigelt, J. (2017). Scaling up biofuels? A critical look at expectations, performance and governance. *Energy Policy*, *110*(May), 719–723. https://doi.org/10.1016/j.enpol.2017.05.004

Gómez-Baggethun, E., & Muradian, R. (2015). In markets we trust? Setting the boundaries of market-based instruments in ecosystem services governance. *Ecological Economics*. *117*, 217–224. https://doi.org/10.1016/j.ecolecon.2015.03.016

Goodman, M. K., & Boyd, E. (2011). A social life for carbon? Commodification, markets and care. *The Geographical Journal*, *177*(2), 102–109. https://doi.org/10.1111/j.1475-4959.2011.00401.x

Gough, C., Garcia-Freites, S., Jones, C., Mander, S., Moore, B., Pereira, C., ... Welfle, A. (2018). Challenges to the use of BECCS as a keystone technology in pursuit of 1.5°C. *Global Sustainability*, *1*, 1–9. https://doi.org/10.1017/sus.2018.3

Gough, C., & Mander, S. (2019). Beyond social acceptability: Applying lessons from CCS social science to support deployment of BECCS. *Current Sustainable/Renewable Energy Reports*, *6*(4), 116–123. https://doi.org/10.1007/s40518-019-00137-0

Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., ... Fargione, J. (2017). Natural climate solutions. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(44), 11645–11650. https://doi.org/10.1073/pnas.1710465114

Gross, A., Hook, L., & Powley, T. (2019, December 13). Boom times are back for carbon offsetting industry. *Financial Times*. Retrieved from https://www.ft.com/content/7e4665a2-1776-11ea-8d73-6303645ac406

Gupta, A., Lövbrand, E., Turnhout, E., & Vijge, M. J. (2012). In pursuit of carbon accountability: The politics of REDD+ measuring, reporting and verification systems. *Current Opinion in Environmental Sustainability*, *4*(6), 726–731. https://doi.org/10.1016/j.cosust.2012.10.004

Gupta, J. (2014). *The history of global climate governance*. Cambridge, England: Cambridge University Press.

Gupta, J. (2012). Glocal forest and REDD+ governance: Win-win or lose-lose? *Current Opinion in Environmental Sustainability*, *4*(6), 620–627. https://doi.org/10.1016/j.cosust.2012.09.014

Haikola, S., Hansson, A., & Fridahl, M. (2019). Map-makers and navigators of politicised terrain: Expert understandings of epistemological uncertainty in integrated assessment modelling of bioenergy with carbon capture and storage. *Futures*, *114*, 102472. https://doi.org/10.1016/j.futures.2019.102472

Hajdu, F., & Fischer, K. (2017). Problems, causes and solutions in the forest carbon discourse: A framework for analysing degradation narratives. *Climate and Development*, *9*(6), 537–547. https://doi.org/10.1080/17565529.2016.1174663

Hajdu, F., Penje, O., & Fischer, K. (2016). Questioning the use of "degradation" in climate mitigation: A case study of a forest carbon CDM project in Uganda. *Land Use Policy*, *59*, 412–422. https://doi.org/10.1016/j.landusepol.2016.09.016

Hajer, M., & Versteeg, W. (2011). Voices of vulnerability: The reconfiguration of policy discourses. In J. S. Dryzek, R. B. Norgaard, & D. Schlosberg (Eds.), *The Oxford handbook of Climate Change and society* (pp. 82–95). Oxford, England: Oxford University Press.

Hamilton, C. (2013). *Earthmasters: The Dawn of the age of Climate Engineering*. New Haven, CT; London, England: Yale University Press.

Hamrick, K., & Gallant, M. (2017). *Unlocking potential—State of the voluntary carbon markets 2017*. Retrieved from https://www.forest-trends.org/wp-content/uploads/2017/07/doc_5591.pdf

Hansson, A., Fridahl, M., Haikola, S., Yanda, P., Pauline, N., & Mabhuye, E. (2019). Preconditions for bioenergy with carbon capture and storage (BECCS) in sub-Saharan Africa: The case of Tanzania. *Environment, Development and Sustainability*, *0123456789*, 1–25. https://doi.org/10.1007/s10668-019-00517-y

Harnesk, D., & Brogaard, S. (2017). Social dynamics of renewable energy—How the European Union's renewable energy directive triggers land pressure in Tanzania. *Journal of Environment & Development*, *26*(2), 156–185. https://doi.org/10.1177/1070496516681043

Heck, V., Gerten, D., Lucht, W., & Popp, A. (2018). Biomass-based negative emissions difficult to reconcile with planetary boundaries. *Nature Climate Change*, *8*(2), 151–155. https://doi.org/10.1038/s41558-017-0064-y

Hermwille, L., & Kreibich, N. (2017). *Identity crisis? Voluntary carbon crediting and the Paris agreement*. Retrieved from https://epub.wupperinst.org/frontdoor/deliver/index/docId/6607/file/6607_Identity_Crisis.pdf

