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Navigating Potential Hype and Opportunity in Governing Marine Carbon Removal

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As the technical and political challenges of land-based carbon dioxide removal (CDR) approaches become more apparent, the oceans may be the new "blue" frontier for carbon drawdown strategies in climate governance. Drawing on lessons learnt from the way terrestrial carbon dioxide removal emerged, we explore increasing overall attention to marine environments and mCDR projects, and how this could manifest in four entwined knowledge systems and governance sectors. We consider how developments within and between these "frontiers" could result in different futures—where hype and over-promising around marine carbon drawdown could enable continued time-buying for the carbon economy without providing significant removals, or where reforms to modeling practices, policy development, innovation funding, and legal governance could seek co-benefits between ocean protection, economy, and climate.

Keywords: marine governance, carbon dioxide removal, negative emissions, Net Zero, IPCC scenarios, climate policy, blue economy, marine law

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IS BLUE THE NEW GREEN?

Marine environments are the blue frontier of a strategy for novel carbon sinks in post-Paris climate governance, from "nature-based" ecosystem management to industrial-scale technological interventions in the Earth system (**Figure 1**). *Marine carbon dioxide removal* (mCDR) approaches are diverse (Royal Society/Royal Academy of Engineering (RS/RAE), 2018; GESAMP, 2019)—although several resemble key terrestrial CDR (tCDR) proposals. Ocean alkalinisation (adding silicate mineral such as olivine to coastal seawater, to increase CO_2 uptake through chemical reactions) is enhanced weathering, "blue carbon" (enhancing natural biological CO_2 drawdown from coastal vegetation) is marine reforestation, and cultivation of marine biomass (i.e., seaweed) for coupling with consequent carbon capture and storage (CCS) is the marine variant of bioenergy and CCS (BECCS).

Wetlands, coasts, and the open ocean are being conceived of and developed as managed carbon removal-and-storage sites, with practices expanded from the use of soils and forests. In this article, we explore increasing overall attention to marine environments and mCDR projects,

