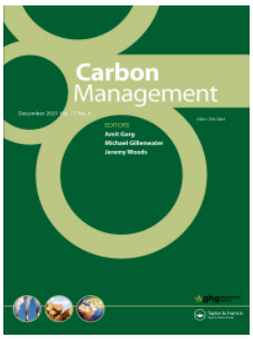

Carbon Management

ISSN: 1758-3004 (Print) 1758-3012 (Online) Journal homepage: www.tandfonline.com/journals/tcmt20

Accounting and monitoring challenges for blue carbon enhancement in national climate policy targets and international carbon markets

Miranda Boettcher, Malte Winkler & Axel Michaelowa

To cite this article: Miranda Boettcher, Malte Winkler & Axel Michaelowa (2025) Accounting and monitoring challenges for blue carbon enhancement in national climate policy targets and international carbon markets, Carbon Management, 16:1, 2585895, DOI: 10.1080/17583004.2025.2585895

To link to this article: https://doi.org/10.1080/17583004.2025.2585895

Published online: 01 Dec 2025.

CARBON MANAGEMENT
2025, VOL. 16, NO. 1, 2585895
https://doi.org/10.1080/17583004.2025.2585895

Taylor & Francis
Taylor & Francis Group

COMMENT

OPEN ACCESS Check for updates

Accounting and monitoring challenges for blue carbon enhancement in national climate policy targets and international carbon markets

Miranda Boettcher[a,b], Malte Winkler[c] and Axel Michaelowa[c,d]

[a]SWP - German Institute for International and Security Affairs, Research Cluster Climate Policy and Politics, Berlin, Germany; [b]Copernicus Institute of Sustainable Development, Environmental Governance Group, Utrecht University, Utrecht, the Netherlands; [c]Perspectives Climate Research gGmbH, Freiburg, Germany; [d]Institute of Political Science, University of Zurich, Zurich, Switzerland

ABSTRACT

"Blue carbon" refers to carbon sequestration in marine ecosystems. While carbon uptake in coastal vegetated areas has been well-studied, emerging techniques to enhance carbon uptake in open ocean environments pose new challenges in terms of accounting and monitoring, reporting, and verification (MRV). Establishing baselines for carbon sequestration is particularly difficult, as the natural ocean sink is influenced by human activities and increased atmospheric CO_2. Furthermore, the durability of biogenic oceanic carbon sinks is uncertain, particularly in the face of climate change impacts. Legal complexities arise due to the transboundary nature of open ocean ecosystems, making it difficult to attribute carbon credits to specific nations. Current MRV methodologies and accounting frameworks do not sufficiently address open ocean blue carbon enhancement. Without robust frameworks and internationally accepted standards, integrating these approaches into national climate policy and carbon markets could lead to overestimating mitigation outcomes. We conclude that governance to incentivize and regulate blue carbon activities should address both climate and environmental impacts and benefits and develop financing models which do not rely on carbon crediting mechanisms.

ARTICLE HISTORY
Received 28 February 2025
Accepted 1 November 2025

KEYWORDS
Blue carbon; blue carbon enhancement; ocean carbon sink; monitoring, reporting and verification (MRV); marine carbon dioxide removal (mCDR); baseline setting

Introduction

Coastal and open ocean ecosystems have been put under increasing pressure in recent decades because of both the impacts of climate change and the diversification of human activities at sea, including tourism, fisheries, shipping, deep sea mining and offshore wind energy production. In addition to existing activities, recent years have seen the rise of discussions about another type of ocean use: its potential to help mitigate climate change.

The term "blue carbon" has long been used to refer to greenhouse gas emission reductions and removals in marine environments, particularly in the context of coastal vegetated areas. Recently, the term marine carbon dioxide removal (mCDR), which aims to leverage biological and chemical processes in marine ecosystems, has emerged [1,2]. In this context, "blue carbon enhancement" is now increasingly being used to describe attempts to deliberately increase the biogenic carbon drawdown potential of both coastal and open ocean environments (see Figure 1). The concept therefore includes activities that involve interventions into diverse ecosystems such as coastal mangroves, seagrasses, saltmarshes, as well as open ocean approaches that focus on either increasing the biological activity at the surface, e.g. microalgal fertilization and artificial upwelling, or accelerating the sinking of particulate organic carbon while reducing its remineralization, e.g. macroalgal cultivation and sinking [3].

