



Is mCDR pollution? Rethinking pollution for the governance of marine carbon dioxide removal

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ABSTRACT

Marine carbon dioxide removal (mCDR) is increasingly explored as component within the global response to climate change, yet its governance remains fragmented and conceptually unsettled. The London Convention and Protocol (LC/LP) provides a primary institutional home for the international governance of mCDR by regulating certain marine interventions as forms of potential pollution. While this classification is often treated as a technical or legal question, this Perspective argues that how mCDR is understood as pollution has important implications for governance. First, it argues that classifying mCDR as pollution provides an institutional anchor for precautionary oversight within LC/LP. Second, it shows that prevailing technocratic understandings of pollution are insufficient for governing mCDR. Third, it explains why recurring calls for more comprehensive and integrative governance of mCDR can be understood as responses to this conceptual mismatch. Drawing on relational conceptions of pollution, the paper reframes pollution as an activity that reconfigures social-ecological relations. In doing so, it provides a conceptual lens for interpreting ongoing developments in mCDR governance without requiring a departure from existing institutional frameworks.

1. Introduction

Marine carbon dioxide removal (mCDR) is emerging as a set of interventions in the marine environment intended to contribute to global climate goals by enhancing the ocean's potential for carbon sequestration and storage (Oschlies et al., 2025). A range of approaches for mCDR are under active scientific and private-sector investigation and include, for example, enhancing ocean alkalinity, large-scale sinking of carbon-rich biomass to the ocean floor and artificial upwelling of nutrient-rich deep-sea ocean water (GESAMP et al., 2019; Helber et al., 2025; NASEM, 2022). If effective and durable, these interventions could generate “negative emissions” that contribute to global net-zero targets (IPCC et al., 2018, IPCC et al., 2022). As interest in mCDR accelerates (Boettcher et al., 2021; De Pryck and Boettcher, 2024), so too does recognition of the deep uncertainties and ethical questions involved in deliberately altering an ocean already under stress from anthropogenic change (Baatz et al., 2025; Cooley et al., 2023; Voget-Kleschin et al., 2024).

The London Convention and Protocol (LC/LP) (IMO, 1996c; IMO, 1972), two interconnected treaties dedicated to the prevention of marine pollution by dumping of wastes and other matters, have emerged as the primary forum for international discussions on mCDR activities as

forms of marine geoengineering (IMO, 2013). Within this framework, mCDR is approached through the treaties' mandate on pollution prevention and control (IMO, 1996b; Ginzky and Frost, 2014; Steenkamp, 2025). Pollution is defined as the introduction of wastes or other matter into the sea that results or is likely to result in deleterious effects (IMO, 1996a). As a result, mCDR is anchored within an existing institutional framework and subject to precautionary international oversight, including when undertaken for legitimate scientific research purposes (McGee et al., 2018; Reynolds, 2021; IMO, 2008; IMO, 2010).

The classification of mCDR or marine geoengineering as a form of pollution raises conceptual and regulatory tensions. Existing scholarship highlights challenges in applying governance frameworks developed for waste disposal to deliberate climate interventions (Webb, 2024). These tensions are particularly visible in the different ways mCDR is framed across governance contexts (Röschel and Neumann, 2023). Within climate policy, mCDR is primarily understood as a potential mitigation response to climate change (IPCC et al., 2022), whereas ocean governance approaches it through regimes concerned with preventing harm from the introduction of matter into the marine environment. Some approaches, particularly ocean alkalinity enhancement, are also discussed in terms of their potential to counteract ocean acidification, thereby invoking analogies to environmental repair (Foteinis et al.,

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2022). At the same time, boundary cases such as artificial upwelling complicate pollution-based classifications from a regulatory perspective, as they do not clearly involve the placement of matter into the marine environment in ways envisaged by existing dumping regimes (Webb et al., 2022). Taken together, these dynamics point to underlying tensions between climate-centered and ocean-centered governance perspectives and illustrate that pollution is not a universally fixed concept, but shaped by the objectives and historical developments of specific governance regimes (Sands et al., 2018).

These tensions also point to the fundamental issue of how pollution itself has been conceptualized within environmental governance. The operationalization of pollution within LC/LP reflects a historically specific, technocratic understanding of pollution as a material input, the harm of which can be measured and managed through thresholds and standards (Boettcher and Kim, 2022; Pintado and Aragão, 2023). This understanding reflects governance approaches developed to regulate industrial emission, waste disposal and marine dumping, in which pollution was typically treated as an unintended by-product of economic activity (Pintado and Aragão, 2023). While effective for regulating industrial pollutants, this approach was not designed for deliberate environmental interventions undertaken with the explicit purpose of climate mitigation. As a result, governance approaches grounded in this framing tend to prioritize the assessment and management of measurable impacts, while placing less emphasis on the social dimension (Röschel, 2025).