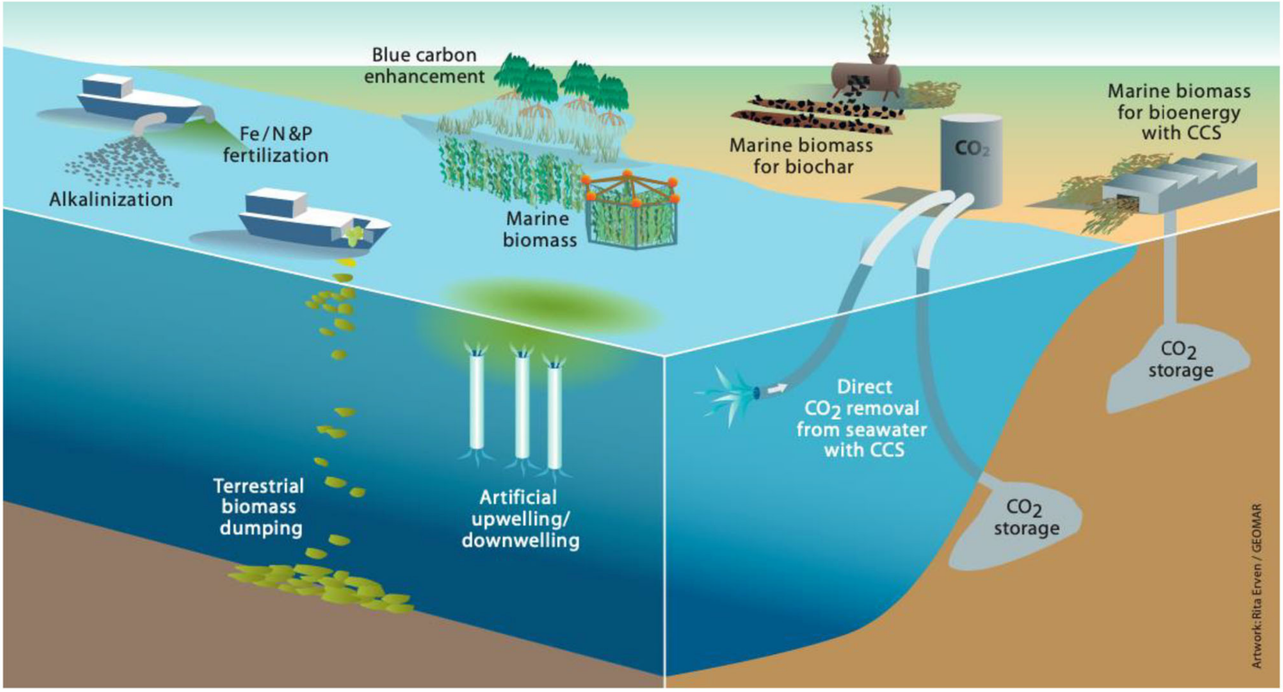

FIGURE 1 | An overview of proposed marine carbon dioxide removal (mCDR) options, artwork © Rita Erven/GEOMAR.

and how this could manifest in four entwined knowledge systems and governance sectors: modeling pathways (in Intergovernmental Panel on Climate Change reports), climate policy and politics (the Paris Agreement and Net Zero commitments), innovation, and international legal frameworks. We compare growing interest in mCDR with that surrounding BECCS—an imperfect proxy for tCDR—as a springboard for thinking about mCDR's knowledge and innovation economy, potentials, and governance of research and development.

Why does BECCS matter? BECCS, and through it, the prospect of large-scale tCDR, emerged at the confluence of key trends in climate assessment and governance: it is an immature technological system that allows ambitious temperature targets to be reached in IPCC mitigation pathways, while reflecting rationales for "buying time" in climate policy and industry (Low and Boettcher, 2020; McLaren and Markusson, 2020). These trends are escalating how terrestrial environments have been made thinkable and practicable as operating spaces for CDR, and reinforcing the legitimacy of CDR as a response to climate change. Throughout, we refer to the dangers of hype and over-promising—by which we intend both the everyday meaning of exaggerative promotion, as well as the processes by which speculative, evolving assessments implicitly or intentionally support novel technologies (e.g., Brown et al., 2000).

But the technical and political feasibility of BECCS has come under deep questioning. Furthermore, there are concerns that BECCS is politically useful precisely as an idea; permitting mitigation pathway modeling and policy rhetoric to expand the (near-term) carbon budget (Carton et al., 2020). Meanwhile, planning around eventual carbon removal could become yet another factor in delaying decarbonization. Hence, we maintain BECCS and tCDR as a guiding comparison–but our interest is on how mCDR could come to prominence, and what kind of governance would be needed to ensure that on balance, mCDR supports rather than undermines opportunities for decarbonisation and sustainable development.

MODELING PATHWAYS

BECCS features heavily in mitigation pathways of the IPCC's Fifth Assessment Report and Special Report on 1.5C–projected by cost-optimizing integrated assessment models (IAMs)–for both technical and political rationales (van Beek et al., 2020). Most CDR technologies consume energy, while in some configurations BECCS increases availability of energy. Moreover, because both bioenergy and CCS were already included in IAMs, it was an easier task for modelers to expand their applications–crucially, in a modified and optimistic form. In reality, applications are less effective, need more space, and are combined with enhanced oil recovery (EOR) (GCCS, 2017; Fuss et al., 2018). Politically, modeling BECCS helps achieve target carbon budgets more cheaply by delaying costly near-term emissions reduction and replacing it with CDR whose future costs are discounted (Rogelj et al., 2019; McLaren, 2020).