In international climate policy discussions, a range of carbon dioxide removal approaches, including blue carbon enhancement proposals, have generated growing interest over the past years, as global greenhouse gas emissions have continued to increase, and the implementation of policies to reduce emissions from

CONTACT Malte Winkler winkler@perspectives.cc Perspectives Climate Research gGmbH, Freiburg, Germany

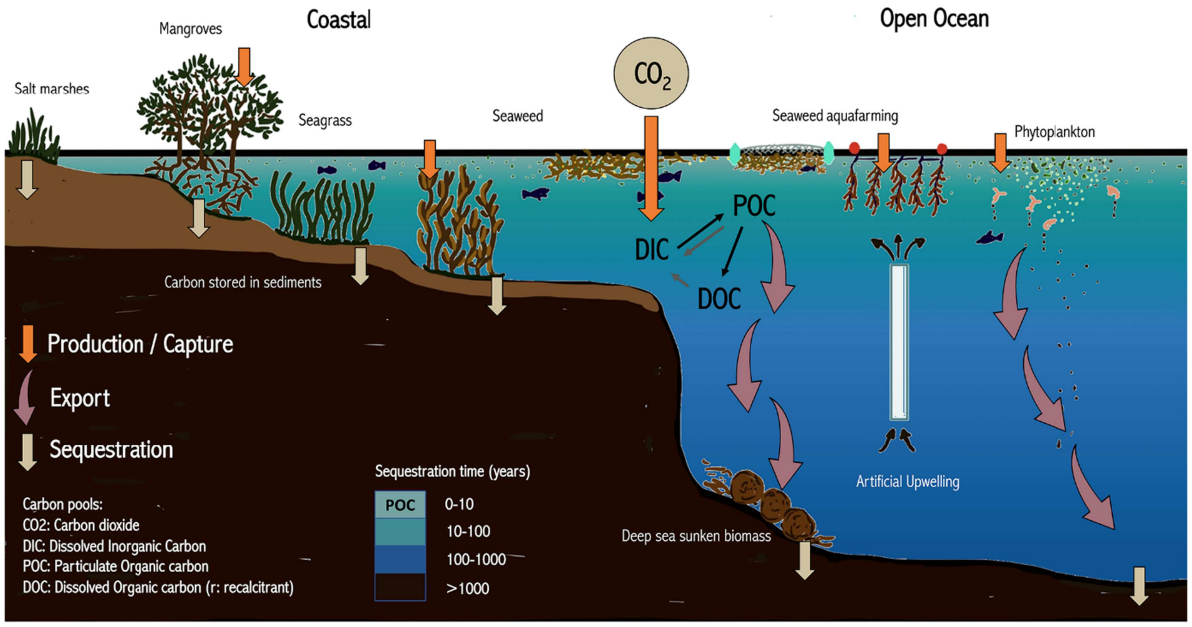

Figure 1. Overview of various approaches to enhance the biological carbon uptake in coastal and open ocean ecosystems ([2], reproduced under the terms of the Creative Commons Attribution License).

fossil fuel use has hit obstacles. This interest applies both to achieving national emission targets under the Paris Agreement and to the generation of carbon credits for trade in international carbon markets.

Coastal blue carbon protection and restoration activities have been addressed in discussions on carbon market governance and accounting for many years (see e.g. [4–10]. Activity-based accounting methodologies are available under different carbon market programs for mangroves [11]. Hasselström et al. [12] suggest a methodology for seagrass; Malerba et al. [13] discuss the role of remote sensing in accounting. Here, emission reduction has dominated so far, and both methodology development and accounting are more mature than they are for blue carbon enhancement [14,15].

Literature specifically on deliberate attempts to increase the carbon sequestration potential of both coastal and open ocean environments is limited, and almost no verification protocols are in place for blue carbon enhancement in the open ocean environment [2,16–18]. Therefore, in this commentary, we focus on the emerging literature on open ocean blue carbon enhancement approaches and discuss whether related activities can be monitored and accounted for in a sufficiently credible manner to become a part of the international mitigation toolbox.

Monitoring, reporting and verification (MRV) of climate change mitigation activities is crucial both on the country level and on the activity level. Credible and effective MRV should adhere to several principles, including accuracy, conservativeness, completeness, consistency, comparability and materiality[1] [19]. Moreover, leakage (indirect effects) and reversals of removals need to be identified to enable their prevention and/or compensation. Consistent accounting should avoid double counting and requires internationally agreed practices and protocols, which are widely lacking for emerging proposals to enhance the removal potential of both coastal and open ocean ecosystems through blue carbon enhancement activities. In addition, issues related to the regulatory characteristics of international waters and related accountability further complicate the integration of open ocean mitigation activities into national climate policies and international carbon markets.