A growing body of scholarship expands the concept of pollution beyond the material as a relational activity that reshapes socio-ecological relations (Ataria et al., 2023; Liboiron, 2021; Murphy, 2021; Brierley, 2020). In this sense, mCDR can be understood as a form of marine pollution in a relational sense, as it consists of deliberate interventions that reconfigure human-ocean relationships under conditions of deep uncertainty. While not all mCDR approaches will transform these relations in the same way, given their differing mechanisms and scales, they share characteristic of intentionally altering marine systems in pursuit of a perceived global benefit.

This Perspective makes three contributions. First, it argues that classifying mCDR as pollution provides an essential institutional anchor within the LC/LP. Second, it shows that prevailing technocratic understandings of pollution are insufficient for governing mCDR, as they fail to capture the relational dimensions through which harm and responsibility are produced. Third, it explains why recurring calls for more holistic and inclusive governance of mCDR can be understood as responses to this conceptual mismatch.

2. Marine CDR as pollution in environmental governance

The LC/LP defines marine pollution broadly as “*the introduction, directly or indirectly, by human activity, of wastes or other matter into the sea which results or is likely to result in such deleterious effects as harm to living resources and marine ecosystems, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities*” (IMO, 1996a). This definition captures deliberate human interventions in the marine environment based on their potential effects, rather than their intent, and applies irrespective of whether activities are undertaken for waste disposal, scientific research or environmental purposes.

Marine CDR approaches currently under international governance consideration as marine geoengineering techniques are treated as pollution under existing frameworks (IMO, 2025a). These approaches include, for example, the addition of alkaline materials, the introduction of nutrients or biomass or the dissolution of minerals, all of which entail purposeful material intervention in marine systems (NASEM, 2022). From a governance perspective, this common characteristic supports their classification as pollution irrespective of their intended climate benefits (Liboiron, 2021), while also highlighting the material focus that currently structures regulatory approaches.

Restorative or mitigation-oriented intent does not remove an activity from the scope of pollution governance. Regulatory frameworks have long subjected activities pursued for environmental or climate objectives to precautionary oversight where they may generate ecological or social risks. For example, offshore wind installations, despite their role in reducing greenhouse gas emissions, are governed through marine spatial planning, environmental impact assessments and licensing regimes that explicitly address ecological impacts and interactions with existing ocean uses (Eitan, 2025). Treating mCDR as pollution does not imply that it is inherently undesirable, but similarly reflects the recognitions that intentional environmental interventions may produce trade-offs and uncertainties that warrant governance.

This logic has been reinforced in recent developments in international environmental law. The 2024 Advisory Opinion of the International Tribunal of the Law of the Sea (ITLOS) emphasizes that States must take measures to prevent pollution of the marine environment, in order not to “transform one type of pollution into another” (ITLOS, 2024). This principle is directly relevant to mCDR, which may reduce atmospheric carbon pollution while simultaneously introducing new effects in the ocean system. Framing mCDR as pollution in governance terms helps make such trade-offs visible. Developments in other areas of international environmental governance, including the ongoing Plastics Treaty negotiations (UNEP, 2025; Stoett et al., 2024), indicate a growing recognition of pollution as a systemic and socio-ecological issue.

Treating mCDR as pollution has therefore served as a baseline classification in international governance. It anchors mCDR within existing legal obligations and establishes a presumption of precaution under conditions of deep uncertainty. At the same time, this classification does not resolve how different forms of harm are recognized and assessed. As currently operationalized, pollution governance under LC/LP remains largely oriented toward measurable material impacts and ecological thresholds. This focus limits its ability to engage with the broader social dimensions, including questions of equity and responsibility, that mCDR may implicate.

Accordingly, mCDR can be understood as pollution in the environmental governance sense, and LC/LP can function as the appropriate institutional home for its regulation. While pollution governance remains fragmented and evolving in practice, the classification provides a critical baseline for international scrutiny. The central challenge explored in the following sections is therefore not whether mCDR should be governed as pollution, but how pollution governance can accommodate the broader relational dimensions potentially associated with mCDR.