Heymann, M., & Dahan Dalmedico, A. (2019). Epistemology and politics in earth system modeling: Historical perspectives. *Journal of Advances in Modeling Earth Systems*, *11*(5), 1139–1152. https://doi.org/10.1029/2018MS001526

Honegger, M., & Reiner, D. (2018). The political economy of negative emissions technologies: Consequences for international policy design. *Climate Policy*, *18*(3), 306–321. https://doi.org/10.1080/14693062.2017.1413322

Hook, L. (2019, April 8). Shell launches $300m forest plan to offset carbon emissions. *Financial Times*. Retrieved from https://www.ft.com/content/bae6481a-59da-11e9-939a-341f5ada9d40

Hughes, H. R., & Paterson, M. (2017). Narrowing the climate field: The symbolic power of authors in the IPCC's assessment of mitigation. *Review of Policy Research*, *34*(6), 744–766. https://doi.org/10.1111/ropr.12255

Hulme, M. (2010). Problems with making and governing global kinds of knowledge. *Global Environmental Change*, *20*(4), 558–564. https://doi.org/10.1016/j.gloenvcha.2010.07.005

Hulme, M. (2011). Meet the humanities. *Nature Climate Change*, *1*(4), 177–179. https://doi.org/10.1038/nclimate1150

Hyams, K., & Fawcett, T. (2013). The ethics of carbon offsetting. *WIREs Climate Change*, *4*(2), 91–98. https://doi.org/10.1002/wcc.207

Intergovernmental Panel on Climate Change. (2014). *Climate change 2014: Mitigation of climate change*. Working Group III contribution to the fifth assessment report of the intergovernmental panel on climate change. doi:https://doi.org/10.1017/CBO9781107415416

Intergovernmental Panel on Climate Change. (2018). *Global Warming of 1.5°C*. An IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change. doi:https://doi.org/10.1017/CBO9781107415324

Intergovernmental Panel on Climate Change (IPCC). (2000). IPCC special report—Land use. *Land-Use Change, and Forestry*. https://doi.org/10.4337/9781849805834.00023

Isyaku, U., Arhin, A. A., & Asiyanbi, A. P. (2017). Framing justice in REDD+ governance: Centring transparency, equity and legitimacy in readiness implementation in West Africa. *Environmental Conservation*, *44*(3), 212–220. https://doi.org/10.1017/S0376892916000588

Jagger, P., Luckert, M. M. K., Duchelle, A. E., Lund, J. F., & Sunderlin, W. D. (2014). Tenure and forest income: Observations from a global study on forests and poverty. *World Development*, *64*(S1), S43–S55. https://doi.org/10.1016/j.worlddev.2014.03.004

Jindal, R., Swallow, B., & Kerr, J. T. (2008). Forestry-based carbon sequestration project in Africa: Potential benefits and challenges. *Natural Resources Forum*, *32*, 116–130. https://doi.org/10.1111/j.1477-8947.2008.00176.x

Jung, M. (2004). The history of sinks—An analysis of negotiating positions in the Climate regime. HWWA discussion paper. Hamburg: Hamburgisches Welt-Wirtschafts-Archiv (HWWA), ZDB-ID 2063855-3. - Vol. 293. https://doi.org/10.2139/ssrn.588649

Jung, M., Michaelowa, A., Nestle, I., Greiner, S., & Dutschke, M. (2005). Common policy on climate change: Land use, domestic stakeholders, and EU foreign policy. In P. G. Harris (Ed.), *Europe and global climate change: Politics, foreign policy and regional cooperation* (pp. 233–253). New York, NY: St. Martin's Press.

Kallis, G., Kostakis, V., Lange, S., Muraca, B., Paulson, S., & Schmelzer, M. (2018). Research on degrowth. *Annual Review of Environment and Resources*, *43*(1), 291–316. https://doi.org/10.1146/annurev-environ-102017-025941

Karlsson, Å.-B. (2020). Vägen till en klimatpositiv framtid: Betänkande av Klimatpolitiska vägvalsutredningen. *Sou* 2020:4. Retrieved from https://www.regeringen.se/48ec20/contentassets/1c43bca1d0e74d44af84a0e2387bfbcc/vagen-till-en-klimatpositiv-framtid-sou-20204

Karsenty, A., Vogel, A., & Castell, F. (2014). "Carbon rights", REDD+ and payments for environmental services. *Environmental Science & Policy*, *35*, 20–29. https://doi.org/10.1016/j.envsci.2012.08.013

Kashwan, P. (2017). *Democracy in the woods: Environmental conservation and social justice in India, Tanzania, and Mexico*. Oxford, England: Oxford University Press.

Kjellen, B. (1994). A personal assessment. In I. M. Mintzer & J. A. Leonard (Eds.), *Negotiating climate change: The inside story of the Rio convention* (pp. 149–174). Cambridge, England: Cambridge University Press.