The “natural” ocean sink and implications for setting the baseline

MRV and accounting of open ocean blue carbon enhancement activities face numerous challenges related to natural scientific, technical, and legal complexities. This is exacerbated by the fact that anthropogenic CO_2 in the atmosphere and seawater increase biomass growth. Therefore, the “natural” ocean sink, i.e.

marine biomass sequestering CO_2, is not purely natural but has inadvertently increased due to human activities [20]. Conservative accounting for carbon activities, which claim to increase the carbon removal potential of marine ecosystems, must ensure that only carbon is accounted as removed that exceeds the passive sequestration triggered by the CO_2 increase in the atmosphere. Accordingly, if a conservative baseline is used, marine ecosystem restoration would only reduce emissions, whereas activities that aim to expand marine biomass or otherwise increase the biogenic carbon sequestration potential of a specific marine ecosystem may be classified as a type of marine carbon dioxide removal. This is further complicated by the fact that humans have fundamentally altered marine ecosystems over the last few centuries, and ecosystems themselves are changing in response to climate change. A "natural" baseline is thus hard or impossible to establish, which has additional repercussions for activities with the aim of biodiversity conservation: it is unclear which "baseline" ecosystem state is chosen as the state to be "restored". The situation can be simplified somewhat if the baseline is anchored in a business as usual (BAU) concept, which has been the key approach in voluntary carbon markets (VCM) in recent decades. However, nowadays baselines are to move away from reflecting BAU, as specified in the regulation of the Paris Agreement Crediting Mechanism (PACM) finalised at COP29 in 2024. We address the baseline issue in blue carbon market activities in more detail below.

Reconciling area-based accounting with the transboundary nature of blue carbon

Accounting for national greenhouse gas emissions under the Paris Agreement includes the national territory and offshore areas over which the country has jurisdiction [21]. The sea area that countries would theoretically have to report greenhouse gas emissions for is based on jurisdiction as defined under the United Nations Convention on the Law of the Sea (UNCLOS; UN General assembly [22]). Under UNCLOS, states' sovereign territory extends only to their territorial sea (up to 12 nautical miles offshore). Therefore, it could be expected that countries would only have to report emissions from within their territorial sea (UNCLOS).

However, reporting obligations could also extend to a country's entire exclusive economic zone (EEZ, up to 200 nautical miles offshore), as this falls within its national jurisdiction. It could also include territorial seas and the EEZs of islands and overseas territories over which a given country has jurisdiction. Collectively, EEZs are vast, covering 41% of the Earth's ocean surface and therefore representing a significant portion of the global ocean carbon sink. The vast areas of EEZs present a range of challenges for carbon accounting, especially when considering attempts to enhance their blue carbon sequestration potential (e.g. via blue carbon enhancement forms of mCDR, such as large-scale offshore macroalgae cultivation or artificial upwelling to increase phytoplankton growth) [2,23].

Areas beyond a country's EEZ are not part of the country's total land area in IPCC greenhouse gas inventories. Emission sources and sinks beyond the EEZ are therefore not reported, with the exception of shipping emissions, which are reported as a memo item.

In summary, the IPCC Guidelines for National Inventories provide standards for reporting some activities related to mCDR in coastal areas, including through its 2013 Supplement on wetlands [24]. While they currently do not provide such standards for activities in EEZs, future refinements could address this and expand national reporting standards to EEZs. While the EEZ oceanic carbon sink is currently not accounted for under the Paris Agreement, it is already considered in estimates of remaining carbon budgets to meet the goals of the Paris Agreement. Therefore, integrating EEZ blue carbon fluxes into national accounting inventories could lead to inconsistencies in global carbon budget calculations [23,25]. Areas beyond EEZs most likely not be covered by national inventories.

Coastal and offshore greenhouse gas emissions, carbon removal, transport and sequestration involve spatially and temporally dynamic marine carbon fluxes that do not respect the legislative boundaries described above. Thus, emission reductions, removals and reversals linked to a specific blue carbon enhancement activity may occur in different jurisdictions and/or in international waters, complicating the integration of related mitigation outcomes into national accounting frameworks. Air–sea fluxes are likely to occur at locations other than those where carbon is stored in the ocean because of circulation and mixing. Tidal influences add spatial and temporal complexity to greenhouse gas fluxes in coastal ecosystems [2,23].

Integrating EEZ carbon fluxes into Nationally Determined Contributions (NDCs) could therefore present a challenge to fair attribution—given the fluid nature of the oceans, the question as to which nation could rightfully claim credit for open ocean blue carbon efforts would arise because of large differences between where uptake initially occurs and where it is subsequently stored. Similar implications arise for proponents in the VCM. The transboundary nature of oceanic (including "blue") carbon presents an increased risk of double counting.

