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Published in:
Wiley Interdisciplinary Reviews: Climate Change

DOI:
10.1002/wcc.826

Publication date:
2023

Document version
Publisher’s PDF, also known as Version of record

Document license:
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Citation for published version (APA):
Is carbon removal delaying emission reductions?

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Funding information
Svenska Forskningsrådet Formas, Grant/Award Numbers: 2018-01686, 2019-01953

Abstract
Carbon dioxide removal is rapidly becoming a key focus in climate research and politics. This is raising concerns of “moral hazard” or “mitigation deterrence,” that is, the risk that promises of and/or efforts to pursue carbon removal end up reducing or delaying near-term mitigation efforts. Some, however, contest this risk, arguing that it is overstated or lacking evidence. In this review, we explore the reasons behind the disagreement in the literature. We unpack the different ways in which moral hazard/mitigation deterrence (MH/MD) is conceptualized and examine how these conceptualizations inform assessments of MH/MD risks. We find that MH/MD is a commonly recognized feature of modeled mitigation pathways but that conclusions as to the real-world existence of MH/MD diverge on individualistic versus structural approaches to examining it. Individualistic approaches favor narrow conceptualizations of MH/MD, which tend to exclude the wider political-economic contexts in which carbon removal emerges. This exclusion limits the value and relevance of such approaches. We argue for a broader understanding of what counts as evidence of delaying practices and propose a research agenda that complements theoretical accounts of MH/MD with empirical studies of the political-economic structures that may drive mitigation deterrence dynamics.

This article is categorized under:
- The Carbon Economy and Climate Mitigation > Benefits of Mitigation
- The Social Status of Climate Change Knowledge > Sociology/Anthropology of Climate Knowledge
- Policy and Governance > Multilevel and Transnational Climate Change Governance

KEYWORDS
carbon removal, climate change mitigation, mitigation deterrence, moral hazard, negative emissions
1 | INTRODUCTION

Carbon dioxide removal (CDR, here also referred to as “carbon removal” or simply “removal”) is rapidly becoming a key focus in climate change research and policy (Buylova et al., 2021; Intergovernmental Panel on Climate Change (IPCC), 2022; Minx et al., 2017). This is perhaps most evident in the proliferation of national and corporate net zero pledges, where removals play a necessary, if not always explicitly acknowledged role (Buck et al., 2023). The growing interest in CDR stems from the idea that emission reductions by themselves will not be sufficient to achieve agreement-upon climate targets. Significant amounts of carbon will need to be removed from the atmosphere, the argument goes, to compensate for continued emissions in “hard-to-abate” sectors, and/or to bring temperatures down again after a temporary overshoot of the 1.5–2°C temperature targets (Luderer et al., 2018; Rogelj et al., 2019).

As interest in carbon removal grows, so does critical scrutiny. Besides raising concerns about the massive land, water, resource, and energy demands of various CDR technologies (Creutzig, 2016; Doelman et al., 2020; Heck et al., 2018; Realmonte et al., 2019), scholars have pointed to the risk of “moral hazard” (Keith, 2000), or what has also been described as mitigation “deterrence”, “deferral”, or “delay” (Carton, 2019; Lenzi, 2018, 2021; Markusson et al., 2018; McLaren, 2016b). While these concepts differ, they all point to the possibility that a focus on carbon removal undermines ambitious decarbonization efforts.

This is not a new concern. It reflects long-standing debates on moral hazards in the climate conversation and mirrors a longer history of “prevarication” in climate research and policy (McLaren & Markusson, 2020). Large-scale removal however seems more susceptible to this risk than other mitigation options. Intended to draw down CO₂ that is already in the atmosphere, it enables an extension of the carbon budget and therefore decouples the stabilization of atmospheric CO₂ concentrations from the need to fully eliminate emissions. Theoretically, CDR provides opportunities for some fossil fuel combustion and land-use emissions to continue, while still meeting climate targets (Buck, 2021a).

There is considerable disagreement on how serious a risk moral hazard or mitigation deterrence (henceforth “MH/MD”) actually is. Some maintain that CDR is already distracting from emission reductions (Anderson & Peters, 2016; Carton, 2019; McLaren & Markusson, 2020), or point to how it might do so (McLaren, 2020; Minx et al., 2018; Otto et al., 2021). Others find no evidence of moral hazard (Merk, Pönitzsch, & Rehdanz, 2019), suggest that the real-world risk might be overstated (Bellamy et al., 2021; Lackner, 2016), or argue that suggestions of a potential trade-off between CDR and emission reductions are ultimately counterproductive (Jebari et al., 2021). How does one reconcile these different assessments? At heart, the MH/MD debate appears to suffer from widely diverging epistemological ideas about how deterrence and delay should be understood, and what constitutes evidence of its occurrence. This disagreement overshadows consideration of how delays in emission reductions can be avoided.

In this review, we explore reasons behind the disagreement in the literature. We unpack diverging conceptualizations of MH/MD and interrogate the foundations behind claims for its existence or lack thereof. While scholars have reviewed the MH/MD question before (Markusson et al., 2018; Oomen, 2021), the rapidly evolving research and policy landscape on carbon removal warrants a comprehensive review. Moreover, much of the earlier literature focuses on “geoengineering” as a single category, comprising both solar radiation management (SRM) and carbon removal. This tends to obscure crucial differences between the two and prevents an assessment of CDR as a distinct case of MH/MD.

Our analysis is based on a combined systematic and analytical literature review. We used Scopus to search combinations of “mitigation deterrence,” “moral hazard” or “delay” with “carbon dioxide removal,” “carbon removal,” “greenhouse gas removal” or “negative emissions.” This gave a sample of 140 texts. We then screened the texts, excluded the ones solely concerned with solar geoengineering, and selected those that explicitly use and/or conceptualize mitigation deterrence or moral hazard. This resulted in a sample of 104 texts. In a second step, we added any relevant literature identified through snowballing during the review of the sample texts. Finally, we ran the original search again to catch new publications; this gave a total sample of 116 texts (see Appendix S1). Some of the reviewed papers use the categories “geoengineering” or “climate engineering,” which means that our analysis is based on papers that either focus exclusively on CDR, or on a combination of CDR and SRM within a broader geoengineering framing.