But significant limits to tCDR are already foreseen, especially in land competition for biomass production (Smith et al., 2019; Doelman et al., 2020). As carbon budgets deplete, IAM work could instead adopt mBECCS: biomass taken from marine sources (i.e., Hughes et al., 2012) would maintain BECCS' advantage as an energy gain. Alternatively, other mCDR options might suggest new co-benefits. Blue carbon–e.g., seagrass or mangrove restoration–could sequester carbon while extending underwater natural habitats and increasing biodiversity (Hejnowicz et al., 2015; Vierros, 2017). Ocean alkalinization potentially removes large amounts of carbon due to large available surface (e.g., Kheshgi, 1995; Hartmann et al., 2013; Keller et al., 2014; Ferrer-Gonzalez and Ilyina, 2015; Renforth and Henderson, 2017), while at the same time directly counteracting ocean acidification (Keller et al., 2018). Oceans suggest huge prospective scale and leverage in modeling approaches (Resplandy et al., 2019). Yet, the technical and social feasibility of using this potential is debatable (Bindoff et al., 2019; GESAMP, 2019).

Ideally, before mCDR approaches are considered in future IAM pathway development, insights from earth system modeling (ESM) should be incorporated. While IAMs have now been coupled with more comprehensive Land-Surface Models that (albeit partially) account for uncertainties surrounding tCDR measures, this was not the case when the modeling of BECCS at large scale began. Even now, most IAMs still only use highly simplistic models to account for ocean-based carbon and heat uptake (Nicholls et al., 2020), and do not account for ocean biogeochemistry at all. An IAM minimally requires only parameters for carbon uptake potential and cost. Additional system-level feedbacks from ESMs–like leakage of CO_2 from the ocean to the atmosphere–*can* be incorporated in IAMs using aggregate emulators, but the magnitude is still subject to large uncertainties (Keller et al., 2018). In summary, mCDR could be implementable in IAMs, but through highly simplified renderings.

Given these considerations, it is unclear whether IAMs might trigger similar hype over mCDR. Yet if mCDR was included in IAMs, the physical uncertainties involved would be sidelined by the IAM imperative toward producing cost-optimized mitigation pathways over time. And modeling could yet inflate an mCDR bubble initiated elsewhere.

CLIMATE POLICY AND POLITICS

The introduction of BECCS into modeled pathways was facilitated by a change in how climate targets were expressed: via "carbon budgets." tCDR—relying on novel anthropogenic removals as well as on enhancement of natural sinks—has gained disproportionate importance as an essential mechanism to stabilize atmospheric CO_2 at concentrations compatible with the 2°C target (McLaren and Markusson, 2020).

The Paris Agreement has since cemented two critical roles for CDR. First, the 1.5°C aspiration brought CDR-heavy pathways to the fore as a way to further stretch the near-term carbon budget: a *time-buying* (Low and Boettcher, 2020) or *stopgap* strategy (Buck et al., 2020a) to ease impacts for vulnerable industries and populations during low carbon transitions. Second, the commitment to achieve Net Zero from "a balance of sources and sinks" makes CDR essential for *capturing residual emissions* accumulating in the atmosphere from the (transitioning) carbon economy (Morrow et al., 2020). CDR arguably underpins a green transition at both ends: highly desirable to wean the economy off carbon dependence today, and essential to clean up what carbon is left in the atmosphere afterward (Buck, 2019).

Parallel to these developments, the role of the oceans has been becoming increasingly central to international climate policy discussions. At COP 21, 23 UNFCCC parties issued the "Because the Ocean" declaration, claiming the Paris Agreement was too land-centric (Because the Ocean, 2015). A second "Because the Ocean" declaration was signed at COP 22 in 2016 by 39 countries, and an agreement was reached to give greater attention to the ocean at subsequent COPs (Because the Ocean, 2016). Recent policy-focused analyses have highlighted opportunities for ocean-based climate action in Nationally Determined Contributions (NDCs) (Gallo et al., 2017) and emphasized "ocean solutions" (e.g., Gattuso et al., 2018, 2021) and an assessment of ocean-based climate strategies was included in in Chapter 5 of the 2019 IPCC Special Report on Ocean and Cryosphere in a Changing Climate (Bindoff et al., 2019).