Challenges to national blue carbon reporting

Given the described challenges, so far, only a small share of countries reports on blue carbon fluxes in their national inventories. According to a recent study [26], only ten out of 44 National Inventory Reports submitted to the United Nations Framework Convention on Climate Change (UNFCCC) by developed country parties by the end of 2023 mentioned coastal ecosystems (Australia, Cyprus, France, Iceland, Japan, Malta, Monaco, New Zealand, United Kingdom, USA[2]). Cyprus, Iceland and Monaco included only a reference to coastal ecosystems without reporting any carbon fluxes. Only Australia reports on seagrass meadows. Most others refer to mangroves, and some refer to tidal marshes. Australia, the UK and France report on mangroves mainly under terrestrial forests. France and the UK report on mangroves in their overseas territories. The level of detail on reporting methods and the quality of the data provided is inconsistent and poorly documented. While the US has comprehensive reporting on tidal marsh habitats with highly differentiated inventory categories and specific factors, France just equates the mineral soil carbon stock of tidal marshes with that of grassland and calcualtes all carbon fluxes with a grid stock variation model, which leads to much lower levels of accuracy and transparency. No country currently reports on open ocean blue carbon fluxes.

To determine the additionality of national measures to increase the anthropogenic carbon sink in the open ocean of a country's territorial sea and/or EEZ, a solid calculation of the baseline carbon sink and how it would have evolved without intervention is needed. However, this is technically extremely difficult and is made even more difficult by the abovementioned spatially and temporally dynamic nature of carbon fluxes in the sea [2,23].

In addition to being technically very challenging, the rare reporting on blue carbon fluxes more generally could be linked to a lack of political will by some countries to include marine ecosystems in their inventories: As they have degraded their coastal ecosystems so badly that they are currently net sources of greenhouse gas emissions rather than sinks, including these ecosystems in reporting would fundamentally change their overall inventory balance for the worse. This could pose a further challenge to the establishment of internationally agreed-upon standards for reporting on coastal and open ocean carbon fluxes to facilitate their consistent integration into NDCs.

International carbon market challenges: baselines, additionality, durability and attribution

International carbon markets build on the premise that some jurisdictions are unable to mobilize greenhouse gas mitigation themselves. Therefore, mitigation activities that would not happen under a BAU situation can generate emission credits that they can sell to entities outside their jurisdiction. Such baseline and credit mechanisms have been established over the last 20 years, sometimes thriving, but recently facing a loss of trust in the wake of "greenwashing" investigations [27]. They include obligatory and voluntary carbon markets and target both greenhouse gas reduction and removal activities [28]. The Paris Agreement's Article 6 establishes two types of international carbon markets—one agreed upon between countries with a limited degree of international oversight (Article 6.2) and a mechanism based on international rules (Article 6.4). During COP29, held in Baku in 2024, the rules, modalities and procedures for Article 6.4 were agreed upon after ten years of negotiations. This marked a significant step towards operationalization of the Paris Agreement Crediting Mechanism (PACM).

The assessment of additionality as well as the application of MRV methodologies for biomass in international carbon markets has, to date, faced significant challenges [27]. With respect to determining

additionality for mangrove-related projects, Williamson et al. [9] propose a more stringent approach compared to the "loose" approach of Houston et al. [4]. This is particularly the case for biomass-based CDR [29]. Owing to a series of widely mediatized scandals regarding non-additional activities and overestimated baselines, the prices and demand for forestry credits in the VCM have plummeted by more than 90% since 2021, and some credit categories cannot be sold anymore at all. Surprisingly, coastal-ecosystem-based blue carbon projects have so far been widely spared from this crisis, while "novel" mCDR options have been criticized (see e.g. [30]). The large mangrove restoration Delta Blue Carbon project in Pakistan has sold emission credits at prices between USD 10 and 50, totaling revenues of USD 40 million [31]. The fact that blue carbon projects are currently facing fewer issues than biomass-based CDR projects on land may also be due to the overall lower number of blue carbon (let alone blue carbon enhancement) projects that are currently generating carbon credits (see [32] for an analysis of the approximately 50 blue carbon projects in international carbon markets), and these issues may potentially increase once blue carbon enhancement projects are implemented at a larger scale. Thus, whether this benign situation will continue when countries try to upscale blue carbon market action, as envisaged, for example, by the government of the Bahamas in marketing blue carbon from seagrass meadows [33], which are deemed to be the largest worldwide [34], remains to be seen.