Krause, T. (2020). Reducing deforestation in Colombia while building peace and pursuing business as usual extractivism? *Journal of Political Ecology*, *27*(1), 401–418. https://doi.org/10.2458/v27i1.23186

Kriegler, E., Edenhofer, O., Reuster, L., Luderer, G., & Klein, D. (2013). Is atmospheric carbon dioxide removal a game changer for climate change mitigation? *Climatic Change*, *118*(1), 45–57. https://doi.org/10.1007/s10584-012-0681-4

Kriegler, E., Weyant, J. P., Blanford, G. J., Krey, V., Clarke, L., Edmonds, J., … van Vuuren, D. P. (2014). The role of technology for achieving climate policy objectives: Overview of the EMF 27 study on global technology and climate policy strategies. *Climatic Change*, *123*(3–4), 353–367. https://doi.org/10.1007/s10584-013-0953-7

Krüger, T. (2017). Conflicts over carbon capture and storage in international climate governance. *Energy Policy*, *100*, 58–67. https://doi.org/10.1016/j.enpol.2016.09.059

Lahsen, M. (2009). A science-policy interface in the global south: The politics of carbon sinks and science in Brazil. *Climatic Change*, *97*(3), 339–372. https://doi.org/10.1007/s10584-009-9610-6

Larkin, A., Kuriakose, J., Sharmina, M., & Anderson, K. (2017). What if negative emission technologies fail at scale? Implications of the Paris agreement for big emitting nations. *Climate Policy*, *3062*(August), 1–25. https://doi.org/10.1080/14693062.2017.1346498

Larson, A. M., & Ribot, J. C. (2007). The poverty of forestry policy: Double standards on an uneven playing field. *Sustainability Science*, *2*(2), 189–204. https://doi.org/10.1007/s11625-007-0030-0

Laude, A. (2019). Bioenergy with carbon capture and storage: Are short-term issues set aside? *Mitigation and Adaptation Strategies for Global Change*, *25*, 185–203. https://doi.org/10.1007/s11027-019-09856-7

Lave, R. (2012). Neoliberalism and the production of environmental knowledge. *Environment and Society*, *3*(1), 19–38. https://doi.org/10.3167/ares.2012.030103

Lawrence Livermore National Laboratory. (2020). *Getting to neutral: Options for negative carbon emissions in California*. Retrieved from https://www-gs.llnl.gov/content/assets/docs/energy/Getting_to_Neutral.pdf

Leach, M., & Scoones, I. (2013). Carbon forestry in West Africa: The politics of models, measures and verification processes. *Global Environmental Change*, *23*(5), 957–967. https://doi.org/10.1016/j.gloenvcha.2013.07.008

Leach, M., & Scoones, I. (2015). *Carbon conflicts and forest landscapes in Africa*. (M. Leach & I. Scoones, Eds.). New York, NY: Routledge.

Lederer, M. (2012). REDD + governance. *WIREs Climate Change*, *3*(February), 107–113. https://doi.org/10.1002/wcc.155

Lenzi, D. (2018). The ethics of negative emissions. *Global Sustainability*, *1*, 1–8. https://doi.org/10.1017/sus.2018.546

Lewis, S. L., Mitchard, E. T. A., Prentice, C., Maslin, M., & Poulter, B. (2019). Comment on "The global tree restoration potential". *Science*, *366*(6463), 1–3. https://doi.org/10.1126/science.aaz0388

Lewis, S. L., Wheeler, C. E., Mitchard, E. T. A., & Koch, A. (2019). Regenerate natural forests to store carbon. *Nature*, *568*, 25–28. https://doi.org/10.1038/d41586-019-01026-8

Lima, M. G. B., & Gupta, J. (2013). The policy context of biofuels : A case of non-governance at the global level ? The policy context of biofuels : A case of non-governance at the global level ? *Global Environmental Politics*, *13*(2), 46–64. https://doi.org/10.1162/GLEP

Lohmann, L. (2001). Democracy or carbocracy? Intellectual corruption and the future of the climate debate (no. 24). *The Corner House*. Retrieved from http://mail.indymedia.ie/attachments/mar2007/democracy_or_carbocracy.pdf

Lohmann, L. (2006). *Carbon trading: A critical conversation on climate change, privatisation and power*. Development Dialogue (Vol. 36). The Dag Hammerskjold Centre: Uppsala, Sweden.

Lohmann, L. (2008). Carbon trading, Climate justice and the production of ignorance: Ten examples. *Development*, *51*(3), 359–365. https://doi.org/10.1057/dev.2008.27

Lohmann, L. (2009). Toward a different debate in environmental accounting: The cases of carbon and cost–benefit. *Accounting, Organizations and Society*, *34*(3–4), 499–534. https://doi.org/10.1016/j.aos.2008.03.002

Lohmann, L. (2011). The endless algebra of climate markets. *Capitalism Nature Socialism*, *22*(4), 93–116. https://doi.org/10.1080/10455752.2011.617507

Lövbrand, E. (2004). Bridging political expectations and scientific limitations in climate risk management—On the uncertain effects of international carbon sink policies. *Climatic Change*, *67*(2–3), 449–460. https://doi.org/10.1007/s10584-004-0080-6x