In the next section, we give a brief history of the MH/MD argument and its relation to the history of carbon removal. We then map different conceptualizations of MH/MD as represented in the literature, identifying the main differences and disagreements. Building on this, we discuss what counts as evidence in the debate on MH/MD. Our discussion and conclusion unravel some of the reasons for the disagreements, and suggest a research agenda that emphasizes the importance of structural, political economic accounts of MH/MD that are theoretically informed, and empirically grounded.
2 | MORAL HAZARD: A BRIEF HISTORY

The debate about MH/MD from CDR and SRM was proposed as a policy option in a 1965 scientific report to the US Government (Fleming, 2010, p. 328). This report focused exclusively on SRM and treated it as the go-to climate solution. MH/MD was not considered a concern simply because emissions reductions were not seen as an option—the report remained completely silent on them.

CDR on the other hand was from the start framed explicitly as a (temporary) substitute for decarbonization. In 1977, a landmark scientific paper put CDR on the map (Fleming, 2010) when US physicist and climate skeptic Freeman Dyson (1977) proposed large-scale planting of fast-growing trees to help stabilize atmospheric CO₂ levels. While Dyson saw the phase-out of fossil fuels as a necessity in the long term, he considered it unlikely in the short term: “it seems inevitable that we shall continue for many decades to burn fossil fuels and to increase the level of atmospheric CO₂” (p. 288). Dyson argued that biological sequestration could be used as a temporary “stop-gap measure to hold the atmospheric CO₂ level down for a few decades and buy time in which a permanent shift from reliance on fossil fuels to renewable photosynthetic (or nuclear) fuels can be completed” (p. 290).

The idea of a trade-off between climate geoengineering (CDR and SRM) and emission reductions was formalized through economic modeling in the early 1990s. The economist William Nordhaus (1992) was the first to put a price on both climate change damages and mitigation, articulating a tension between climate action and economic growth (Oomen, 2021). His Dynamic Integrated Climate-Economy (DICE) model of global climate–economy interactions treated all forms of mitigation as a cost, that is, as a deviation from an economically desirable state. This led Nordhaus (1992) to conclude that “from a purely economic point of view” (p. 1319), geoengineering, which was modeled as having “extremely low economic costs” (p. 1317), was the preferred approach to climate stabilization. Nordhaus in this way developed an economic case, based on cost-optimization, for prioritizing CDR and SRM over emission reductions.

But substituting CDR and SRM for other forms of mitigation was controversial. Nordhaus co-authored an important 1992 US National Academy of Science (NAS) report about climate policy, which discussed several geoengineering options (Fleming, 2010). While industry representatives on the author panel, including Robert Frosch from car manufacturer General Motors, advocated geoengineering as a way of avoiding the cost of emission reductions (Fleming, 2010), some scientists were less convinced. Many report contributors were worried that even the thought that we could offset some aspects of inadvertent climate modification by deliberate modification schemes could be used as an excuse by those who would be negatively affected by controls on the human appetite to continue polluting and using the atmosphere as a free sewer.

(Schneider, 1996: 295)

This may have been the first mention of the MH/MD problem in academic literature (Horton & Reynolds, 2016). A few years later, Keith (2000) gave the problem a name, adopting a term from the insurance sphere: “moral hazard.”

Nordhaus’ cost-optimization approach to climate modeling quickly became dominant (Oomen, 2021), and with it came an ongoing temptation to substitute rapid and near-term emission reductions with future technologies. As fossil fuel use and emissions continued to increase, the substitution logic made its entrance into international climate negotiations. In the 1997 Kyoto Protocol, carbon sinks in the form of afforestation and reforestation were positioned as offsets for ongoing emissions (Dooley & Gupta, 2017), and in the 2000s, carbon capture and storage (CCS) technology was marshaled to allow the sustained use of fossil-fuelled energy infrastructure. Concerns about MH/MD were expressed for both of these approaches, although a different terminology was used (Asayama, 2021; Carton et al., 2020; FERN, 2001; Markusson et al., 2017). With the Paris Agreement in 2015 and the subsequent 1.5°C report (IPCC, 2018a), a broader range of CDR methods emerged as substitution options - in part a re-labeling of previous forestry and carbon capture ideas (Beck & Mahony, 2018; Low & Schäfer, 2020; van Beek et al., 2022). After repeated failures to reduce emissions, or indeed to deploy the technologies meant to counterbalance them (McLaren & Markusson, 2020), the trickle of articles on MH/MD has turned into a flow (see Figure 1).

In short, the emergence and growth of the MH/MD debate went hand in hand with the mainstreaming of various substitutes for direct emission reductions. This occurred at a time when climate policy became thoroughly shaped by neoliberal ideas (Mitchell, 2011; Stoddard et al., 2021)—not least the idea of cost-efficiency as a key criterion against which mitigation options should be weighed; and a belief in the limitless capacity of markets to solve problems (Blum & Lovbrand, 2019; Lohmann, 2012). As both the Nordhaus example and the history of carbon (offset) markets
show, such ideas became key drivers of the substitution logic in science as well as policy. Any assessment of the risks of MH/MD, therefore, needs to take into consideration the political economic conditions that make substitution an attractive proposition. We return to this point later.

3 | UNPACKING MORAL HAZARD, MITIGATION DETERRENCE, AND DELAY

Over the years, the moral hazard question has emerged in different forms and contexts, to the extent that it is not always clear if scholars are actually talking about the same thing (Tsipiras & Grant, 2022). A range of alternative concepts have been proposed to denote moral hazard concerns, e.g. in the form of “mitigation obstruction” (Lenzi, 2018; Morrow, 2014) or “risk compensation” (Keith, 2013; Reynolds, 2015). The most elaborate reframing comes from McLaren (2016b), who coined the term “mitigation deterrence” (MD) to broaden understandings of MH in relation to SRM. McLaren and colleagues later elaborated and refined this argument for CDR, resulting in a body of work that is somewhat distinct from the MH literature (Markusson et al., 2018, 2022; McLaren, 2020; McLaren et al., 2021). We here refer to the entirety of the debate with the abbreviation MH/MD, while using MH or MD to denote individual texts or arguments that deal with the specificities of either of these concepts.