3. The limitations of the technocratic pollution paradigm for mCDR

International environmental governance has traditionally approached pollution in technocratic terms, focusing on the interaction between a material agent and an environmental receptor and evaluating the risks or harms that arise from that interaction. This risk- and impact-centered orientation underpins regulatory approaches that assess the safety of substances and activities based on their measurable consequences for human health and ecosystems. While this approach has been widely applied to governing diverse forms of pollution, its limitations can be recognized in contexts characterized by diffuse sources, delayed and spatially displaced impacts, as well as conditions of deep uncertainty (Wiering et al., 2020; Workman et al., 2020).

These limitations become particularly visible in the context of mCDR. Within existing governance approaches, marine geoengineering as form of pollution is typically assessed as an exchange between a deliberate intervention and the marine environment, most clearly in cases involving material additions such as alkaline substances or biomass. However, not all mCDR approaches fit within this framing. Boundary cases such as artificial upwelling, which involve a physical change to the ocean's condition rather than introduction of new matter,

challenge the applicability of pollution concepts rooted in material inputs and discharges (Webb et al., 2022). Diverse mCDR approaches may generate unintended and unevenly distributed impacts across ecological and social systems that are difficult to predict and assess through conventional risk-based approaches. While environmental impact assessments remain indispensable to the effective governance thereof, this framing treats pollution primarily as a technical interaction, abstracting it from the broader contexts in which interventions are conceived and deployed.

A key governance challenge arises from the conditions of deep uncertainty under which mCDR operates as intervention connected to the climate and ocean system (Neumann et al., 2026). Unlike conventional pollution challenges, where risks can often be estimated probabilistically, mCDR involves structural ignorance regarding long-term ecological and socio-economic outcomes. The precautionary principle was developed to address such conditions, where uncertainty cannot be reduced to a quantifiable risk (Dovers and Handmer, 1995). However, governance approaches that rely primarily on measurable thresholds and impact detection may struggle to respond adequately under such conditions. The challenge is further amplified in the marine environment, where harms are often difficult to observe and spatially displaced (Révelard et al., 2022; Weller et al., 2019). Oceanic processes disperse, transform and transport substances in ways that challenge attribution and monitoring, while baseline conditions are often poorly constrained (Cloux et al., 2024; Pilechi et al., 2022).

Under these conditions, a governance logic centered primarily on detecting and managing environmental impacts risks responding too late to meaningfully shape decisions about whether mCDR should be deployed at all, and may also prove insufficient for governing how different approaches are scaled, combined and distributed in practice. By contrast, the social dimension of mCDR decision-making, including for example decisions to research, authorize, scale and justify deliberate ocean interventions, are immediate in the sense that they precede and shape potential environmental outcomes (Röschel, 2025). This suggests that precaution cannot be limited to managing environmental effects alone, but must also engage with social decisions and institutional processes through which exposure to uncertain and potentially irreversible change is created.

These limitations point to a broader blind spot in technocratic pollution governance. By framing pollution as a material interaction between intervention and environment, governance approaches tend to treat the social dimension as external to assessment processes and thereby ineffectively govern interrelated and non-linear socio-environmental challenges (Agrawal et al., 2022). The marine environments affected by these interventions are embedded in complex social relations (Satterfield et al., 2026; Lezaun, 2021), and as a result, mCDR as pollution cannot be fully understood or effectively governed without accounting for the relational dynamics through which environmental change is produced and experienced.

4. Pollution as relational activity

An alternative understanding of pollution offers a way to address the limitations identified above without abandoning pollution as a governance category. Rather than treating pollution as a material interaction between a substance and an environment, relational approaches conceptualize pollution as an activity that reconfigures social, ecological and technological relations. From this perspective, pollution is defined by how interventions reshape relationships between actors, environments and systems (Liboiron, 2021).

Applied to mCDR, this perspective shifts attention from material inputs to the broader social contexts of interventions. Marine CDR approaches are proposed, developed and advanced by specific actors, while their ecological and social impacts, both positive and negative, are distributed across specific marine contexts. Even where direct or immediate harm is uncertain, mCDR reconfigures human-ocean relations

by positioning the ocean as a site for deliberate climate intervention and by redistributing responsibilities for managing climate risk. Understanding pollution relationally recognizes that mCDR methods vary in scale, reversibility and the kinds of relations they affect. It also recognizes that they each involve a deliberate decision to alter marine systems under conditions of uncertainty in order to secure a perceived collective benefit. This decision necessarily entails trade-offs, including how risks and responsibilities are distributed across different actors and contexts.