Lövbrand, E. (2009). Revisiting the politics of expertise in light of the Kyoto negotiations on land use change and forestry. *Forest Policy and Economics*, *11*(5–6), 404–412. https://doi.org/10.1016/j.forpol.2008.08.007

Lövbrand, E. (2011). Co-producing European climate science and policy: A cautionary note on the making of useful knowledge. *Science and Public Policy*, *38*(3), 225–236. https://doi.org/10.3152/030234211X12924093660516

Lövbrand, E., Beck, S., Chilvers, J., Forsyth, T., Hedren, J., Hulme, M., … Vasileiadou, E. (2015). Who speaks for the future of earth? How critical social science can extend the conversation on the Anthropocene. *Global Environmental Change*, *32*, 211–218. https://doi.org/10.1016/j.gloenvcha.2015.03.012

Lövbrand, E., & Stripple, J. (2006). The climate as political space: On the territorialisation of the global carbon cycle. *Review of International Studies*, *32*(2), 217–235. https://doi.org/10.1017/S0260210506006991

Lövbrand, E., & Stripple, J. (2011). Making climate change governable: Accounting for carbon as sinks, credits and personal budgets. *Critical Policy Studies*, *5*(2), 187–200. https://doi.org/10.1080/19460171.2011.576531

Lovell, H., Bulkeley, H., & Liverman, D. (2009). Carbon offsetting: Sustaining consumption? *Environment and Planning A*, *41*(10), 2357–2379. https://doi.org/10.1068/a40345

Lovell, H., & Mackenzie, D. (2011). Accounting for carbon: The role of accounting professional organisations in governing climate change. *Antipode*, *43*(3), 704–730. https://doi.org/10.1111/j.1467-8330.2011.00883.x

Low, S., & Buck, H. J. (2020). The practice of responsible research and innovation in "climate engineering." *WIREs Climate Change*, *11*(3), 1–17. https://doi.org/10.1002/wcc.644

Low, S., & Schäfer, S. (2020). Is bio-energy carbon capture and storage (BECCS) feasible? The contested authority of integrated assessment modeling. *Energy Research and Social Science*, *60*, 101326. https://doi.org/10.1016/j.erss.2019.101326

Lund, J. F. (2015). Paradoxes of participation: The logic of professionalization in participatory forestry. *Forest Policy and Economics*, *60*, 1–6. https://doi.org/10.1016/j.forpol.2015.07.009

Lund, J. F., Sungusia, E., Mabele, M. B., & Scheba, A. (2017). Promising change, delivering continuity: REDD+ as conservation fad. *World Development*, *89*(13), 124–139. https://doi.org/10.1016/j.worlddev.2016.08.005

Luttrell, C., Sills, E., Aryani, R., Ekaputri, A. D., & Evinke, M. F. (2018). Beyond opportunity costs: Who bears the implementation costs of reducing emissions from deforestation and degradation? *Mitigation and Adaptation Strategies for Global Change*, *23*, 291–310. https://doi.org/10.1007/s11027-016-9736-6

Lyons, K., & Westoby, P. (2014). Carbon markets and the new 'carbon violence': A Ugandan study. *International Journal of African Renaissance Studies - Multi-, Inter- and Transdisciplinarity*, *9*(2), 77–94. https://doi.org/10.1080/18186874.2014.987956

MacKenzie, D. (2009). Making things the same: Gases, emission rights and the politics of carbon markets. *Accounting, Organizations and Society*, *34*(3–4), 440–455. https://doi.org/10.1016/j.aos.2008.02.004

Mackey, B., Prentice, I. C., Steffen, W., House, J. I., Lindenmayer, D., Keith, H., & Berry, S. (2013). Untangling the confusion around land carbon science and climate change mitigation policy. *Nature Climate Change*, *3*(6), 552–557. https://doi.org/10.1038/NCLIMATE1804

Markusson, N., Balta-Ozkan, N., Chilvers, J., Healey, P., Reiner, D., & McLaren, D. (2020). Social Science Sequestered. *Frontiers in Climate*, *2*(2), 1–6. https://doi.org/10.3389/fclim.2020.00002

Markusson, N., Dahl Gjefsen, M., Stephens, J. C., & Tyfield, D. (2017). The political economy of technical fixes: The (mis)alignment of clean fossil and political regimes. *Energy Research and Social Science*, *23*, 1–10. https://doi.org/10.1016/j.erss.2016.11.004

Markusson, N., McLaren, D., & Tyfield, D. (2018). Towards a cultural political economy of mitigation deterrence by negative emissions technologies (NETs). *Global Sustainability*, *1*, 1–9. https://doi.org/10.1017/sus.2018.10

Mathews, A. (2011). *Instituting nature: Authority, expertise, and power in Mexican forests*. Cambridge, MA: MIT Press.

McAfee, K. (2012). The contradictory logic of global ecosystem services markets. *Development and Change*, *43*(1), 105–131. https://doi.org/10.1111/j.1467-7660.2011.01745.x

McAfee, K. (2016). Green economy and carbon markets for conservation and development: A critical view. *International Environmental Agreements: Politics, Law and Economics*, *16*(3), 333–353. https://doi.org/10.1007/s10784-015-9295-4

McAfee, K., & Shapiro, E. N. (2010). Payments for ecosystem services in Mexico : Nature, neoliberalism, social movements, and the state. *Annals of the Association of American Geographers*, *100*(3), 579–599.