The moral hazard concept originates in neoclassical economics, particularly principal-agent theory. It denotes a situation where an economic actor lacks the incentive to guard against risk because they are protected from the consequences of that risk, for example, through insurance (Marshall, 1976). The concept essentially captures how rational, individual decision-makers have implicit and often unconscious incentives to impose risks and costs on others (Peacock, 2021). Implied in this is a critique of the behavior of the decision-maker(s) as selfish and reckless, and therefore a normative assessment of moral hazard as inherently undesirable (Shrum et al., 2020; Tsipiras & Grant, 2022). Applied to climate policy, the MH argument suggests that rational actors might choose CDR over emission reductions, despite the possibility that CDR methods could prove unscalable or less effective than anticipated, because CDR appears cheaper and because these actors will not face the consequences of mitigation failure (Hart et al., 2022; Shue, 2017; The Royal Society, 2009). This could then lead to higher cumulative emissions and associated climate damages. The argument may also work if carbon removal does deliver as promised, because of the various burdens and foregone benefits associated with choosing CDR over emissions reductions, e.g. continued air pollution associated with fossil fuel use (McLaren, 2016a) or the enormous land and resource needs associated with various CDR methods (Boysen et al., 2017; Dooley & Kartha, 2018; Otto et al., 2021; Realmonte et al., 2019; Smith et al., 2016).

Some have questioned the validity of applying MH this way, in part because CDR or geoengineering are not classical principal-agent problems (Wagner & Zizzamia, 2021). In the case of CDR, it is not always clear who bears the risks that come with substitution—for example, when the burden of climate action is passed on to other contemporary actors or future generations (Anderson & Peters, 2016; Boettcher & Schäfer, 2017; Callies & Moellendorf, 2021; McLaren, 2016b).
The people betting on CDR are often relatively shielded from the adverse effects that would result if substitution fails. Because the insured is not the one most at risk, the insurance analogy breaks down.

The concept of mitigation deterrence takes a step away from the original MH concept, in that it focuses on the process of substitution itself. Markusson et al. (2018) define MD as “the prospect of reduced or delayed mitigation resulting from the introduction or consideration of another climate intervention” (p. 1). This definition departs from the moral hazard framing in at least two ways. First, it does not necessarily see “deterrence” as the result of intentional decision-making. MD can equally be an emergent effect, that is, the unforeseen and even unacknowledged result of disparate decisions taken for different reasons by any number of people, or indeed as the result of a particular political-economic regime (Markusson et al., 2018). This broader framing allows for a wider set of possible substitution mechanisms than those proposed by principal-agent theory.

The second key difference is that in MD, substitution is not necessarily an undesirable process. Markusson et al.’s (2018) depiction of MD as “not inherently problematic” (p. 1) reflects a longstanding unease with the a priori assumption of undesirability that characterizes much of the MH literature (Hale, 2012; Lenzi, 2018; Morrow, 2014). As Preston (2013) points out, “simply calling something a moral hazard does not actually establish a wrong unless it can be shown that the behavior the hazard precipitates is itself morally problematic” (p. 25). At least in theory, it is possible to imagine scenarios in which some form of substitution is justified (Lawford-Smith & Currie, 2017; Lenzi, 2021; Morrow, 2014). If one could achieve the same climate policy objectives by using removals, without introducing undesirable risks or side effects, then there would be no reason to prioritize emission reductions (see McLaren, 2016b). In practice though, carbon removal entails numerous trade-offs, resource constraints and socioeconomic risks (Creutzig, 2016; Dooley & Kartha, 2018; Fuss et al., 2018; Smith & Torn, 2013), indicating that CDR is far from functionally equivalent to emission reductions (Carton et al., 2021).

This way of understanding the MH/MD concern highlights the deeply subjective character of assessing substitution risks. Among others, such assessment will depend on climate policy goals and broader political/societal objectives (McLaren, 2016b; see also Bellamy et al., 2021). If climate policy is defined narrowly, as an exclusive effort to achieve specific temperature targets, then some forms of CDR might seem a reasonable substitute for emission reductions. If, on the other hand, it is defined more broadly, also taking into account other climate impacts, climate justice, biodiversity protection, technological uncertainties, and so forth, then answers look very different (McLaren, 2016b). Even though scholars are seldom explicit about climate policy objectives when assessing MH/MD, these are crucial for understanding diverging assessments of substitution risks.

The subjective undertones of MH/MD discussions are amplified by the future and largely hypothetical character of CDR claims. It is one thing to assess substitutability between two existing alternatives, but quite another to do so between two mitigation options that work on different timescales and are at least partially based on conjectural technological claims. Since CDR practices do not currently exist at scale, much of the literature has so far been concerned with the discursive promise of CDR rather than its physical deployment (Boettcher & Schäfer, 2017; Carton et al., 2021; Markusson et al., 2018; Morrow, 2014; Preston, 2013). This gives rise to a particular form of MH/MD concern, in which CDR promises serve to diminish emission reduction efforts in the present but then fail to be followed by actual, future CDR deployment. This uncertainty about eventual outcomes creates plenty of room for inflated narratives, empty commitments, and outright greenwashing. The ongoing controversy around corporate net zero pledges vividly illustrates some of these dynamics (Greenpeace UK, 2021; High-Level Expert Group on the Net Zero Emissions Commitments of Non-State Entities (HLEG), 2022; Stabinsky et al., 2021).

The debate is characterized by other conceptual divergences as well, including, for example, on who or what should be seen as the driver of MH/MD (Stilgoe, 2015). The literature variously focuses on modelers and climate engineering researchers (Lawford-Smith & Currie, 2017; Morrow, 2014; Oomen, 2021; Schenuit et al., 2021), policy makers and governments (Craik, 2015; Himmelsbach, 2018), the general public (Campbell-Arvai et al., 2017; Corner & Pidgeon, 2014), companies (Coffman & Lockley, 2017; Craik, 2015), or political and economic institutions (Carton, 2019; Malm & Carton, 2021; Markusson et al., 2018; McLaren & Markusson, 2020). Similar ambiguity exists regarding the exact object that it is being deterred. Stilgoe (2015) for instance asks if we are “talking about politicians losing interest in mitigation, consumers making unsustainable choices, researchers turning attention away from climate science, or engineers giving up on clean technology?” (p. 113). The literature also varies as to whether CDR deters gradual climate action or more transformative societal responses, such as degrowth, rapid reductions in energy demand (Muraca & Neuber, 2018) and fossil fuel phase-out (Buck, 2021a). It is worth noting here that the term “mitigation deterrence” is somewhat unfortunate when it comes to describing these dynamics, because removals are officially seen as a second component of
mitigation, along with emission reductions (e.g., in the official IPCC (2018b) glossary). The MD concept is therefore more correctly described as concerned with deterrence not of “mitigation” in its entirety but of “emission reductions”.

