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PERSPECTIVE

Towards a fair, reliable, and practical verification framework for Blue Carbon-based CDR

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Abstract

While the (re-)establishment of Blue Carbon Ecosystems (BCE) is seen as an important tool to mitigate climate change, the credibility of such nature-based solutions has been marred by recent revelations ranging from weak accounting to malpractice. In light of this, there is a clear need to develop monitoring, reporting and verification (MRV) systems towards the reliable, practical, and accurate accounting of additional and durable carbon dioxide removal (CDR). We propose the development of a Blue Carbon Ecosystem Digital Twin (BCE-DT) as a practical solution, integrating real-time data and models into What-If Scenarios of CDR aimed at the quantification of CDR additionality and durability. Critically, such a solution would be amenable to projects across a broad range in spatial scale and ecosytem type. In parallel, we propose the creation of an independent and not-for-profit Standards Development Organization (SDO) for the management of this Digital Twin and oversight of the certification process based on MRV. Considering the interwoven nature of the scientific and policy/legal needs we raise, an improved dialogue and collaboration between the scientific and policy communities is clearly needed. We argue that this BCE-DT, along with its oversight and implementation by a SDO, would fit this niche and support the fair and accurate implementation of MRV critically needed for BCE-based CDR to proceed.

1. Climate mitigation via Blue Carbon Ecosystem (re-)establishment

The management and protection of Blue Carbon Ecosystems (BCE), -commonly defined as seagrass, mangrove, and salt marsh ecosystems (but see, e.g. Lovelock and Duarte 2019 about the inclusion of additional ecosystems), is a tool in the portfolio of Nature-based Solutions (NbS) for climate change protection and plays a small but growing role in carbon exchange markets. However, such NbS activities and their assessment frameworks (e.g. REDD+ and VERRA) have recently come under scrutiny (Seddon *et al* 2020, 2021, Levinthal *et al* 2023, West *et al* 2023) due to faulty or misleading accounting (Boyd *et al* 2023, Johannessen and Christian 2023), although the issue had plagued the sector for some time (Anderson 2012). While these assessment frameworks lack rigor and fairness, allowing projects to select from a 'methods buffet' for assessment, including everything from proxies and default values to field data and models (e.g. Verra Methodology VM0033), nevertheless, when implemented fairly and accurately, such NbS could facilitate effective (Bertram *et al* 2021, Feng *et al* 2023), although small (Johannessen and Christian 2023, Smith *et al* 2023) emissions avoidance. However, avoided emissions do not actively remove CO_2 from the atmosphere, and are therefore unfit for negative-emissions goals, as they lack additionality.

The (re-)establishment (sensu Zimmer *et al* 2022) of BCE is a strongly desired NbS for atmospheric CO_2

removal (CDR), which is seen as a relatively low-risk approach towards climate mitigation (Gattuso *et al* 2018), especially when applied at responsible and sustainable levels (Deprez *et al* 2024). Recognizing this, the first global stocktake calls on Parties to accelerate, *inter alia*, ocean-based mitigation in support of nationally determined contributions (NDCs), specifically naming the restoration of oceans and coastal ecosystems (FCCC/PA/CMA/2023/L.17). While this is a laudable ambition, improved accounting mechanisms are needed for a fair and reliable implementation of BCE-based CDR (Christianson *et al* 2022, Mengis *et al* 2023, Palter *et al* 2023). Such assessment mechanisms, termed monitoring, reporting and verification (MRV), will assess the rate of additional carbon sequestration and storage, considering the biogeochemical complexity of these systems including potential reversals due to greenhouse gas emission (Rosentreter *et al* 2023), carbonate precipitation (Van Dam *et al* 2021, Fakhraee *et al* 2023) and lateral fluxes (Akhand *et al* 2020, Santos *et al* 2021, Reithmmaier *et al* 2023). Such an MRV framework should enable knowledge-based decision-making at different political levels, depending on the bodies responsible for the CDR assessment.

The goal of this perspective is to present a fair, reliable and practical MRV framework for the certification of BCE-based CDR both for market-based CO_2 removals and NDCs. We propose a framework consisting of a strong observational foundation feeding into an earth system model in near real-time, in essence a BCE digital twin. On the policy/legal side, we propose the implementation of an intergovernmental Standards Development Organization (SDO), responsible for the oversight of a fair and reliable certification process. We discuss some legal barriers that need to be addressed, before such a framework can be implemented.