McDermott, C. L. (2014). REDDuced: From sustainability to legality to units of carbon-the search for common interests in international forest governance. *Environmental Science and Policy*, *35*, 12–19. https://doi.org/10.1016/j.envsci.2012.08.012

McLaren, D. (2020). Quantifying the potential scale of mitigation deterrence from greenhouse gas removal techniques. *Climatic Change*. 1–18. https://doi.org/10.1007/s10584-020-02732-3

McLaren, D., & Markusson, N. (2020). The co-evolution of technological promises, modelling, policies and climate change targets. *Nature Climate Change*, *10*(May), 392–397. https://doi.org/10.1038/s41558-020-0740-1

McLaren, D., Tyfield, D. P., Willis, R., Szerszynski, B., & Markusson, N. O. (2019). Beyond "net-zero": A case for separate targets for emissions reduction and negative emissions. *Frontiers in Climate*, *1*(August), 1–5. https://doi.org/10.3389/fclim.2019.00004

Meadowcroft, J. (2013). Exploring negative territory carbon dioxide removal and climate policy initiatives. *Climatic Change*, *118*(1), 137–149. https://doi.org/10.1007/s10584-012-0684-1

Merk, C., Pönitzsch, G., & Rehdanz, K. (2019). Do climate engineering experts display moral-hazard behaviour? *Climate Policy*, *19*(2), 231–243. https://doi.org/10.1080/14693062.2018.1494534

Methmann, C. (2013). The sky is the limit: Global warming as global governmentality. *European Journal of International Relations*, *19*(1), 69–91. https://doi.org/10.1177/1354066111415300

Milne, S., Mahanty, S., To, P., Dressler, W., Kanowski, P., & Thavat, M. (2019). Learning from "actually existing" REDD+: A synthesis of ethnographic findings. *Conservation and Society*, *17*(1), 84–95. https://doi.org/10.4103/cs.cs_18_13

Minx, J. C., Lamb, W. F., Callaghan, M. W., Bornmann, L., & Fuss, S. (2017). Fast growing research on negative emissions. *Environmental Research Letters*, *12*(3), 035007. https://doi.org/10.1088/1748-9326/aa5ee5

Minx, J. C., Lamb, W. F., Callaghan, M. W., Fuss, S., Hilaire, J., Lenzi, D., … del Mar Zamora, M. (2018). Negative emissions: Part 1—Research landscape and synthesis. *Environmental Research Letters*, *13*, 1–29.

Mulligan, J., Rudee, A., Lebling, K., Levin, K., Anderson, J., & Christensen, B. (2020). *CarbonShot: Federal policy options for carbon removal in the United States*. Retrieved from www.wri.org/publication/carbonshot-federal-policy-options-for-carbon-removal-in-the-united-states

Moe, E., & Røttereng, J. K. S. (2018). The post-carbon society: Rethinking the international governance of negative emissions. *Energy Research and Social Science*, *44*, 199–208. https://doi.org/10.1016/j.erss.2018.04.031

Muradian, R., Arsel, M., Pellegrini, L., Adaman, F., Aguilar, B., Agarwal, B., … Urama, K. (2013). Payments for ecosystem services and the fatal attraction of win-win solutions. *Conservation Letters*, *6*(4), 274–279. https://doi.org/10.1111/j.1755-263X.2012.00309.x

Nel, A. (2015). The neoliberalisation of forestry governance, market environmentalism and re-territorialisation in Uganda. *Third World Quarterly*, *36*(12), 2294–2315. https://doi.org/10.1080/01436597.2015.1086262

Nel, A., & Hill, D. (2014). Beyond " win – win " narratives: The varieties of eastern and Southern African carbon forestry and scope for critique. *Capitalism Nature Socialism*, *25*(4), 19–35. https://doi.org/10.1080/10455752.2014.948466

Nemet, G. F., Callaghan, M. W., Creutzig, F., Fuss, S., Hartmann, J., Hilaire, J., … Smith, P. (2018). Negative emissions—Part 3: Innovation and upscaling. *Environmental Research Letters*, *13*(6), 1–30. https://doi.org/10.1088/1748-9326/aabff4

Newell, P., & Simms, A. (2019). Towards a fossil fuel non-proliferation treaty. *Climate Policy*, 1–12. https://doi.org/10.1080/14693062.2019.1636759

Nori. (2020). *The Nori carbon removal marketplace*. Retrieved from https://nori.com

Oberthür, S., & Ott, H. E. (1999). *Instituting The Kyoto protocol: International climate policy for the 21st century*. Journal of Chemical Information and Modeling (Vol. 53). Berlin and Heidelberg, Germany: Springer-Verlag.