This conceptual plurality is illustrative of the subjective and ultimately political nature of the debate. The position any one person takes on MH/MD ultimately hinges on how they assess the risks, costs, benefits, and likelihood of (future) carbon removal relative to near-term emission reductions. Such assessment will at least in part reflect the values, interests, and worldviews of that person. In the next section, we discuss how the political nature of this debate plays out in the academic literature, by exploring the epistemological assumptions underlying claims about the evidence base for MH/MD.

4 WHY WE DISAGREE ABOUT THE ROLE OF CARBON REMOVAL

Debates about the validity of MH/MD concerns are long-standing and go back to the early geoengineering literature (Kreuter, 2021), where the apparent absence of empirical evidence was pointed out as a key weakness (Merk, Klaus, et al., 2019; The Royal Society, 2009). While few scholars completely reject the possibility that CDR might lead to MH/MD, considerable disagreement exists around how to assess the nature and severity of the problem. Some see this debate as unduly selective because conventional mitigation methods too might fail—implying that an exclusive focus on emission reductions could deter the development of CDR methods that might ultimately be needed (Fridahl, 2019; Nordhaus, 2018). Others make a clear distinction between MH/MD dynamics in integrated assessment models (IAMs), and “actual” MH/MD, suggesting that indications of the former do not necessarily reflect real-world risks of MH/MD (Bellamy et al., 2021; Minx et al., 2018; Uden et al., 2021).

We here summarize this debate, roughly distinguishing between three common approaches to examining MH/MD in the literature. The first concerns the role of CDR in IAMs, where there is general agreement that MH/MD exists, yet disagreement as to whether this results in real-world MH/MD. The second and third approaches concern attempts to assess MH/MD risks outside of models. The second set of studies approaches MH/MD as an expression of individualist preferences, choices, and actions, while the third sees MH/MD as the outcome of structural dynamics in society. Our distinction between individualistic and structural conceptualizations of MH/MD here builds on that of Markusson et al. (2018) and Oomen (2021), who use a similar typology. These three strands of scholarship reflect different methodological and conceptual choices, as well as differing ideas of what constitutes evidence of MH/MD. Our categorization of them is intended to draw attention to key epistemological differences in the MH/MD literature and how these inform some of the ongoing disagreements. We argue that differences in how the question of MH/MD is approached conceptually and empirically in these studies to a large extent determine the conclusions that are reached.

4.1 MH/MD as an attribute of IAMs

In IAMs, mitigation pathways for achieving specific temperature targets are ultimately the outcome of a cost-optimized combination of different technologies. The inclusion of a new set of supposedly cost-effective technologies (such as Bioenergy with Carbon Capture and Storage (BECCS)) in these models inevitably directs resources away from other mitigation technologies. Without the inclusion of large-scale CDR, models would need to rely on larger amounts of conventional mitigation to achieve the same temperature targets, and more near-term emission reductions overall (Healey et al., 2021). Alternatively, they would leave some emissions unabated, resulting in a breach of the 1.5°C or 2°C targets. Within the boundaries of these temperature thresholds, therefore, IAMs demonstrate an immediate trade-off between CDR and emission reductions.

This substitution dynamic is an inherent and generally agreed-upon attribute of IAMs, and is amplified by assumptions in the models that make CDR appear particularly attractive (Beck & Oomen, 2021; Low & Schäfer, 2020; van Beek et al., 2022). IAMs for example tend to allow for temperature overshoot and often feature high discount rates (5% is common), both of which lead to the deferral of emission reductions and significant reliance on future removals (Emmerling et al., 2019; Grant et al., 2021; Riahi et al., 2021). Lenzi (2018) calls this “mitigation obstruction by design” (p. 2) and argues that it is commonly recognized by modelers themselves. Likewise, Minx et al. (2018) observe that “the availability of [Negative Emissions Technologies] within climate models displaces some mitigation” and that this effect is widely acknowledged and “potentially very large” (p. 20). Grant et al. (2021) demonstrate this by introducing uncertainty of CDR deployment into their model, which significantly increases near-term emission reductions. In sum, while
the exact magnitude of substitution depends on a host of assumptions that vary across models and scenarios, and while the inclusion of removals in IAMs may increase overall mitigation ambitions, it is unequivocal that it also substitutes for reductions, and does so on very large scales (Grant et al., 2021; McLaren, 2020).

The substitution of emission reductions in models leads scholars to argue that science is a key arena where MH/MD risks play out, raising “ethical questions about appropriate research design” (Minx et al., 2018). Indeed, a now extensive literature argues that specific assumptions made across IAMs result in modeled mitigation pathways that downplay the need and opportunities for phasing out fossil fuels, which in turn may inspire political complacency (Anderson & Peters, 2016; Carton, 2020; Larkin et al., 2017; Stoddard et al., 2021). This literature sees modeling results as fundamentally performative, that is, they do not just represent different policy options, but also help bring these into being (Beck & Mahony, 2017, 2018; Beck & Oomen, 2021; Rivadeneira & Carton, 2022). Such concerns caution against an overly rigid distinction between MH/MD dynamics in models and “the real world”. While abstract and hypothetical exercises, IAMs are not isolated from political reality, but help create authoritative narratives around CDR, including ones that legitimize the substitution of emission reductions (Markusson et al., 2018).

However, not all scientists interpret substitution in models as a form of MH/MD. Belaia et al. (2021), for example, show that emission reductions are delayed when introducing CDR (and SRM) into the DICE model, but they argue that such delays are “optimal” and therefore distinct from the idea of MH, which in their view “should be defined as reductions in mitigation relative to the optimal policy that includes [solar geoengineering] and CDR” (p. 18). Their study is an attempt to distinguish between desirable and undesirable forms of substitution, using the economic reasoning put forward by Nordhaus (1992).