Whether terrestrial or marine, CDR does not have to be delivered at scale in order to exert perverse effects in climate governance. Rather, CDR may already be powerful as a promise that ongoing emissions can be reversed (Geden, 2016). Rhetoric on scaling up carbon sinks bridges the gap in reality between slow progress and future aspirations for climate action. In this sense, it may prematurely promise a "technological fix"—a technological solution to an otherwise intractable political problem (Nightingale et al., 2019). Indeed, CDR has the potential—if not guarded against in research and governance—to follow in the tracks of Kyoto Protocol-era carbon trading and offset schemes, carbon capture and storage, biofuels, shale gas, and other sociotechnical options in climate governance in which rationales and avenues for delaying and disincentivizing deep emissions cuts have emerged (Carton et al., 2020; Low and Boettcher, 2020; McLaren and Markusson, 2020).

Nonetheless, CDR loses credibility if it becomes implausible within modeling or real-world constraints. There is precedent: buying time with CCS—which has yet to be implemented at a globally-meaningful scale despite a history of over-promising (Krüger, 2017; Røttereng, 2018)—has now had to be further supplemented by CDR and BECCS (McLaren and Markusson, 2020). And now, projections of the adverse impacts of BECCS at scale may be causing it to lose credibility in both models and in political discussions. Without a credible prospect of large-scale CDR, this mutually-reinforcing complex of targets and modeling (Geden, 2016) will come under stress to generate emergency action, or find a new technology or strategy to enable continued time-buying.

CDR advocates might also hope to escape the limits that sovereign territories impose on land-bound techniques. It might be tempting for global powers or big business, pursuing neoliberal politics, to treat the "high seas" as a new frontier for overuse and exploitation (Mansfield, 2004). Existing opportunities could entrench such geopolitical and commercial moves. Providing new sinks for integration into carbon markets, following established logics and instruments for carbon offsetting and trading, may be attractive both commercially and politically (Schneider et al., 2019). Opportunities surrounding still-immature "bridging" fuels, such as algae-for-oil and marine biofuels, may be influential (Maeda et al., 2018)—even though such deployments can undermine potential for long-term carbon storage (McLaren, 2020). And actors may seek to strategically position themselves for further exploitation of resources such as minerals and fisheries in the "blue economy."

INNOVATION AND INDUSTRY

The idea of the "blue economy" emerged from Rio+20 (Voyer et al., 2018), and mCDR arises in this context. The story of terrestrial limits being transcended through development of marine frontiers is already mapped out for aquaculture (the "blue revolution" to bring cultivation to oceanic space), biofuels, and mineral and resource extraction (deep-sea mining); it follows a "blue growth" logic, as the availability of land and land-based resources seems foreclosed. Discourses prevalent in the blue economy–oceans as natural capital, as good business, as integral to small island developing states, as small-scale fisheries (ibid.)–are all present in the umbrella concept of mCDR.

This connection with the blue economy implies different sorts of actor coalitions than feature in tCDR, and perhaps different rationales. Coalitions may include ocean conservation organizations concerned with the dire state of the oceans (e.g., Blue Carbon Initiative (BCI), 2012; World Wildlife Fund (WWF), 2021a,b), as well as firms developing ocean sensing and monitoring technologies (e.g., Solid Carbon, 2020; Ocean Networks Canada, 2021). In the US and Germany, key oceanic research institutes and networks are developing road maps citing "enormous potential" (Oceans Visions Alliance, 2021) and "sustainable utilization" of mCDR (Deutsche Allianz Meeresforschung (DAM), 2020), and some seek to explore the potentials of commercial viability. Insofar as the ocean is perceived as both "a new economic and epistemological frontier" (Ertör and Hadjimichael, 2020), new rationales for urgency and experimentation with mCDR may emerge.