Ojha, H. (2006). Techno-bureaucratic doxa and challenges for deliberative governance: The case of community forestry policy and practice in Nepal. *Policy and Society*, *25*, 131–175.

Osborne, T. (2011). Carbon forestry and agrarian change: Access and land control in a Mexican rainforest. *The Journal of Peasant Studies*, *38*(4), 859–883. https://doi.org/10.1080/03066150.2011.611281

Osborne, T. (2015). Tradeoffs in carbon commodification: A political ecology of common property forest governance. *Geoforum*, *67*, 64–77. https://doi.org/10.1016/j.geoforum.2015.10.007

Osborne, T., & Shapiro-Garza, E. (2018). Embedding carbon markets: Complicating commodification of ecosystem services in Mexico's forests. *Annals of the American Association of Geographers*, *108*(1), 88–105. https://doi.org/10.1080/24694452.2017.1343657

Otto, J. (2018). Precarious participation: Assessing inequality and risk in the carbon credit commodity chain. *Annals of the American Association of Geographers*, *109*(1), 187–201. https://doi.org/10.1080/24694452.2018.1490167

Overland, I., & Sovacool, B. K. (2020). The misallocation of climate research funding. *Energy Research and Social Science*, *62*, 101349. https://doi.org/10.1016/j.erss.2019.101349

Parson, E. A. (2017). Climate policymakers and assessments must get serious about climate engineering. *Proceedings of the National Academy of Sciences*, *114*(35), 9227–9230. https://doi.org/10.1073/pnas.1713456114

Paterson, M., & P-Laberge, X. (2018). Political economies of climate change. *WIREs Climate Change*, *9*(2), 1–16. https://doi.org/10.1002/wcc.506

Phelps, J., Friess, D. A., & Webb, E. L. (2012). Win-win REDD+ approaches belie carbon-biodiversity trade-offs. *Biological Conservation*, *154*, 53–60. https://doi.org/10.1016/j.biocon.2011.12.031

Phelps, J., Webb, E. L., & Agrawal, A. (2010). Does REDD + threaten to recentralize forest governance? *Science*, *328*, 312–313. https://doi.org/10.1126/science.1187774

Pielke, R. J. (2018). Opening up the climate policy envelope. *Issues in Science and Technology*, (Summer), *XXXIV* (4), 33–40.

Pokorny, B., Johnson, J., Medina, G., & Hoch, L. (2012). Market-based conservation of the Amazonian forests: Revisiting win-win expectations. *Geoforum*, *43*(3), 387–401. https://doi.org/10.1016/j.geoforum.2010.08.002

Preston, C. J. (2013). Ethics and geoengineering: Reviewing the moral issues raised by solar radiation management and carbon dioxide removal. *WIREs Climate Change*, *4*(1), 23–37. https://doi.org/10.1002/wcc.198

Redford, K. H., Padoch, C., & Sunderland, T. (2013). Fads, funding, and forgetting in three decades of conservation. *Conservation Biology*, *27*(3), 437–438. https://doi.org/10.1111/cobi.12071

Røttereng, J. K. S. (2018a). The comparative politics of climate change mitigation measures: Who promotes carbon sinks and why? *Global Environmental Politics*, *18*(1), 52–75. https://doi.org/10.1162/GLEP_a_00444

Røttereng, J. K. S. (2018b). When climate policy meets foreign policy: Pioneering and national interest in Norway's mitigation strategy. *Energy Research and Social Science*, *39*, 216–225. https://doi.org/10.1016/j.erss.2017.11.024

Rutt, R. L. (2013). *Social protection in REDD + initiatives: A review*. Retrieved from https://pdfs.semanticscholar.org/1b02/407b55f8f7677708fbdf90639eaf76e94e0c.pdf?_ga=2.87004699.249417722.1593700991-1300312592.1593700991

Saeed, A. R., McDermott, C., & Boyd, E. (2017). Are REDD+ community forest projects following the principles for collective action, as proposed by Ostrom? *International Journal of the Commons*, *11*(1), 572–596. https://doi.org/10.18352/ijc.700

Saito-Jensen, M., Rutt, R. L., & Chhetri, B. B. K. (2014). Social and environmental tensions: Affirmative measures under REDD + carbon payment initiatives in Nepal. *Human Ecology*, *42*(5), 683–694. https://doi.org/10.1007/s10745-014-9674-4

Sarmiento Barletti, J. P., & Larson, A. M. (2017). *Rights abuse allegations in the context of REDD+ readiness and implementation: A preliminary review and proposal for moving forward*. Center for International Forestry Research (CIFOR), (190).

Schlamadinger, B., Bird, N., Johns, T., Brown, S., Canadell, J., Ciccarese, L., … Yamagata, Y. (2007). A synopsis of land use, land-use change and forestry (LULUCF) under the Kyoto protocol and Marrakech accords. *Environmental Science and Policy*, *10*(4), 271–282. https://doi.org/10.1016/j.envsci.2006.11.002

Schneider, J., Schwarze, S., Bsumek, P. K., & Peeples, J. (2016). *Under pressure—Coal industry rhetoric and neoliberalism*. London, UK: Palgrave Macmillan.