Belaia et al.’s argument points to a major but unarticulated disagreement in the MH/MD literature: What is the baseline against which “delay” and “substitution” should be measured? The “obstruction by design” argument rests on a comparison against a 1.5/2°C baseline that involves rapid near-term mitigation without, for example, BECCS or Direct Air Capture and Storage (DACCS). Belaia et al. implicitly argue for a different baseline, namely one that already incorporates an “optimal” amount of carbon removal. Yet another possibility is that in the absence of large-scale CDR, emissions reductions alone would fail to keep global temperatures below 1.5/2°C. In this case, the relevant baseline for assessing MH/MD claims should be scenarios that result in higher temperatures. Whether CDR substitutes for reductions or complements them partly comes down to this (often unarticulated) choice of baseline – that is, what one believes would happen without removals and how one views the possibility of far more radical emission reductions, e.g. through demand-side measures and/or degrowth pathways (Keyßer & Lenzen, 2021; Muraca & Neuber, 2018). If you believe that the world cannot achieve ambitious temperature targets in the absence of large-scale CDR, those removals inevitably appear complementary to emission reductions. If instead, you think it is possible that widespread emission reductions can happen significantly more rapidly than suggested in CDR-heavy pathways, then CDR clearly functions as a substitute. Here, then, is another way in which competing interpretations of MH/MD rely on subjective assumptions about the world and the limits of social, political, and/or technological change.

### 4.2 Individualistic accounts of MH/MD

Turning now to examinations of MH/MD outside of the confines of models, we first consider studies that rely on individualistic conceptualizations. By this, we mean approaches that focus on the perceptions, preference statements, and/or purportedly rational decision-making by autonomous actors, either individuals or institutions. A number of empirical studies approach MH/MD from this perspective, using a range of different methods. While many of these studies employ a general geoengineering framing that includes both CDR and SRM (Austin & Converse, 2021; Corner & Pidgeon, 2014; Lin, 2013; McLaren et al., 2016; Merk, Klaus, et al., 2019; Merk, Pönitzsch, & Rehdanz, 2019; Wibeck et al., 2017), some focus exclusively on CDR (Campbell-Arvai et al., 2017; Cox et al., 2020b; Hart et al., 2022; Wenger et al., 2021).

Some of these studies are premised on testing whether learning about CDR (or geoengineering as a whole) reduces the perceived threat of climate change and/or support for mitigation. Reynolds (2015) cites existing studies showing mixed results and even support for what he terms a “reverse moral hazard,” that is, the idea that learning about CDR/geoengineering leads to an increased willingness to undertake emission reductions (see also, e.g., Fabre & Wagner, 2020; Wagner & Zizzamia, 2021). Likewise, recent experimental studies in a US context by Hart et al. (2022) and Austin and Converse (2021) show little or no evidence that learning about CDR decreases support for mitigation action. In contrast, an earlier online survey of US citizens did find indications of MH/MD, as participants reduced their support
for mitigation policy when learning about BECCS (Campbell-Arvai et al., 2017). The ambiguous results from these studies should be interpreted with care. The observed “reverse moral hazard”, for instance, could just be the result of people realizing how dire the climate crisis is when being introduced to notions of CDR/geoengineering (McLaren et al., 2016).

A different way of assessing MH/MD is to examine how study participants allocate resources between different climate policy options. Merk, Pöntitzsch, and Rehdenz (2019) asked a variety of climate experts to allocate a limited carbon budget to either mitigation, adaptation, SRM, or CDR, and found that geoengineering experts “do not systematically reduce the share of the budget earmarked for mitigation” (p. 239). In a study based on economic games, Andrews et al. (2022) conclude that citizens do not demonstrate a tendency towards moral hazard, because they invest equally in mitigation efforts irrespective of whether geoengineering is available.

The studies mentioned above ask participants how they themselves think or would act. If the gaze is shifted to how people believe others (e.g., decision makers) react to CDR, then results tend to confirm MH/MD concerns. Participants in deliberative workshops organized in the US and UK by Cox et al. (2020b) identified MH/MD as a main concern and generally described CDR as a form of “non-transition”. Interviewees in another study rejected a binary choice between emissions reductions and CDR, but expressed concern about mitigation deterrence, worrying that it provides an opt-out for incumbent actors (Cox et al., 2020a). In the game experiment by Andrews et al. (2022), participants who played the role of policy makers steered away from geoengineering options because they anticipated that citizens would demonstrate MH behavior. Similarly, focus group participants in a study by Wibeck et al. (2015) worried that other people would treat geoengineering promises as alternatives to lifestyle changes, although they were not concerned about their own behavior.

A fourth group of studies tests how individuals react to arguments about MH/MD rather than CDR. Results vary. Corner and Pidgeon (2014) found that participants saw MH/MD as a real risk, while MH/MD claims were not deemed credible among participants in a study by Wenger et al. (2021). In research by Himmelsbach (2018), expert interviewees went so far as to describe MH/MD claims as irrational. Bellamy et al. (2021) found that stakeholders were already aware of MH/MD problems and that deliberation about these risks may help avoid them. These varying results illustrate the importance of considering how MH/MD is framed in surveys or workshops. For instance, the study by Wenger et al. (2021), which found that citizens do not deem a moral hazard framing credible, presented the MH concern to participants like this: “NETs offer us the solution for reducing climate change. This means that we do not have to reduce our emissions or change our way of life.” This framing actually asks people if they believe that NETs can carry the entire mitigation burden on its own, rather than whether they are concerned with substitution. When participants rejected this framing, the conclusion should arguably be that they do not believe CDR can stand alone as a climate “solution”—rather than that they dismiss the risk of moral hazard.

Our review of the individualistic literature thus shows a variety of conclusions that may in part be explained by framing and choice of method. For instance, while studies of how individuals react to CDR show little support for the MH/MD hypothesis, studies of how individuals think others react tend to show support. This divergence could be due to MH/MD being a less virtuous characteristic, leading people to underreport it to researchers when asked directly (Rosenfeld et al., 2016). We also observe that conclusions on how individuals assess arguments about MH/MD seem sensitive to the precise framing used in studies, and that there is reason to be cautious about the interpretation of responses.

More generally, questions can be raised about the broader relevance of these studies. Even if it could be shown that the general public, experts, or even policy makers tend to exhibit MH/MD in the controlled contexts of scientific studies, it is unclear how those findings would be transferrable to much more messy, real-world settings (Ott, 2018; Svoboda, 2017), where the actions of individual actors do not just reflect their own preferences or the outcomes of rational, deliberate decision-making, but tend to be “cultivated, by vanguard visions, political leaders, activists, and media environments” (Oomen, 2021). Numerous social, cultural, economic, and political processes shape the choices that individual actors (can) make, which might make carbon removal an alluring substitute for emission reductions even when it seems entirely irrational to do so (Muraca & Neuber, 2018; Scott, 2018). Understanding how MH/MD risks play out, therefore, requires that we take these structural processes seriously.