However, the seas are not an empty frontier, but busy (Bennett, 2019), which will near-inevitably lead to ocean use conflicts. Marine spatial planning may be able to optimize interactions between carbon removal and other ocean uses (Boucquey et al., 2016). However, if local opposition to ocean exploitation on other fronts grows, this could be detrimental to the prospects of mCDR. Already there are concerns about displacement of coastal communities, "ocean grabbing," and privatization of seas and coastlines (Barbesgaard, 2018; Ertör and Hadjimichael, 2020).

Under a commercial orientation of research and development, mCDR is likely to be hyped, to attract venture capital. But venture capitalists have their own agenda, and the demands of investors for early profitability and "exit" (a trade sale or initial public offering allowing investors to recover their stakes) push green-tech down predictable paths (Buck, 2016 on tCDR specifically; Goldstein, 2018). Inventors are sidelined in favor of experienced financial and business managers, and long-term ambitions to transform society with disruptive technology are shelved in favor of configurations that can deliver profitable incremental gains in existing sectors. We should recall CCS and BECCS, where EOR dominates real-world applications, rather than long-term storage, despite optimistic scientific and commercial roadmaps (GCCS, 2017; Fuss et al., 2018).

While commercial interests may drive speculation and investment in mCDR, it is not likely to get very far without strong regulation and investment by the state, which can provide incentives and infrastructure. Carbon markets will matter in determining the fate of carbon captured in mCDR, but so will utilization opportunities and marketable "co-benefits." Endeavors such as the non-profit Project Vesta, for enhanced weathering in coastal environments (Project Vesta, 2021), or the philanthropically funded Ocean CDR knowledge hub (Ocean CDR, 2021), are founded by entrepreneurs or are designed to appeal to entrepreneurs, even though recognized market protocols for the forms of mCDR they explore have not fully emerged yet. Moreover, the entrepreneurial discourse tends to retain an amnesia about failed commercial attempts surrounding the introduction of ocean iron fertilization into voluntary markets (Strong et al., 2015). And large-scale offshore CCS projects (Southern States Energy Board (SSEB), 2021; Northern Lights, n.d.) seem likely to require expensive infrastructures dependent on state support and partnerships.

LAW AND GOVERNANCE

In contrast to state-regulated tCDR spaces, the ocean could be framed as comparatively free from regulation. Nevertheless, legally, the ocean is not an "open frontier." Coastal states' laws may regulate mCDR in their territorial sea (UNCLOS, art 2, 3) and exclusive economic zone (EEZ) where states have limited sovereign rights concerning natural resources, environmental protection and scientific research (ibid., art 56, 57). Numerous international regimes also provide rules regarding marine scientific research and environmental protection that are pertinent to mCDR in all marine jurisdictions. Key regimes include the Convention on the Law of the Sea (UNCLOS, Part XII, XIII) and the London Protocol for the Dumping of Waste at Sea (Brent et al., 2019).

There is, however, a significant governance gap regarding the utilization of the ocean as a carbon sink. The Paris Agreement adopted de facto limits for atmospheric CO_2 concentrations, but no such limits exist for ocean CO_2 uptake (Stephens, 2015). Preliminary attempts to govern mCDR through the 2013 amendment to the London Protocol (Brent et al., 2019) aim to prevent environmental harm rather than regulate common use of the ocean for carbon drawdown. The prospect of mCDR as part of the "blue economy" raises significant questions about governing the ocean as a carbon sink, not only regarding environmental protection but also equal access and benefit-sharing for developing states. Taken on its own, this governance