1.1. MRV needs for BCE-based CDR

When a project (re-)establishes a BCE with the purpose of CDR targeted either at existing voluntary markets or a future compulsory market (where CO_2 removals are mandated under a 'polluter pays' system), two key factors must be addressed: additionality (CDR would not have happened otherwise) and durability (this CO_2 is kept out of the atmosphere for a considerable length of time; also referred to as permanence). Additionality can be demonstrated by measuring the net amount of CO_2 removed from the atmosphere, compared to a counterfactual baseline where no action is taken, while also accounting for the life-cycle assessment of the CDR intervention and possible future CO_2 losses. Demonstrating durability may be more challenging, as (1) no unified time horizon exists beyond which CDR is considered 'durable', and (2) durability varies across ecosystem compartments, ranging from transient (e.g. leafy biomass and litter), to intermediate durability (dissolved inorganic carbon), to clearly durable (recalcitrant sediment organic carbon). Clear requirements for additionality and durability are also needed to ensure that the price of carbon credits scales with the quality of CO_2 removals, making the quantification of additionality and durability with appropriate precision and accuracy a key task of MRV.

BCE-based CDR is, and will continue to be, implemented at many scales, ranging from bespoke small-scale operations carried out by local actors to large (inter)national restoration projects. Considering that economies of scale exist in BCE-based CDR, such that larger projects have a relatively larger fraction of total budget available for monitoring, a danger exists that the cost-burden of MRV becomes prohibitive for smaller projects. As such, MRV solutions should aim for fairness by not being based solely on expensive *in-situ* or remote-sensing measurements but should also rely on modeling (Bach *et al* 2023, Ho *et al* 2023), which will in turn be supported by observational data collected within other CDR projects. While Mengis *et al* (2023) already mentioned the dual need for models and observations, their proposed MRV framework is customized to each BCE-based CDR effort and relies on extensive *in-situ* observations. To our point of view, overly extensive monitoring needs and site-specific customization could present a practical barrier to MRV success and create an economic disadvantage for smaller CDR projects with likewise small budgets. While we agree that MRV must be built on a foundation of quality observations, we attempt to circumvent the cost-burden of MRV for smaller projects by proposing a practical MRV framework agnostic to project scale and ecosystem type.

2. An MRV framework for BCE-based CDR

2.1. Policy and legal considerations

While the international community has tried to take policy action, legislation on MRV is fragmented and insufficient. The Paris Agreement introduced 'the Mechanism', a global carbon market for UN-recognized carbon credits overseen by the 'Article 6.4 Supervisory Body' (6.4SB). In light of the recent COP28, the 6.4SB published recommendations on how to deal with CO_2 removals, including MRV (Recommendation A6.4-SB009-A02). Unfortunately, Parties could not reach a decision in Dubai, and the Mechanism is still not operational. Until international policy changes are made, and a public verification mechanism can be developed, we will continue to rely on private and voluntary standards like VERRA's VCS. Unfortunately, though, the non-binding nature of these voluntary standards means that associated certificates cannot be counted towards countries' NDCs, and are therefore unable to address the largest

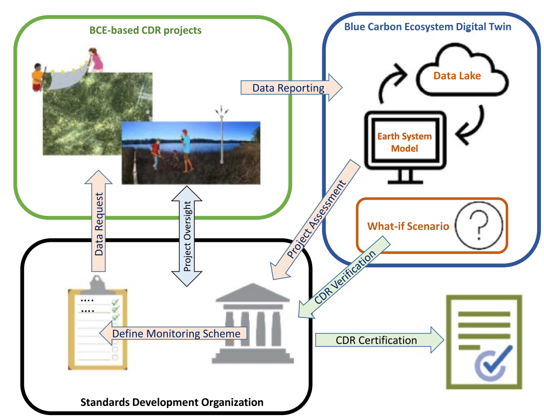

Figure 1. Conceptual diagram of the proposed MRV framework, including a Blue Carbon ecosystem digital twin (BCE-DT) and the implementation of an independent and not-for-profit Standards Development Organization (SDO). Some graphics are sourced from the Integration and Application Network (ian.umces.edu/media-library).

fraction of human emissions. In the end, this uncertainty regarding which legal body is responsible for the MRV and certification of carbon credits is a major challenge for legislators trying to create a reliable MRV framework for BCE-based CDR.