### 4.3 Structural accounts of MH/MD

A third strand of MH/MD scholarship focuses on social, cultural, economic, and political processes and how these play out as uneven power relations, material conditions, and collective discourses and narratives. These operate at several scales and in different contexts and are not necessarily the result of any actor’s intentional choices (Markusson et al., 2018). A common thread in this literature is questions of justice and fairness, such as the various trade-offs and
side-effects of different CDR methods (Horton & Reynolds, 2016; McLaren et al., 2016; McLaren & Corry, 2021; Preston, 2013; Waller et al., 2020), the additional mitigation burden that delayed climate action places on future generations (McLaren et al., 2016; Waller et al., 2020; Wieding et al., 2020), the effects of CDR on existing inequalities (Healey et al., 2021), or the procedural injustices associated with implementing and governing carbon removal (McLaren et al., 2016).

Some of the studies we have classified as individualistic also highlight these structural dimensions of MH/MD. Carbon removal experts interviewed by Cox et al. (2020a) for example expressed a general concern for how removal would work “within existing incumbent capitalist systems” (p. 211) and had reservations about the role of private corporations in financing, researching, and developing carbon removal. Similarly, in a series of deliberative workshops organized by McLaren et al. (2021), participants expressed concerns about the role of vested interests and incumbency in the development and deployment of carbon removal. They felt that carbon-intensive industries had a strong motivation to exploit carbon removal opportunities in order to avoid stranded fossil fuel assets (in line with, e.g., Pradhan et al. (2021)). These industries were deemed likely to co-opt removals as offsets and to try and strategically exploit weaknesses in policies that incentivize removals: “The thing with any system you put together...Barclays Bank have some skyscraper in Canary Wharf full of people just looking for loopholes” (p. 8). Participants were particularly skeptical about the role of carbon markets in governing removals, and also reflected on the interests that government, industry, and the general public have in upholding current lifestyles and consumption patterns.

These concerns resonate with a growing literature on the political economy of large-scale CDR. Scott (2018) for example argues that allowing the private sector to develop technologies such as DACCS and create property rights for them creates financial incentives to promote those technologies even if alternative technologies would better serve public interests” (p. 73). Muraca and Neuber (2018) observe that because businesses are dependent on guaranteeing profit, they have an engrained interest in “minimizing mitigation costs in the short run” (p. 1820). This limits the scope of mitigation options they might be interested in and predisposes them to offloading environmental costs on other social groups or regions, or into the future, for example, through the use of carbon removal. Carton (2019) too identifies close compatibility between large-scale carbon removal and the interests of carbon-intensive industries, arguing that removals are attractive for these industries because they help moderate the devaluation of fossil fuel assets (see also Hall & Davis, 2021). Taken together, this literature suggests that a combination of economic and political commitments to existing infrastructures and energy strategies is creating path dependencies that make non-CDR pathways seem unfeasible (Oomen, 2021; Rabitz et al., 2022; Sarnoff, 2020).

Structural MH/MD accounts thereby highlight how the promise of future removal fulfills an important function for incumbent actors, reducing the “perceived economic threat of mitigation” (Gunderson et al., 2019, p. 2) while seemingly alleviating social demands for effective climate action (Carton, 2019; Ott, 2018). They stress that, like most technologies in contemporary society, CDR is likely to be organized in ways that “serve the dominant interests” (Gunderson et al., 2019, p. 3). Aside from legitimizing carbon-intensive production processes, this may occur by diverting captured carbon into new commodity chains, potentially leading to an unfulfilled promise of permanent removal (compare McLaren, 2020). Already now, some actors are casting CDR as primarily a business opportunity, for instance to enable enhanced oil recovery (Buck, 2021b; Long & Scott, 2013) and the production of “carbon negative oil” (Coffin, 2021). Plans also exist to turn CO₂ into synthetic fuels or use it as a feedstock for all kinds of consumer products, from shoes to food and vodka (Malm & Carton, 2021; Stuart et al., 2020).

Scholars also identify structural MH/MD dynamics within climate policy. Governments’ endorsement of carbon sinks to help offset emissions was a central controversy in the negotiations of the Kyoto Protocol (Dooley & Gupta, 2017), where some of the countries most hostile to international climate policy emerged as the strongest carbon sink proponents (Jung, 2004). Renewed focus on land-based sinks could give these dynamics fresh impetus. And as has been the case with fossil CCS (Markusson et al., 2017; Stuart et al., 2020), countries might have reasons to promote BECCS as an alternative to more politically unpopular forms of mitigation (see, e.g., Geden et al., 2018). Recent studies already bear out some of these concerns: in national climate plans submitted to the UN and EU, countries are relying on significant amounts of land-based CDR (Dooley et al., 2022; Smith et al., 2022). The plans of for instance the UK and US even explicitly state “that CDR (mainly BECCS) could allow other sectors to decarbonize more slowly” (Buylova et al., 2021, p. 11). These examples illustrate the already existing use of CDR for strategic political purposes, allowing the alignment of otherwise conflicting interests (see Geden, 2016; Jegen & Mérand, 2014)—in this case, seemingly ambitious climate action and continued dependence on carbon-intensive activities.

In sum, a substantial literature discusses structural mitigation deterrence dynamics, drawing on a wide range of backgrounds and concepts, and often describing MH/MD as an outcome of neoliberal capitalism (Markusson
et al., 2022; McLaren & Markusson, 2020). For the most part, this literature remains on a theoretical and conceptual plane, depicting and theorizing likely mechanisms through which MD could occur, but not necessarily illustrating them empirically (though see Malm & Carton, 2021; Buylova et al., 2021; Stuart et al., 2020). Partly, this is because CDR has so far manifested itself mainly as a future promise. Now that CDR is moving from conjecture into actual policymaking, corporate investments, the emergence of start-ups, and on-the-ground projects, more empirical and case-based accounts of MD become possible and indeed necessary. In the remainder of this paper, we argue that taking structural dimensions of MH/MD seriously means moving away from debates on whether or not MH/MD is a thing, to a discussion of how it manifests itself in different spatial and temporal contexts, among different actors, and what can be done to contain it.