A relational understanding of pollution helps explain why governance principles and guidance developed across informal and expert mCDR governance initiatives consistently move beyond risk-based assessment and emphasize more holistic, participatory and integrative approaches (Röschel and Neumann, 2024; Boettcher et al., 2023; Doney et al., 2025). Rather than representing entirely new demands, such calls can be understood as responses to a mismatch between technocratic understandings and formal governance of pollution and the relational realities of mCDR. When pollution is framed solely as a material interaction, governance struggles to account for e.g., the distribution of risks, the legitimacy of decision-making processes and the broader social implications of intentional environmental change.

Empirical developments within LC/LP and the wider mCDR governance landscape illustrate this dynamic. Recent efforts by the LC/LP Correspondence Group on Marine Geoengineering to develop assessment frameworks for prioritized marine geoengineering techniques, alongside revisions to the existing ocean fertilization assessment framework, indicate attempts to move beyond narrowly biophysical assessments. Draft criteria already include consideration of “environmental and societal impacts/risks, e.g., risks to ecosystems and to humans and conflicts with other human uses” (IMO, 2025b; IMO, 2025a). Such developments suggest that governance practice is already stretching the concept of pollution beyond purely technocratic understandings in order to address dimensions of harm and responsibility that existing frameworks struggle to capture.

A relational understanding of pollution therefore provides a conceptual framework for interpreting these developments and clarifying their underlying drivers. It helps explain why governance debates return to questions of justice and why these concerns cannot be fully addressed within a purely technocratic framing. Environmental impact assessments remain essential, but can be understood as one component within a broader evaluative framework that also considers social relations and responsibilities (Baatz et al., 2025). In this sense, a relational conception of pollution provides a bridge between precautionary regulation and justice-oriented governance, allowing pollution to remain the organizing category while expanding what pollution governance is expected to address.

5. Conclusion

Marine CDR sits uneasily within existing pollution governance. As a deliberate intervention that alters marine systems under conditions of deep uncertainty, its classification as pollution provides an essential institutional anchor within LC/LP, enabling precautionary oversight and situating mCDR within an established regulatory framework. At the same time, this classification exposes the limits of governance approaches originally developed for more conventional forms of pollution.

The central challenge is therefore not whether mCDR should be governed under LC/LP, nor whether pollution governance should be replaced. Rather, it is whether prevailing understandings of pollution are capable of capturing the full range of harms, responsibilities and relations that deliberate marine interventions entail. As this paper has shown, the dominant technocratic interpretation of pollution abstracts interventions into material interactions with the environment, narrowing governance attention to measurable risks and thresholds while sidelining questions of equity, power, responsibility and legitimacy that are integral to environmental governance (Bennett and Satterfield, 2018).

A relational understanding of pollution offers a way to interpret these limitations. By conceptualizing pollution as an activity that reconfigures social-ecological relations, it makes visible the dimensions of mCDR that remain obscured within technocratic framings. In doing so, it also explains why governance debates repeatedly call for more holistic, participatory and integrative approaches, as they are responses to a conceptual mismatch between how pollution is defined and how mCDR operates in practice.

Recent developments within the LC/LP, including efforts to expand assessment frameworks beyond strictly biophysical impacts and to incorporate broader social and ethical considerations, suggest that governance is already stretching beyond a purely technocratic paradigm. A relational understanding of pollution helps situate these developments as indications that existing frameworks are already being pushed to accommodate dimensions of harm and responsibility that extend beyond material risk.

In conclusion, the answer to whether mCDR is pollution is both “yes” and inherently incomplete. Marine CDR is appropriately governed as pollution within LC/LP because it involves deliberate interventions that may generate uncertain and potentially harmful changes to marine systems. Yet governing mCDR as pollution also requires rethinking what pollution itself is understood to encompass. A relational understanding of pollution clarifies why pollution governance is evolving and why it is increasingly being asked to address social dimensions alongside ecological and technological concerns. In the context of mCDR, pollution governance is not solely concerned with preventing unwanted environmental harm, but with governing deliberate environmental intervention undertaken under conditions of deep uncertainty in pursuit of a perceived collective benefit.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the author(s) used Chat-GPT 5 on a limited basis in order to check language of selected sentences of the manuscript. After using this tool, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

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Declaration of competing interest

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Data availability

No data was used for the research described in the article.

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