Scott, J. (1990). *Domination and the arts of resistance: Hidden transcripts*. New Haven, Connecticut: Yale University Press.

Scott, V., Gilfillan, S., Markusson, N., Chalmers, H., & Haszeldine, R. S. (2013). Last chance for carbon capture and storage. *Nature Climate Change*, *3*(2), 105–111. https://doi.org/10.1038/nclimate1695

Shackley, S., Risbey, J., Stone, P., & Wynne, B. (1999). Adjusting to policy expectations in climate change modeling: An interdisciplinary study of flux adjustments in coupled atmosphere-ocean general circulation models. *Climatic Change*, *43*, 413–454.

Shackley, S., & Wynne, B. (1995). Integrating knowledges for climate change. Pyramids, nets and uncertainties. *Global Environmental Change*, *5*(2), 113–126. https://doi.org/10.1016/0959-3780(95)00017-I

Shackley, S., & Wynne, B. (1996). Representing uncertainty in global climate change science and policy: Boundary-ordering devices and authority. *Science, Technology & Human Values*, *21*(3), 275–302. https://doi.org/10.1177/016224399602100302

Shapiro-Garza, E. (2013). Contesting the market-based nature of Mexico's national payments for ecosystem services programs: Four sites of articulation and hybridization. *Geoforum*, *46*, 5–15. https://doi.org/10.1016/j.geoforum.2012.11.018

Shell. (2018). *Sky scenario*. Retrieved from https://www.shell.com/energy-and-innovation/the-energy-future/scenarios/shell-scenario-sky.html

Shell. (2019). *Shell invests in nature as part of broad drive to tackle CO2 emissions*. Retrieved from https://www.shell.com/media/news-and-media-releases/2019/shell-invests-in-nature-to-tackle-co2-emissions.html

Sheppard, D., & Hook, L. (2019). Eni to plant vast forest in push to cut greenhouse gas emissions. *The Financial Times*. Retrieved from https://www.ft.com/content/7c4d944e-470d-11e9-b168-96a37d002cd3

Shue, H. (2017). Climate dreaming: Negative emissions, risk transfer, and irreversibility. *Journal of Human Rights and the Environment*, *8*(2), 203–216. https://doi.org/10.1038/nature18307

Smith, B. (2020). Microsoft will be carbon negative by 2030. *Official Microsoft Blog*. Retrieved from https://blogs.microsoft.com/blog/2020/01/16/microsoft-will-be-carbon-negative-by-2030/

Smith, P., Davis, S. J., Creutzig, F., Fuss, S., & Minx, J. (2016). Biophysical and economic limits to negative CO2 emissions. *Nature Climate Change*, *6*(December), 42–50. https://doi.org/10.1038/NCLIMATE2870

Stephan, B., & Paterson, M. (2012). The politics of carbon markets: An introduction. *Environmental Politics*, *21*(4), 545–562. https://doi.org/10.1080/09644016.2012.688353

Sungusia, E. (2018). *Reproducing forestry: Education, scientific authority, and management practices in Tanzania*. Sokoine University of Agriculture and University of Copenhagen Retrieved from http://www.suaire.suanet.ac.tz:8080/xmlui/handle/123456789/2797

Sungusia, E., & Lund, J. F. (2016). Against all policies: Landscape level forest restoration in Tanzania. *World Development Perspectives*, *3*(February), 35–37. https://doi.org/10.1016/j.wdp.2016.11.012

Swyngedouw, E. (2010). Apocalypse forever? Post-political populism and the spectre of climate change. *Theory, Culture & Society*, *27*, 213–232. https://doi.org/10.1177/0263276409358728

Swyngedouw, E. (2011). Depoliticized environments: The end of nature, climate change and the post-political condition. *Royal Institute of Philosophy Supplement*, *69*, 253–274. https://doi.org/10.1017/S1358246111000300

Swyngedouw, E. (2013). The non-political politics of climate change. *ACME2*, *56*, 1–8. https://doi.org/10.1002/j.1477-8696.2001.tb06490.x

Tavoni, M., & Socolow, R. (2013). Modeling meets science and technology: An introduction to a special issue on negative emissions. *Climatic Change*, *118*(1), 1–14. https://doi.org/10.1007/s10584-013-0757-9

Temu, A., Okali, D., & Bishaw, B. (2006). Forestry education, training and professional development in Africa. *International Forestry Review*, *8*(1), 118–125. https://doi.org/10.1505/ifor.8.1.118

The National Academies of Sciences, Engineering, Medicine. (2019). *Negative emissions technologies and reliable sequestration: A Research agenda*. Retrieved from https://www.nap.edu/catalog/25259/negative-emissions-technologies-and-reliable-sequestration-a-research-agenda

The Royal Society. (2018). *Greenhouse gas removal*. Retrieved from https://royalsociety.org/-/media/policy/projects/greenhouse-gas-removal/royal-society-greenhouse-gas-removal-report-2018.pdf