A key question for blue carbon enhancement is to properly specify the baseline, i.e. determine which level of removal would have happened in the absence of the activity. Houston et al. [4] confound baseline setting with additionality determination. Their incomplete discussion of how to treat "allochthonous" carbon, i.e. carbon entering the activity area from outside (see [35] for estimates of the share of allochthonous carbon in mangrove soils and [36] in seagrass beds), shows that key concepts underlying international carbon markets have not yet been properly addressed by the blue carbon community. Accounting for CO_2 imported into the blue carbon ecosystem from somewhere else, e.g. through soil carbon from river runoff, would overestimate removal, as this carbon is not from the atmosphere but has been bound in soil for a long time. In our view, allochthonous carbon should thus not be credited (see also [9]).

Another risk is non-permanence inherent to biogenic carbon sequestration and further durability issues given that sea level rise or other impacts of climate change and/or ocean activities (i.e. dredging, trawl fishing, deep-sea mining) may destroy the biogenic carbon store. While the debate about the minimum time needed to store carbon is ongoing, many researchers argue that it should exceed 100 years, and many blue carbon enhancement approaches are unlikely to meet this durability threshold [37].

The likely most difficult aspect of blue carbon enhancement activity crediting is signal attribution: natural ecosystems have high variability in time and space. This increases the complexity in carbon fluxes and stocks as well as the uncertainty in the impacts of climate change on carbon fluxes. Carbon enhancement measures that seek to increase the biogenic sequestration potential of marine environments will likely have small impact compared to this background noise, leading to challenges in signal attribution against natural variability in diverse ecosystems [2,23].

How to govern blue carbon enhancement for climate change mitigation

Blue carbon enhancement is currently being hyped in international climate policy discussions, and some scholars are calling for caution regarding its potential [38–40]. While some coastal blue carbon activities are already being reported in some countries' inventories, there is currently no sufficiently elaborate and reliable MRV framework for most blue carbon enhancement activities. Governments should be discouraged from claiming all biological removals in marine ecosystems as mCDR, as the "passive sink" created by increasing atmospheric CO_2 concentrations will not be sustained once concentrations are stabilized [20]. Including EEZ blue carbon fluxes in NDCs (currently) would be both conceptually and practically highly problematic.

Reliable MRV for carbon fluxes in the marine environment currently does not exist. Robust baselines, attributions of additionality and demonstrable durability of carbon sequestration are currently not achievable for all open ocean blue carbon enhancement methods [41]. As discussed above, the baselines of VCM projects undertaken to date do not address the question of allochthonous carbon and thus overestimate

the baseline. If one applies conservative default parameters, the viability of many blue carbon (enhancement) projects under international carbon markets would be doubtful because the revenues from emission credit sales would be significantly lower than those under current baselines. A key prerequisite for the robust and credible integration of blue carbon enhancement into accounting and crediting mechanisms is the development of reliable, internationally standardized MRV protocols, which include baseline assessment and additionality criteria. Several initiatives and organizations currently aim at developing robust frameworks and methodologies for blue carbon enhancement activities, e.g. the European Marine Board (EMB) working group on marine CDR.[3] The recently agreed upon outline for the planned IPCC CDR methodology report indicates that it will also include an update to the Wetlands Supplement to cover enhancement of carbon sinks in mangroves, tidal marshes, and seagrass in coastal waters [42].

However, while the MRV capacity is being developed, there is a need to think more broadly and creatively about how to govern and incentivize blue carbon activities for climate change mitigation, going beyond carbon crediting mechanisms. Incentivisation mechanisms could include bonds with a lower coupon than normal bonds, debt-for-climate swaps and private mitigation contributions. "Blue bonds" fund projects that support ocean conservation, sustainable marine resource management, and coastal climate resilience, for example, in the Seychelles [43]. They are issued by governments, development banks, and financial institutions to attract private investors seeking environmental and social returns and are willing to accept a lower interest rate than normally paid on the market. Debt for climate swaps [44] buy the sovereign debt of distressed countries well below issuance value and convert it into domestic currency, which is then earmarked for climate change mitigation and adaptation. The first example of a pure debt for climate aiming at blue carbon is the Seychelles Conservation and Climate Adaptation Trust.[4] Mitigation contributions by private companies are generated by such companies funding mitigation abroad without claiming emissions credits out of that investment. The Swiss foundation MyClimate[5] offers mitigation contribution units but remains rather close to the classic carbon market model.

Beyond the need to generate incentives for blue carbon investments, there is a need to develop integrative regulatory approaches for blue carbon activities to help overcome the current disconnect between climate mitigation and marine protection policy [38]. The European Union's *Marine Strategy Framework Directive* (MSFD 2008/56/EC) could play a key role in this endeavour. The MSFD takes an ecosystem-based approach to the management of human activities that have an impact on the marine environment and thereby offers a framework for the integration of biodiversity protection and climate change action into EU Member States' marine spatial planning. This type of ecosystem-based management has emerged as a critical strategy for reconciling marine biodiversity protection objectives with other activities in marine environments [45], with examples of ecosystem-based approaches to marine governance in France (SNML) and the Netherlands (the North Sea Agreement) showing that it could help mandate and regulate blue carbon activities that have synergistic climate and biodiversity effects.