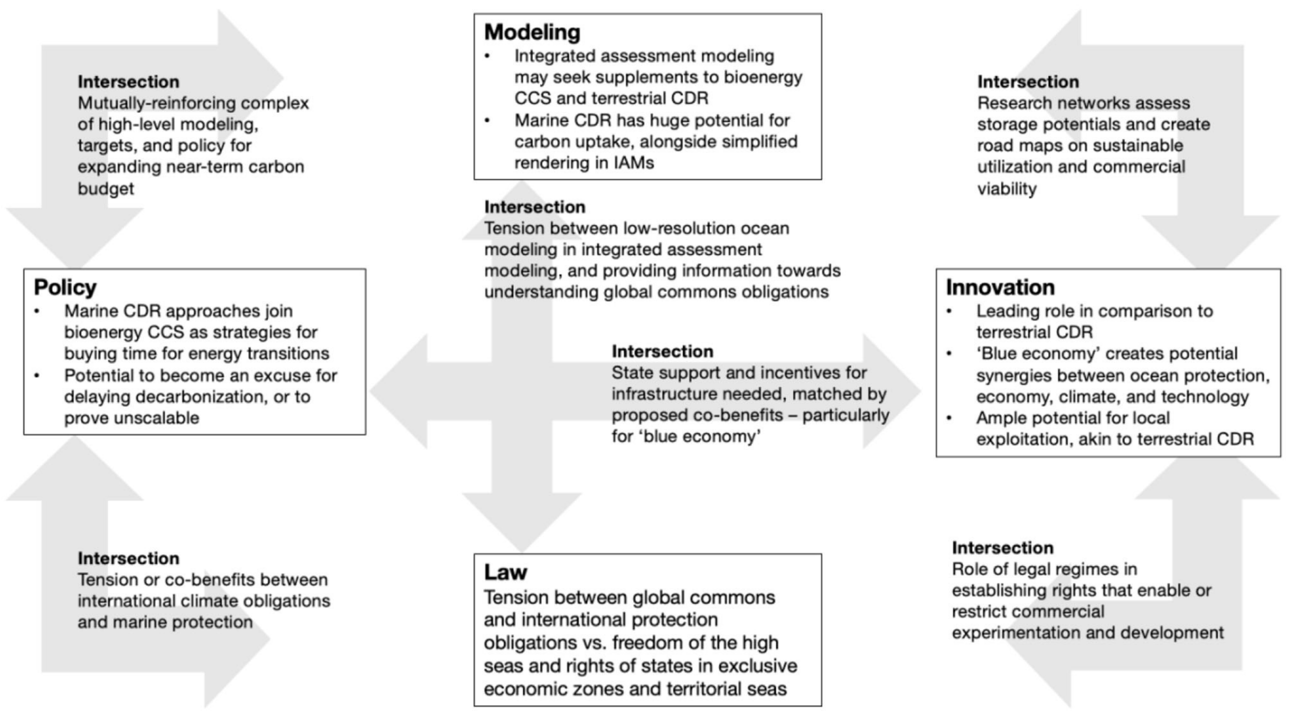

FIGURE 2 | Emerging frontiers for the governance of marine carbon dioxide removal (mCDR) options.

gap could suggest that this common resource is free to exploit. However, other rights and obligations in international ocean governance must still be considered—making different interpretations regarding mCDR possible.

For example, a state might conduct ocean alkalinization in territorial waters to minimize the effects of ocean acidification on coastal ecosystems, and associated tourism and shellfish industries (Renforth and Henderson, 2017). This activity would primarily be for the purpose of marine environmental protection, but could also result in CO_2 drawdown. Commercial interests and marketable co-benefits could play a role, especially if financial incentives were in place. The state responsible may claim the activity is consistent with international obligations to mitigate climate change *and* protect the marine environment (i.e., UNCLOS art 192), as well as their exclusive sovereign rights within their territorial sea (UNCLOS, art 2). However, other states could claim the OA activity is inconsistent with international law or require cooperation and coordination between states, especially if there is the risk of significant transboundary harm or impacts on the marine environment.