Thomas, S., Dargusch, P., Harrison, S., & Herbohn, J. (2010). Why are there so few afforestation and reforestation clean development mechanism projects? *Land Use Policy*, *27*(3), 880–887. https://doi.org/10.1016/j.landusepol.2009.12.002

Thompson, A. (2010). Rational design in motion: Uncertainty and flexibility in the global climate regime. *European Journal of International Relations*, *16*(2), 269–296. https://doi.org/10.1177/1354066109342918

Tjernshaugen, A. (2011). The growth of political support for CO2 capture and storage in Norway. *Environmental Politics*, *20*(2), 227–245. https://doi.org/10.1080/09644016.2011.551029

Torvanger, A. (2019). Governance of bioenergy with carbon capture and storage (BECCS): Accounting, rewarding, and the Paris agreement. *Climate Policy*, *19*(3), 329–341. https://doi.org/10.1080/14693062.2018.1509044

Turnhout, E. (2018). The politics of environmental knowledge. *Conservation and Society*, *16*(3), 363–371.

Turnhout, E., Dewulf, A., & Hulme, M. (2016). What does policy-relevant global environmental knowledge do? The cases of climate and biodiversity. *Current Opinion in Environmental Sustainability*, *18*, 65–72. https://doi.org/10.1016/j.cosust.2015.09.004

Turnhout, E., Gupta, A., Weatherley-Singh, J., Vijge, M. J., de Koning, J., Visseren-Hamakers, I. J., … Lederer, M. (2017). Envisioning REDD + in a post-Paris era: Between evolving expectations and current practice. *WIREs Climate Change*, *8*(1), 1–13. https://doi.org/10.1002/wcc.425

Turnhout, E., Neves, K., & De Lijster, E. (2014). "Measurementality" in biodiversity governance: Knowledge, transparency, and the intergovernmental science-policy platform on biodiversity and ecosystem services (ipbes). *Environment and Planning A*, *46*(3), 581–597. https://doi.org/10.1068/a4629

Tyree, S., & Greenleaf, M. (2009). The environmental injustice of "clean coal": Expanding the national conversation on carbon capture and storage technology to include an analysis of potential environmental justice impacts. *Environmental Justice*, *2*(4), 167–171. https://doi.org/10.1089/env.2009.0040

Van Vuuren, D. P., Den Elzen, M. G. J., Lucas, P. L., Eickhout, B., Strengers, B. J., Van Ruijven, B., … Van Houdt, R. (2007). Stabilizing greenhouse gas concentrations at low levels: An assessment of reduction strategies and costs. *Climatic Change*, *81*(2), 119–159. https://doi.org/10.1007/s10584-006-9172-9

Vaughan, N. E., & Gough, C. (2016). Expert assessment concludes negative emissions scenarios may not deliver. *Environmental Research Letters*, *11*(9), 1–7. https://doi.org/10.1088/1748-9326/11/9/095003

Vedeld, P., Cavanagh, C., Petursson, J., Nakakaawa, C., Moll, R., & Sjaastad, E. (2016). The political economy of conservation at mount Elgon, Uganda: Between local deprivation, regional sustainability, and global public goods. *Conservation and Society*, *14*(3), 183–194. https://doi.org/10.4103/0972-4923.191155

Veldman, J. W., Aleman, J. C., Alvarado, S. T., Michael Anderson, T., Archibald, S., Bond, W. J., ... Zaloumis, N. P. (2019). Comment on "The global tree restoration potential." *Science*, *366*, eaay7976. https://doi.org/10.1126/science.aay7976

Waller, L., Rayner, T., Chilvers, J., Gough, C. A., Lorenzoni, I., Jordan, A., & Vaughan, N. (2020). Contested framings of greenhouse gas removal and its feasibility: Social and political dimensions. *WIREs Climate Change*, *11*(4), 1–17. https://doi.org/10.1002/wcc.649

Wiedmann, T., Lenzen, M., Keyßer, L. T., & Steinberger, J. K. (2020). Scientists' warning on affluence. *Nature Communications*, *11*(1), 1–10. https://doi.org/10.1038/s41467-020-16941-y

Williamson, P. (2016). Scrutinize CO2 removal methods. *Nature*, *530*, 153–155.

Wilson Rowe, E. (2015). Locating international REDD+ power relations: Debating forests and trees in international climate negotiations. *Geoforum*, *66*, 64–74. https://doi.org/10.1016/j.geoforum.2015.09.008

Workman, M., Dooley, K., Lomax, G., Maltby, J., & Darch, G. (2020). Decision making in contexts of deep uncertainty—An alternative approach for long-term climate policy. *Environmental Science and Policy*, *103*, 77–84. https://doi.org/10.1016/j.envsci.2019.10.002

Wynne, B. (1984). The institutional context of science, models, and policy: The IIASA energy study. *Policy Sciences*, *17*, 277–320. https://doi.org/10.1007/BF00138709

Wynne, B. (1993). Public uptake of science: A case for institutional reflexivity. *Public Understanding of Science*, *2*(4), 321–337. https://doi.org/10.1088/0963-6625/2/4/003

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