Conclusions

MRV and accounting for blue carbon enhancement activities remain demanding, particularly in the open ocean. The need for reliable MRV and nationally accountable mitigation outcomes are challenged by the complexity of natural processes in open systems, which cross jurisdictional boundaries and dynamically react to increased atmospheric and oceanic greenhouse gas concentrations. Internationally accepted reporting standards for blue carbon fluxes are yet to be developed and widely implemented. At present, there is a lack of sufficiently robust, comprehensive MRV to enable credible implementation and accounting of open ocean blue carbon enhancement activities. Until such capacities can be established, including open ocean blue carbon fluxes in NDCs or international carbon markets would be highly problematic. Therefore, priority should be given to further developing internationally accepted reporting standards, robust regulatory frameworks and funding mechanisms to govern coastal blue carbon activities. As reporting and accounting methodologies for carbon fluxes in different coastal environments are at varying stages of development, the near-term focus should be on activities with relatively well-established climate and environmental benefits, within those coastal environments for which well-differentiated inventory categories have been established.

In developing regulatory frameworks and funding mechanisms for these types of activities, it is key to avoid repeating mistakes of past baseline and credit carbon market systems, which have raised similar concerns about the additionality of activities generating credits, overestimation of baselines, ensuring permanence of carbon stores and preventing leakage of emissions to outside of the activity area. Moreover, the achievement of sustainable co-benefits has been inconsistent in the past. In addition to thoroughly reforming international carbon markets, policies to incentivize and regulate blue carbon activities should prioritize measures that minimize harm to marine environments, provide direct funding support or mandates for the provision of benefits to local populations, and consider multiple types of climate and environmental benefits (see e.g. [46]). Given the potential co-benefits of some blue carbon activities, e.g. for fisheries, increased coastal resilience against storms and sea level rise, a governance system addressing both climate and environment impacts of blue carbon activities and harnessing multiple sources of finance seems appropriate, in order to overcome the current disconnect between climate and marine protection policy.

Endnotes

1. Materiality describes the significance of information in relation to reporting an activity's mitigation outcome [47]
2. For National Inventory Reports see National Inventory Submissions 2023 | UNFCCC National Inventory Submissions 2023 | UNFCCC (accessed February 17th, 2025).
3. See Marine carbon dioxide removal | European Marine Board (accessed February 17th, 2025) for more information.
4. See SeychellesDebtSwapCaseStudy_webversion.pdf (accessed February 17th, 2025) for more information.
5. See myclimate—your partner for effective climate protection (accessed February 17th, 2025) for more information.

Acknowledgements

MB aknowledges funding from the German Federal Ministry of Research, Technology and Space (grant number 03F0962C). MW and AM aknowledge funding from the German Federal Ministry of Research, Technology and Space (grant number 01LS2108B).

Author contributions

None.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

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

References

[1] IPCC. IPCC Special Report on the ocean and cryosphere in a changing climate. Cambridge: Cambridge University Press; 2019.
[2] Mengis N, Paul A, Fernández-Méndez M. Counting (on) blue carbon—challenges and ways forward for carbon accounting of ecosystem-based carbon removal in marine environments. PLoS Clim. 2023;2(8):e0000148. doi: 10.1371/journal.pclm.0000148
[3] GESAMP. The state of the science for marine carbon dioxide removal (mCDR) – a scientific summary for policy-makers. Paris: UNESCO-IOC. (IOC Technical Series, 209); 2025. doi: 10.5281/zenodo.15490407
[4] Houston A, Kennedy H, Austen W. Additionality in blue carbon ecosystems: recommendations for a universally applicable accounting methodology. Glob Change Biol. 2024;30:e17559. doi: 10.1111/gcb.17559
[5] Macreadie P, Robertson AI, Spinks B, et al. Operationalizing marketable blue carbon. One Earth. 2022;5:485–492. doi: 10.1016/j.oneear.2022.04.005