5 WHY A STRUCTURAL UNDERSTANDING OF MH/MD IS NECESSARY

The different approaches to MH/MD that emerge from this review are indicative of an implicit disagreement on what constitutes evidence of delay or deterrence. To make MH/MD scholarship useful for assessing ongoing political and economic developments with CDR, we see a need to broaden common understandings of what evidence looks like in the MH/MD debate, and foreground social science epistemologies that take structural dimensions seriously.

Current controversies surrounding the proliferation of net zero pledges illustrate this need. The recent explosion of such pledges vividly shows the key role that CDR now plays in climate policy—as part of an objective to achieve “a balance between anthropogenic emissions by sources and removals by sinks of GHGs” (United Nations Framework Convention on Climate Change (UNFCCC), 2015, art. 4)—but also puts in focus the real risk of substitution. Numerous assessments have found that net zero pledges are insufficiently transparent or specific (Day et al., 2022; Hans et al., 2022; Rogelj et al., 2021), bet on excessive amounts of land-based removals (Dooley et al., 2022), and allow the proclamation of ambitious climate policy by corporations who continue to invest in new fossil fuel extraction (Bragg et al., 2021). Some companies seem intent on achieving their net zero targets by offsetting a substantial part of their emissions with CDR, including some that are generally seen as easy to abate (Greenpeace UK, 2021). Concerned by the profusion of unsupported pledges, the UN recently published 10 recommendations to increase the quality of net zero targets and “draw a red line around greenwashing” (HLEG, 2022). These recommendations follow calls by scientists to separate targets for emission reductions and CDR (Healey et al., 2021; McLaren et al., 2019) and significantly improve on net zero pledges more generally (Fankhauser et al., 2021; Rogelj et al., 2021).

For many critics, the various forms of greenwashing occurring under the guise of net zero constitute a strong indication of MH/MD (Dyke et al., 2021; Friends of the Earth, 2021; Stabinsky et al., 2021). Some of the above assessments explicitly identify net emissions accounting and the widespread embrace of removals as one more mechanism for corporations to delay or deter rapid emission reductions. This emerging CDR governance landscape exemplifies the increasing importance of structural MH/MD analyses. This is because the forms of evidence that IAM assessments and individualist studies seek are a poor fit for understanding the kind of dynamics emanating from the net zero debate. For instance, analyzing net zero pledges in the same way as one would be modeled mitigation pathways would entail making an assumption about counterfactual baselines: would a target-setting entity have eliminated more of its emissions in the absence of large-scale CDR, or would it simply have missed its targets? Which of these alternative futures is true is a question that cannot be answered.

Similarly, individualist MH/MD studies tend to rely on experimental or hypothetical settings that seem of limited relevance for understanding the net zero debate in all its complexity. The concerns raised in the net zero literature point to the important role that norms and values, unequal abatement opportunities, and at least partly conflicting social, economic, and political interests and conditions play in how different actors are setting targets. Considering these structural factors is necessary to help explain why some companies seem intent on achieving their net zero goals almost exclusively with emission reductions, while others are betting heavily on (mostly nonpermanent) removals (Day et al., 2022). Some companies clearly have a vested interest in continuing to exploit fossil fuels, while others have much to gain from full decarbonization. Some might be more sensitive to consumer or shareholder pressures, have limited capacity for decarbonization, or simply be ideologically fixated on resisting rapid mitigation. Company “preferences” will also be conditioned by how CDR is governed. Currently, many companies already claim carbon neutrality because the availability of cheap and low-quality offsets (including some removals) provides an easy and cost-effective way to do so. If weak regulation enables those conditions to persist, then that will affect the rationale for substitution under net zero as well.
To abstract from these dynamics in attempts to find evidence for or against MH/MD seems exceedingly odd and yields an unsatisfactory assessment of the actual political risks entailed by carbon removal. No amount of modeling or experimental studies can tell us what targets companies or countries would have set in the absence of carbon removal, under actually existing social, political, and economic conditions. Taking these conditions seriously, therefore, entails a need to foreground structural accounts in efforts to understand the risks and dynamics of substitution. This starts by asking what we know about how contemporary society operates and what that means for the likely use and deployment of CDR. It means exploring how different actors engage with the net zero concept, and in what ways those engagements align or conflict with their political or economic interests. Given what we already know about the power relations that prevail in fossil-fuelled society, it would be irresponsible not to ask these questions, and what they mean for the likelihood that CDR will be used in ways that end up compromising climate targets.

Close attention to such structural processes provides a retort to common critiques of the MH/MD concept, including the idea that it has a weak empirical basis (Colvin et al., 2020) or that it is exclusively a construct of IAMs (Uden et al., 2021). A paper by Jebari et al. (2021) presents perhaps the most elaborate version of this critique, arguing that MH/MD concerns might be a self-fulfilling prophecy and themselves constitute a moral hazard, because they make it seem “as though the use of carbon capture or solar geoengineering technologies can serve as potential substitutes for mitigation efforts” (Jebari et al., 2021, p. 3). Their critique illustrates a common misunderstanding of the MH/MD argument, namely that it casts emission reductions and carbon removal as an either/or question. The assumption here seems to be that MH/MD concerns entail that removals would substitute for all emission reductions. Yet few MH/MD accounts contrast 100% emission reductions with 100% removals—the reason some scholars are concerned about net zero pledges certainly is not that companies now only intend to invest in removals. Nor does the MH/MD problem disappear just because some degree of carbon removal is acknowledged as “unavoidable”—at a minimum because the global carbon cycle is unavoidable. CDR evidently does play a role—the question is which one. It matters whether we rely on 95% emission reductions and 5% removals to balance out agricultural emissions, or on 70% emission reductions and 30% removals to compensate for the emissions of companies or wealthy individuals that deem it inconvenient to decarbonize. It makes all the difference what balance is enshrined in net zero targets, which is why separate targets are so important (McLaren et al., 2019).

Jebari et al.’s (2021) main point—“Policy makers don’t have to choose between emission reductions and removals—we need to do both”—is an increasingly common argument in the public debate on removals. As a rebuttal to MH/MD concerns, it is deeply unhelpful. It evacuates power and politics from the CDR discussion by simply wishing away the potential for trade-offs and conflicts. It fails to ask the perhaps single most important question in the net zero debate right now: How much of each should different actors be doing, and who decides that—on what grounds? And how do we prevent incumbent and politically powerful actors from claiming their own emissions as “unavoidable”—not because they are technically impossible to eliminate, but because it is politically or economically inconvenient to do so? (see, e.g., Buck et al., 2023). These are real questions that policy makers, businesses, and researchers need to grapple with, and that the MH/MD literature forces us to take seriously. A structural MH/MD perspective, in other words, foregrounds a concern for the pace and scope of decarbonization and centers on an analysis of the political, economic, social, and cultural dynamics that might tip the net zero balance in the wrong direction.