In addition to conflicting legal interpretations, this hypothetical example highlights broader tensions between different paradigms of ocean governance: the traditional focus on individual sovereign rights, vs. a more modern direction toward international cooperation and the safeguarding of the ocean as a common interest (Tanaka, 2019). Although still emerging, this second paradigm further weighs against any presumptions that states have unlimited sovereign rights in their own waters or absolute freedom in high seas areas to conduct mCDR. On balance, international oceans governance may discourage states, and by extension their citizens and corporations, from considering mCDR to be a convenient policy option.

CHARTING A COURSE

Tracking developments within and between these "frontiers" gives a more holistic picture of the contexts and activities through which marine environments are being imagined as enhanced carbon sinks, and the potentials and risks of mCDR are becoming understood (**Figure 2**). Unlike BECCS, mCDR is emerging less from a high-level modeling-policy complex (sections Modeling Pathways and Climate Policy and Politics), and more from innovation projects that pose co-benefits and conflicts between ocean protection, economy, and climate (section Innovation and Industry). Moreover, mCDR's "global commons" dimensions could serve as a springboard for more coordinated international governance (section Law and Governance). This mapping is double-edged: some possibilities are exploitative or delay decarbonization, while others present co-benefits underpinned by international legal obligations.

Let us consider the emergence of perverse logics in the research and governance of mCDR, and project a future to be avoided. In global modeling assessments, mCDR approaches bridge the growing gap between the Paris targets and mitigation efforts, as tCDR capacities run up against biophysical and techno-economic limits. Net Zero commitments spread further, with promised investments into patchworks of ecosystems management and industrial-scale approaches, and with an eye to integrating mCDR with carbon offsets and markets. These ambitions facilitate a spectrum of mCDR projects pushed in innovation circles under uneven regulation. The projects cite co-benefits between ocean protection and business, but create phantom commodities (ultimately proving unscalable) as investment sinks for governments and venture capitalists. Few removals are delivered, and many of those are deployed as offsets for continued emissions, or as stopgaps for carbon infrastructures. Meanwhile, international law produces contested implications for how to balance the right to use the oceanic commons as a carbon sink with the obligation of marine protection.

But we can imagine a different future, harnessing opportunities on these frontiers. Optimism for delivery of mCDR in line with climate and development goals demands careful steps to prevent hype and over-promising from these opportunities, including reforms in modeling practices, policy development, innovation funding and legal governance.

Parallels can be drawn directly with tCDR debates. To avoid unrealistic evaluation of future mCDR availabilities through limited treatments of techno-economic "feasibility" (Forster et al., 2020; Thoni et al., 2020), mitigation pathways and scientific roadmaps could be tempered with widespread, localized engagements on a range of mCDR projects, exploring the conditions that breed social resistance and commercial orientations that divert carbon away from long-term storage (Buck et al., 2020b; Low and Buck, 2020; Cox et al., 2021). Updates to Paris-mandated Nationally Determined Contributions must be wary of feeding mCDR into carbon offsetting and trading. Ongoing intergovernmental negotiations over Paris' Article 6 on potential market mechanisms could separate targets and processes for emissions reduced from decarbonization vs. those from CDR, forestalling double-counting (McLaren et al., 2019).

Governance can also harness conditions that differentiate marine from terrestrial spaces. Effective governance of the seas could be informed by existing transnational frameworks for governing aquaculture, marine food resources, and marine renewables, as well as from managing the seas for conservation. Cross-sectoral marine governance therefore offers opportunities: ocean conservation organizations could partner with research initiatives and innovation efforts. In the legal sphere, the right to use and the obligation to protect the ocean could be combined in novel co-benefits. States–working with research and environmental networks and commercial entities–could ensure that mCDR is in line with their international obligations to mitigate climate change and protect the oceans (e.g., from acidification), and their national right to use ocean resources as part of a "blue growth" strategy.

DATA AVAILABILITY STATEMENT

The original contributions generated for the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors contributed equally to the conceptualizing, writing, and editing of this perspective.

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