[6] Schindler Murray L, Milligan B, et al. The blue carbon handbook: blue carbon as a nature-based solution for climate action and sustainable development (Ocean Panel Special Report). London; 2023.
[7] Vanderklift MA, Marcos-Martinez R, Butler JR, et al. Constraints and opportunities for market-based finance for the restoration and protection of blue carbon ecosystems. Mar Policy. 2019;107:103429. doi: 10.1016/j.marpol.2019.02.001
[8] Wedding LM, Moritsch M, Verutes G, et al. Incorporating blue carbon sequestration benefits into sub-national climate policies. Glob Environ Change. 2021;69:102206. doi: 10.1016/j.gloenvcha.2020.102206
[9] Williamson P, Gore C, Johannessen S, et al. Additionality revisited for blue carbon ecosystems: ensuring real climate mitigation. Glob Change Biol. 2025;31:e70181. doi: 10.1111/gcb.70181
[10] Friess D, Howard J, Huxham M, et al. Capitalizing on the global financial interest in blue carbon. PLoS Clim. 2022;1(8):e0000061. doi: 10.1371/journal.pclm.000006
[11] Needelman B, Emmer I, Oreska M, et al. Blue carbon accounting for carbon markets In: Windham-Myers L, Crooks S, Troxler T, editors. A blue carbon primer. The state of coastal wetland carbon science, practice and policy. London: Taylor & Francis; 2018. p. 283–292. doi: 10.1201/9780429435362-20
[12] Hasselström L, Thomas J-B. A critical review of the life cycle climate impact in seaweed value chains to support carbon accounting and blue carbon financing. Clean Environ Syst. 2022;6:100093. doi: 10.1016/j.cesys.2022.100093
[13] Malerba M, Duarte de Paula Costa M, Friess D, et al. Remote sensing for cost-effective blue carbon accounting. Earth Sci Rev. 2023;238:104337. doi: 10.1016/j.earscirev.2023.104337
[14] Sun Y, Zhang H, Lin Q, et al. Exploring the international research landscape of blue carbon: based on scientometrics analysis. Ocean Coast Manage. 2024;252:107106. doi: 10.1016/j.ocecoaman.2024.107106
[15] Zhang J, Gan S, Yang P, et al. A global assessment of mangrove soil organic carbon sources and implications for blue carbon credit. Nat Commun. 2024;15:8994. doi: 10.1038/s41467-024-53413-z
[16] Arcusa S, Sprenkle-Hyppolite S. Snapshot of the carbon dioxide removal certification and standards ecosystem (2021–2022). Clim Policy. 2022;22:1–14. doi: 10.1080/14693062.2022.2094308
[17] IEAGHG. Measurement, reporting and verification and accounting for carbon dioxide removal in the context of both project-based approaches and national greenhouse gas inventories; 2024. https://doi.org/10.62849/2024-09
[18] Schulte I, Burke J, Arcusa S, et al. Monitoring, reporting and verification In: Smith In SM, Geden O, Gidden MJ, Lamb WF, Nemet GF, Minx JC, Vaughan NE, editors. The state of carbon dioxide removal 2024. 2nd ed; Oxford 2024. pp. 182–204. doi: 10.17605/OSF.IO/F85QJ
[19] International Initiative for Article 6 Methodology Tools. Tool for monitoring, reporting and verification of emissions, reductions and removals. Freiburg: Final tool, Perspectives Climate Research; 2023.
[20] Allen M, Frame D, Friedlingstein P, et al. Geological net zero and the need for disaggregated accounting for carbon sinks. Nature. 2024;638:343–350. doi: 10.1038/s41586-024-08326-8
[21] IPCC. 2006 IPCC guidelines for national greenhouse gas inventories. Available at Publications – IPCC-TFI; 2006 [accessed February 17th, 2025].
[22] UN General Assembly. Convention on the law of the sea. [accessed February 17, 2025]; 1982. https://www.un.org/Depts/los/convention_agreements/convention_overview_convention.htm.
[23] Berger M, Comte A, Kwiatkowski L, et al. Unaccountable counting: the folly of incorporating open ocean carbon sinks in nationally determined contributions. C R Géosci. 2024;356:123–137. doi: 10.5802/crgeos.271/. https://comptes-rendus.academie-sciences.fr/geoscience/articles/
[24] IPCC. 2013 supplement to the 2006 IPCC guidelines for national greenhouse gas inventories: Wetland. [accessed October 14th, 2025]; 2013. Available athttps://www.IPCC-nggip.iges.or.jp/public/wetlands/
[25] Lamboll RD, Nicholls ZRJ, Smith CJ, et al. Assessing the size and uncertainty of remaining carbon budgets. Nat Clim Change. 2023;13(12):1360–1367. doi: 10.1038/s41558-023-01848-5
[26] Reise J, Wissner N, Urrutia C. Blue carbon ecosystems in nationally determined contributions and national greenhouse gas reporting (forthcoming). Berlin: Öko-Institut, for the German Environment Ministry; 2025 Öko-Institut, for the German Environment Ministry. https://www.umweltbundesamt.de/en/publikationen/blue-carbon-ecosystems-in-nationally-determined
[27] Michaelowa A, Shishlov I, Brescia D. Evolution of international carbon markets: lessons for the Paris Agreement. WIREs Clima Change. 2019;10:e613. doi: 10.1002/wcc.613
[28] Michaelowa A, Honegger M, Poralla M, et al. International carbon markets for carbon dioxide removal. PLoS Clim. 2023;2(5):e0000118. doi: 10.1371/journal.pclm.0000118
[29] Honegger M, Michaelowa A, Roy J. Potential implications of carbon dioxide removal for the sustainable development goals. Clim Policy. 2021;21:678–698. doi: 10.1080/14693062.2020.1843388
[30] Temple J. Running tide is facing scientist departures and growing concerns over seaweed sinking for carbon removal. MIT Technol Rev. 2022. (accessed February 17, 2025).
[31] Kunbhar Z. Pakistan's mangrove carbon credit sales hit $40mn, boosts target to $12bn by 2075. Arab News. 2023. https://www.arabnews.com/node/2357126/pakistan.
[32] Tavonvunchai N, Niner H, McQuatters-Gollop A, et al. A global review of the status and trend of verified blue carbon projects. 2024. SSRN Paper. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4875179
[33] Simon F. "Greater than the amazon": Bahamas pitches seagrass meadows carbon project to international buyers. Carb Pulse. 2025;8(1):2025.