2.2. Envisioning an independent and not-for-profit Standards Development Organization (SDO)

As BCE-based CDR projects are, and will continue to be, distributed around the globe, there is a need for a unified international assessment framework to enable a fair, reliable and internationally-accepted assessment framework. This is especially critical for CO_2 removals for the purpose of NDCs, ensuring CO_2 removals are calculated in a uniform and commonly-accepted way, across political boarders. Such a framework should be overseen by an international Standards Development Organization (SDO), to enable a fair and independent certification process. Further, the costs for MRV and certification are also currently a burden for small-scale projects, notably when the certification process is run through a company making profit out of this process. We therefore suggest creating an independent and non-profit SDO in an intergovernmental setting like the IPCC or UNFCCC, to oversee the CDR certification process. Such an SDO would be tasked with the initialization, maintenance, and oversight of the Digital Twin system described below, as well as the definition of field-data collection requirements for specific BCE-based CDR projects and curation and issuance of carbon credits (figure 1).

2.3. A Blue Carbon Ecosystems Digital Twin (BCE-DT)

In line with the need for a fair and reliable MRV framework, we propose the establishment of a Blue Carbon Ecosystem—Digital Twin (BCE-DT), a single and centrally managed model which represents the global diversity of BCE and their carbon budget(s). DTs are distinguished from traditional modeling approaches by their near real-time synchronization with the observed world, and the application of Artificial Intelligence (Tzachor *et al* 2023) and Earth System Models (Irrgang *et al* 2021), with the ability to conduct What-If Scenarios as key attribute. While oversight of this BCE-DT must be at the intergovernmental level, it could be structured similar to the rapidly developing Digital Twin of the Ocean, where *in-situ* data, models, and Artificial Intelligence are integrated for an improved characterization of natural spatial and temporal variability (Pillai *et al* 2022), adapting to both anthropogenic and natural changes as they occur. Applied to BCE-based CDR, the proposed BCE-DT would enable a near real-time assessment of carbon budgets, and the construction of parallel scenarios where CDR activity is turned on and off, allowing a near real-time assessment of CDR additionality (as the difference between CDR-on vs CDR-off scenarios).

2.4. Proposed MRV framework integrating BCE-DT and SDO

The MRV framework we propose would operate as shown in figure 1. First, an Artificial Intelligence-enriched Earth-System Model is co-designed with stakeholder input and is integrated into a High-Performance Computing framework. A centralized data repository (termed 'Data Lake' in figure 1) is established as a central part of the BCE-DT, fostering seamless integration of near real-time data (Tzachor *et al* 2023). The establishment and operation of this BCE-DT system is then internationally-coordinated by the SDO.

Next, projects seeking accreditation register with the SDO, providing key information like ecosystem type, restoration methods, size, geographic setting, and other relevant data related to carbon stocks and fluxes. These initial data are integrated into the BCE-DT, and used to create a first baseline estimate of carbon sequestration. From this baseline, the BCE-DT identifies to which model parameters net carbon sequestration and storage are most sensitive to. Based on these MRV-critical parameters, the SDO prescribes a monitoring plan for key variables, at an appropriate spatial and temporal coverage, considering that larger projects can afford costlier, but still critical methods, including parameters like tracer injections, dissolved organic carbon outwelling, eddy covariance or radioisotope tracing. The BCE-DT thus ensures these MRV-critical observations (Hurd *et al* 2024, Howard *et al* 2023) are indeed collected despite their cost, providing a significant advantage in integrated monitoring/modeling (benefiting small projects with restricted monitoring budgets), while also supporting efficient resource management. Next, these observations are regularly added to the Data Lake, along with those provided by the scientific community, improving DT performance and therefore accuracy of estimated carbon sequestration rates with time, while also adapting to changing climatic and anthropogenic forcing.

Finally, the BCE-DT is used to simulate What-if Scenarios where CDR activity is turned on and off, and additionality is assessed as the difference between net CO_2 removal in CDR-on and CDR-off (baseline, or 'counterfactual') scenarios. CDR certificates are then issued by the SDO, and updated annually, allowing the valuation to adjust as the project develops, and natural conditions change. This approach enables the SDO to dynamically optimize the BCE-DT, ensuring that its representation of global BCE will improve and adapt as efficiently as possible, as new data arrive and the environment changes. Environmental issues, such as hydronamic changes, watershed pollution and climate change, but also social factors, like political instability, have all presented challenges to BCE (re-)establishment projects previously (Bayraktarov *et al* 2016, Wylie *et al* 2016). Therefore, the BCE-DT's capacity to 'update its priors' will encourage BC actors to design projects in ways that make CDR durable and resiliant to future social and environmental changes (Mengis *et al* 2023). An added benefit of the BCE-DT is its relative practicality, compared with more bespoke approaches to MRV. Each project, regardless of size, will benefit from swift and efficient access to data and information collected at all other CDR projects; the Data Lake will also improve the efficiency of the entire system.