6 | ADVANCING THE DEBATE ON MH/MD

In this review, we have identified and discussed three common approaches to MH/MD in the scientific literature, and analyzed how these relate to conceptual and methodological diversity and the way evidence for delay or deterrence is understood.

We find, first, that scholars tend to agree that there are significant MH/MD effects in IAM scenarios, even if they disagree on whether that has any bearing on the real world—despite literature discussing the performativity of climate model output. Second, we find that research based on individualist conceptualizations (and methodologies) tends to be most skeptical of MH/MD concerns, with various studies suggesting there is no evidence for MH/MD, or even indications of the opposite effect. These studies build on an epistemology where proof for or against delay or deterrence is derived from individual actors’ preference-statements, perceptions, choices, or actions. Because studies do not show a consistent tendency towards MH/MD among participants, the empirical basis for MH/MD is then questioned (Colvin et al., 2020). We argue that the limitations of this approach, in terms of interpretation of results and real-world relevance, means that the ambiguity of the evidence in these studies does not constitute evidence that MH/MD is absent.
Third, we suggest that structural accounts, among others drawing on political economy, provide us with the tools necessary to understand whether and how substitution is playing out across various social and political contexts, as for instance in net zero pledges. Generally speaking, such accounts rely on two modes of analysis (Ott, 2018): The first explores theoretically how political and economic systems operate, what dynamics and power relations exist within them, what kind of functions CDR performs within these and therefore whether MH/MD risks seem likely. Our review shows that structural accounts of MH/MD predominantly take this theoretical approach and find an abundance of reasons for why substitution between carbon removal and emission reductions is an exceedingly likely prospect, and why that would entail risks and undesirable social and environmental effects. The second mode of structural analysis draws on more empirical methods. There are so far few studies of this kind.

We believe more attention to empirically focused, structural analysis would significantly advance the conversation on MH/MD. It could help us understand why opportunities and promises of carbon removal find support in society, and in which contexts they do so (Ott, 2018). One way of doing this could be to analyze the discourses and narratives of different actors in the emerging CDR space. Such “framing analysis” is already used in similar contexts (see, e.g., Gunderson et al., 2019 for CCS) and could help answer whether and how carbon removal is being legitimized or promoted by various companies, policy makers, interest organizations or researchers, what purposes and interests this serves, and what implications it might have for mitigation ambitions or indeed broader environmental justice goals. Empirical MH/MD research could also analyze emerging CDR funding networks and governance approaches; how different actors are positioned, or position themselves, in the CDR value chain, toward different removal methods; how different localities are imagined as CDR spaces; how net zero pledges are used and/or translated into concrete projects on the ground; etc. Aside from net zero pledges, a logical starting point for a structural research agenda on MH/MD is the carbon (offset) market, which is being imagined as a crucial tool for scaling removals, yet also facilitates the kinds of substitution—based on economic logics—that lie at the heart of MH/MD concerns (Joppa et al., 2021).

Taking a step back, our review finds a clear connection between epistemological choices (and methods) made in the literature, and the evidence that studies find, or do not find, for MH/MD. If nothing else, this illustrates the deeply subjective, normative undertones of the debate. Abstracting away from the uneven power relations and vested interests that characterize our deeply suboptimal world, as tends to happen in individualistic MH/MD accounts, is to turn a blind eye to certain forms of evidence, and ultimately leaves those interests and power relations unchallenged. Structural accounts too, of course, make normative assumptions about the world. These assumptions too need to be scrutinized, and we would contend that the explicitly political nature of many of these accounts generally tends to facilitate such scrutiny. More critical attention to the political and normative assumptions underlying various MH/MD claims is important to help broaden the kind of questions being asked in this debate.

While theorization remains crucially important, the time is ripe to complement it with empirical understandings of the rapidly developing political and economic realities of MH/MD, across different geographical and temporal settings. In the current climate policy environment, with the rapid proliferation of ambiguous net zero pledges and the emergence of numerous CDR policy initiatives, such research is not only important but critical to prevent widespread mitigation deterrence.

**AUTHOR CONTRIBUTIONS**

**Wim Carton:** Conceptualization (equal); funding acquisition (lead); investigation (equal); writing – original draft (lead); writing – review and editing (lead). **Inge-Merete Hougaard:** Conceptualization (equal); data curation (lead); formal analysis (lead); investigation (equal); methodology (lead); writing – original draft (equal); writing – review and editing (equal). **Nils Markusson:** Conceptualization (equal); formal analysis (supporting); investigation (equal); writing – original draft (equal); writing – review and editing (equal). **Jens Friis Lund:** Conceptualization (equal); investigation (supporting); writing – original draft (supporting); writing – review and editing (supporting).

**ACKNOWLEDGMENT**

We would like to thank Jonas Allesson, Lina Lefstad, Kirstine Lund Christiansen, and Natalia Rubiano for helpful comments on an earlier version of this text.

**FUNDING INFORMATION**

The authors gratefully acknowledge research funding from the Swedish Research Council for Sustainable Development (FORMAS), dnr. 2018-01686 and dnr. 2019-01953.
CONFLICT OF INTEREST
There are no conflicts of interest to declare.

DATA AVAILABILITY STATEMENT
Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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ENDNOTE
1 Whether CDR actually is cheaper than emission reductions is contested, and will depend on the CDR method and the mitigation action that it is compared with. For afforestation, past experiences on the voluntary offset market show its appeal as a cost-effective alternative to emission reductions. Technologies such as BECCS and DACCS on the other hand might be attractive mainly because of the assumptions made in models (e.g., discount rates, or models’ tendency to see mitigation as a cost rather than an investment).

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SUPPORTING INFORMATION

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How to cite this article: Carton, W., Hougaard, I.-M., Markusson, N., & Lund, J. F. (2023). Is carbon removal delaying emission reductions? WIREs Climate Change, 14(4), e826. https://doi.org/10.1002/wcc.826