[34] Fu C, Frappi S, Havlik M, et al. Substantial blue carbon sequestration in the world's largest seagrass meadow. Commun Earth Environ. 2023;4(2023):474. doi: 10.1038/s43247-023-01154-0
[35] Fulton CJ, Barneche DR, Davis K, et al. Tracing blue carbon flows across diverse seascapes. Glob Change Biol. 2025;31:e70420. doi: 10.1111/gcb.70420
[36] Ward E, Cerasuolo M, Ragazzola F, et al. Global patterns in seagrass leaf and sediment carbon isotope fractionation have implications for carbon provenance calculations in blue carbon accreditation. Ecol Indic. 2024;167:112546. doi: 10.1016/j.ecolind.2024.112546
[37] Brunner C, Hausfather Z, Knutti R. Durability of carbon dioxide removal is critical for Paris climate goals. Commun Earth Environ. 2024;5:645. doi: 10.1038/s43247-024-01808-7
[38] Boettcher M, Schenuit F, Geden O. Into the blue: the role of the ocean in climate policy. SWP Comment 2023/C. 2023;12(03):01. doi: 10.18449/2023C12. 2023.
[39] De Pryck K, Boettcher M. The rise, fall and rebirth of ocean carbon sequestration as a climate 'solution. Glob Environ Change. 85:102820. doi:10.1016/j.gloenvcha.2024.102820
[40] Johannessen J, Christian R. Why blue carbon cannot truly offset fossil fuel emissions. Commun Earth Environ. 2023;4:411. doi: 10.1038/s43247-923-01068-x
[41] Muri H, Sulpis O, Argüello G, et al. Monitoring, reporting and verification for marine carbon dioxide removal. In: Muñiz Piniella A, Rodriguez Perez A, Kellett P, Alexander B, Bayo Ruiz F, Teodosio MC, Heymans JJ, editors. Future science brief N°. 13 of the European Marine Board. Ostend, Belgium; 2025. pp. 2593–5232.
[42] IPCC (2025Decision IPCC-LXIII-6, available at https://www.ipcc.ch/site/assets/uploads/2025/11/Decision-6-MR-CDR.pdf (accessed November 11, 2025)
[43] Bosmans P, de Mariz F. The blue bond market: a catalyst for ocean and water financing. J Risk Financ Manag. 2023;16:184. doi: 10.3390/jrfm16030184
[44] Warland L, Michaelowa A. Can debt for climate swaps be a promising climate finance instrument? In: Perspectives. 2015. pp. 1–26.
[45] Galparsoro I, Montero N, Mandiola G, et al. Assessment tool addresses implementation challenges of ecosystem-based management principles in marine spatial planning processes. Commun Environ Econ Issues. 2025;6:55. doi: 10.1038/s43247-024-01975-7
[46] McLaren D, Carver L. Disentangling the “net” from the “offset”: learning for net-zero climate policy from an analysis of “no-net-loss” in biodiversity. Front Clim. 2023;5:1197608. doi: 10.3389/fclim.2023.1197608
[47] UNFCCC. Decision 9/CMP.7. Materiality standard under the clean development mechanism; 2011. https://UNFCCC.int/sites/default/files/resource/docs/2011/cmp7/eng/10a02.pdf#page=11