3. Next steps and concluding statement

While we argue that the framework presents a practical solution for MRV of BCE-based CDR, we acknowledge that several steps must be taken, before such a coupled BCE-DT and SDO can be implemented.

1. First, the quality, quantity and integration of marine chemical, biological, and physical observational data must improve, while their acquisition costs should decline. This calls for extensive interdisciplinary efforts in the natural and data sciences.
2. Second, a fair and practical regulation framework to de-risk the uncertain legal environment surrounding MRV, aiding the transition from voluntary exchanges towards mechanisms enabling CDR for NDCs and compulsory markets is needed. For example, BCE-based CDR carried out by introducing propagules into the marine environment potentially falls under dumping or geo-engineering prohibitions of international law, which Parties have also transposed into national law (Law of the Sea Convention, London Protocol & 2013 London Amendment, not (yet) in force). Recently, Parties to the LC and LP expressed concern regarding the potential for severe deleterious effects of biomass cultivation for CO_2 removal and the considerable uncertainty regarding their effects on the marine environment (LC 45/LP 18). This question of whether planned activities pose threats to marine or coastal ecosystem explains the current precautionary approach to BCE-based CDR. A sound framework for impact assessment, based on reliable science is needed to legally balance environmental concerns against quality of CO_2 removals.
3. Lastly, whether and how the co-benefits, risks, and societal interactions of BCE (re-)establishment can be assessed and valued has to be resolved. Such environmental and societal co-benefits/risks of BCE (re-)establishment are numerous, and we argue should be incorporated into project valuation, as a separate MRV system outside that for CDR.

To summarize, we propose a paired observational and modeling system, the BCE-DT, coupled with an independent and not-for-profit SDO as an MRV framework for BCE-based CDR certification. This proposed framework could address a set of key problems that are preventing or slowing CDR deployment, including: (1) the problem of selective observations or otherwise dishonest accounting, (2) bias against smaller BCE-based CDR projects, and (3) the need for consistent assessment mechanisms for additionality and durability. While we acknowledge that the development and implementation of such a framework, coupling the BCE-DT and the SDO, will be an enormous task, we believe it offers a fair and practical solution to the above issues and should be seen as a priority on both policy and scientific agendas.

Data availability statement

No new data were created or analyzed in this study.

Author contributions

An initial draft of this manuscript was written by BVD following a discussion with M Z, V H, and D K about the need for improved MRV in BCE-based CDR. E S and J S investigated legal frameworks and digital twins, respectively, and contributed text. All authors discussed the concept openly and contributed to writing the final manuscript.

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References

Akhand A, Watanabe K, Chanda A, Tokoro T, Chakraborty K, Moki H, Tanaya T, Ghosh J and Kuwae T 2020 Lateral carbon fluxes and CO_2 evasion from a subtropical mangrove-seagrass-coral continuum *Sci. Total Environ.* **752** 142190

Alexandra D, Leadley P, Dooley K, Williamson P, Cramer W, Gattuso J-P, Rankovic A, Carlson E L and Creutzig F 2024 Sustainability limits needed for CO_2 removal *Science* **383** 484–6

Anderson K 2012 The inconvenient truth of carbon offsets *Nature* **484** 7

Bach L T, Ho D T, Boyd P W and Tyka M D 2023 Toward a consensus framework to evaluate air–sea CO_2 equilibration for marine CO_2 removal *Limnol. Oceanogr. Lett.* **8** 685–91

Bayraktarov E, Saunders M I, Abdullah S, Mills M, Begher J, Possingham H P, Mumby P J and Lovelock C E 2016 The cost and feasibility of marine coastal restoration *Ecol. Appl.* **26** 1055–74

Bertram C, Quaas M, Reusch T B H, Vafeidis A T, Wolff C and Rickels W 2021 The blue carbon wealth of nations *Nat. Clim. Change* **11** 704–9

Boyd P W, Bach L, Holden R and Turney C 2023 Carbon offsets aren't helping the planet—four ways to fix them *Nature* **620** 947–9

Christianson A B, Cabré A, Bernal B, Baez S K, Leung S, Pérez-Porro A and Poloczanska E 2022 The promise of blue carbon climate solutions: where the science supports ocean-climate policy *Front. Mar. Sci.* **9** 851448

Feng C, Ye G, Zeng J, Zeng J, Jiang Q, He L, Zhang Y and Xu Z 2023 Sustainably developing global blue carbon for climate change mitigation and economic benefits through international cooperation *Nat. Commun.* **14** 6144

Gattuso J P *et al* 2018 Ocean solutions to address climate change and its effects on marine ecosystems *Front. Mar. Sci.* **5** 337

Ho D T, Bopp L, Palter J B, Long M C, Boyd P, Neukermans G and Bach L 2023 Monitoring, reporting, and verification for ocean alkalinity enhancement *Scientific Synthesis Reports and Assessments* (https://doi.org/10.5194/sp-2-oae2023-12-2023)

Howard J *et al* 2023 Blue carbon pathways for climate mitigation: known, emerging and unlikely *Mar. Policy* **156** 105788

Hurd C L, Gattuso J and Boyd P W 2024 Air-sea carbon dioxide equilibrium: will it be possible to use seaweeds for carbon removal offsets? *J. Psychol.* **60** 4–14

Irrgang C, Boers N, Sonnewald M, Barnes E A, Kadow C, Staneva J and Saynisch-Wagner J 2021 Towards neural Earth system modelling by integrating artificial intelligence in Earth system science *Nat. Mach. Intell.* **3** 667–74

Johannessen S C and Christian J R 2023 Why blue carbon cannot truly offset fossil fuel emissions *Commun. Earth Environ.* **4** 411

Levinthal R and Weller R 2023 Mega-eco projects: a global assessment of large-scale ecological restoration initiatives *Socio-Ecol. Pract. Res.* **5** 341–61

Lovelock C E and Duarte C M 2019 Dimensions of Blue Carbon and emerging perspectives *Biol. Lett.* **15** 20180781

Mengis N, Paul A and Fernández-Méndez M 2023 Counting (on) Blue Carbon—challenges and ways forward for carbon accounting of ecosystem-based carbon removal in marine environments *PLoS Clim.* **2** e0000148

Mojtaba F, Planavsky N J and Reinhard C T 2023 Ocean alkalinity enhancement through restoration of Blue Carbon Ecosystems *Nat. Sustain.* **6** 1087–94

Palter J, Cross J, Long M, Rafter P and Reimers C 2023 The science we need to assess marine carbon dioxide removal *Eos* **104** 17

Pillai U, Pinardi N, Alessandri J, Federico I, Causio S, Unguendoli S, Valentini A and Staneva J 2022 A digital twin modelling framework for the assessment of seagrass nature based solutions against storm surges *Sci. Total Environ.* **847** 157603

Reithmaier G M S *et al* 2023 Carbonate chemistry and carbon sequestration driven by inorganic carbon outwelling from mangroves and saltmarshes *Nat. Commun.* **14** 8196

Rosentreter J A *et al* 2023 Coastal vegetation and estuaries are collectively a greenhouse gas sink *Nat. Clim. Change* **13** 1–9

Santos I R, Burdige D J, Jennerjahn T C, Bouillon S, Cabral A, Serrano O, Wernberg T, Filbee-Dexter K, Guimond J A and Tamborski J J 2021 The renaissance of Odum's outwelling hypothesis in 'Blue Carbon' science *Estuar. Coast. Shelf Sci.* **255** 107361

Seddon N, Chausson A, Berry P, Girardin C A J, Smith A and Turner B 2020 Understanding the value and limits of nature-based solutions to climate change and other global challenges *Phil. Trans. R. Soc.* B **375** 20190120

Seddon N, Smith A, Smith P, Key I, Chausson A, Girardin C, House J, Srivastava S and Turner B 2021 Getting the message right on nature-based solutions to climate change *Glob. Change Biol.* **27** 1518–46

Smith S *et al* 2023 State of carbon dioxide removal 1st edn (https://doi.org/10.17605/OSF.IO/W3B4Z)

Tzachor A, Hendel O and Richards C E 2023 Digital twins: a stepping stone to achieve ocean sustainability? *npj Ocean Sustain.* **2** 16

Van Dam B R, Zeller M A, Lopes C, Smyth A R, Böttcher M E, Osburn L, Zimmerman T, Pröfrock D, Fourqurean J W and Thomas H 2021 Calcification-driven CO_2 emissions exceed 'Blue Carbon' sequestration in a carbonate seagrass meadow *Sci. Adv.* **7** 1–10

West T A P, Wunder S, Sills E O, Börner J, Rifai S W, Neidermeier A N, Frey G P and Kontoleon A 2023 Action needed to make carbon offsets from forest conservation work for climate change mitigation *Science* **381** 873–7

Wylie L, Sutton-Grier A E and Moore A 2016 Keys to successful blue carbon projects: lessons learned from global case studies *Mar. Pollut.* **65** 76–84

Zimmer M *et al* 2022 When nature needs a helping hand: different levels of human intervention for mangrove (re-)establishment *Limnol. Oceanogr. Lett.* **5** 784322