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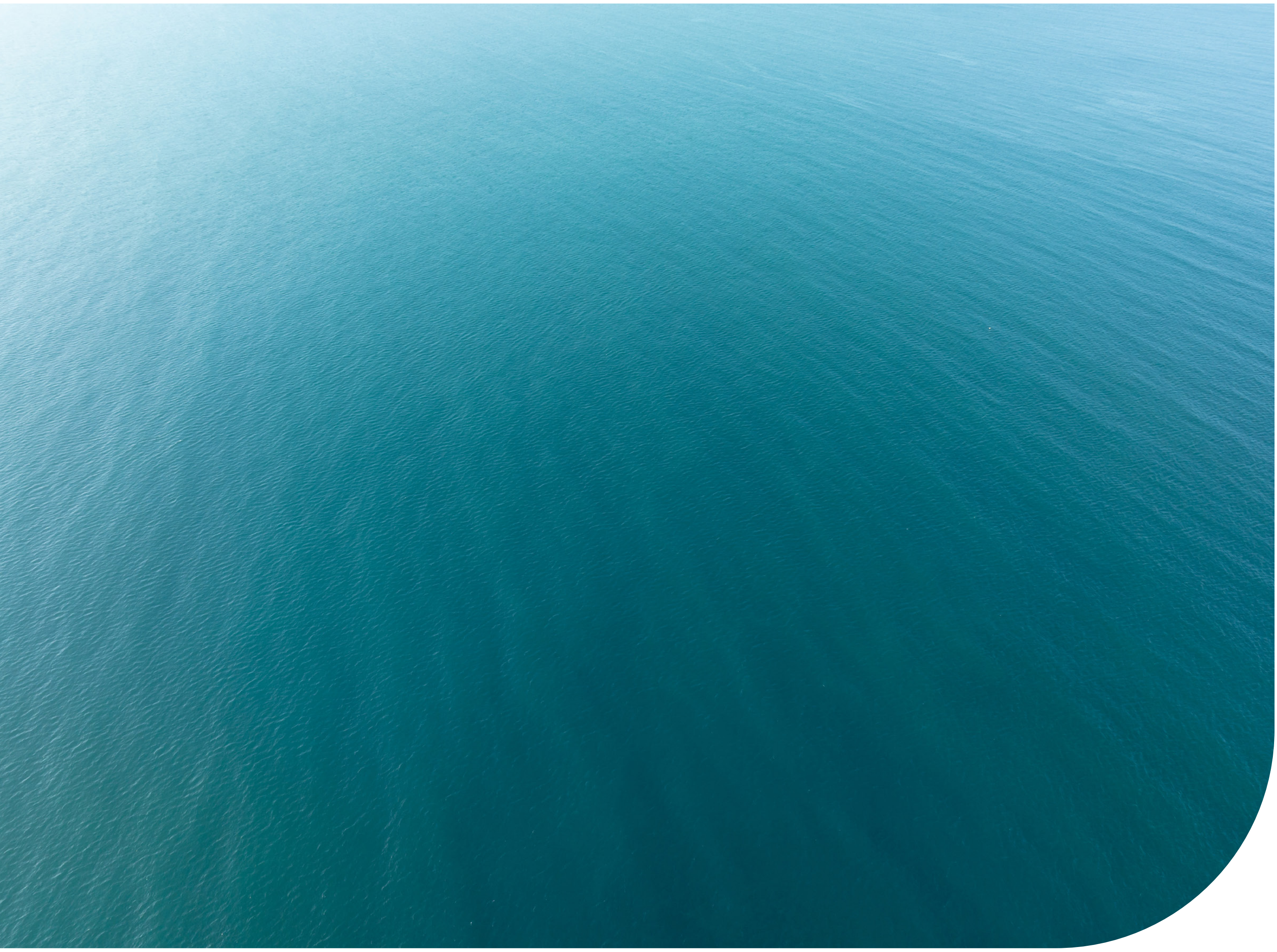
September 2026



Policy informing brief

Marine carbon in climate, ocean and biodiversity governance: evaluating readiness for ocean-based carbon removal strategies

BERNARDO

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Date	September 2026
ISSN number	2295-7464
DOI	https://dx.doi.org/10.48470/139
Thanks to	VLIZ library division, VLIZ policy and innovation division, the BERNARDO consortium
Layout	Verleye Thomas J., Dauwe Steven (VLIZ)
Cover	© Shutterstock paid license - all pictures for non-commercial use. Cover © lzf; p.17 © JopStock; p.38 © lzf; p. 58 © Ethan Daniels; p. 83 © Netfalls Remy Musser
Citation	Dauwe, S., Verleye T. J., Pirlet, H., Chisala, C. (2026). Marine carbon in climate, ocean and biodiversity governance: evaluating readiness for ocean-based carbon removal strategies. VLIZ Beleidsinformerende Nota's, 2026_002. Flanders Marine Institute (VLIZ): Ostend. 101 pp.

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CONTENT

Preface

This policy brief is developed within the context of the BERNARDO project (Linking Blue Economy with Marine Carbon Budgets through Observations; VLAIO 2023-2027). BERNARDO aims to deliver a high-resolution, balanced marine carbon budget for a shelf sea (the Belgian North Sea), thereby establishing a robust scientific baseline for marine carbon accounting. This baseline carbon budget is evaluated against several use cases within the Belgian North Sea and coastal zone, enabling a quantitative assessments of the impact of Blue Economy activities on the carbon budget, consequently supporting emerging applications in carbon footprinting, environmental impact assessments, and climate finance.

In this context, the project highlights and responds to a critical policy challenge as, despite its central role in climate regulation, marine carbon is not yet "policy-ready". From a systematic analysis, three interrelated bottlenecks could be identified: (i) fragmented policy frameworks, (ii) insufficiently developed monitoring, reporting and verification (MRV) systems for marine carbon, and (iii) the lack of operational marine carbon accounting frameworks. Together, these barriers prevent the integration of marine carbon into climate policy, carbon accounting systems, market-based mechanisms and the in-situ implementation of marine carbon removal techniques (mCDR); an increasingly explored but still uncertain marine climate mitigation pathway.

Against this backdrop, this policy brief assesses how carbon, as a key climate-regulating component underpinning major ocean ecosystem services, is currently addressed across international, European, and regional climate, ocean, and biodiversity frameworks. The brief particularly focuses on evaluating the extent to which these frameworks can support the integration and governance of mCDR.

The findings of this policy brief underscore that progressing towards policy-relevant marine carbon management requires a coherent and integrated governance architecture in which policy frameworks, MRV protocols and accounting and certification mechanisms are aligned. Robust, science-based carbon accounting emerges as a foundational condition to enable credible climate action, while also taking biodiversity protection and sustainable Blue Economy objectives into account.

In this context, BERNARDO contributes by providing a spatially explicit, detailed carbon baseline and advanced methodologies that directly support the development of MRV systems and carbon accounting practices. The outputs of BERNARDO offer concrete entry points for integrating marine carbon into policy instruments such as marine spatial planning, environmental impact assessments, greenhouse gas inventories and emerging carbon certification frameworks.

Overall, this policy informing brief aims to inform policymakers and relevant stakeholders on the opportunity of a transition towards a more integrated governance approach at the ocean-climate-biodiversity nexus. One that, by means of a full valuation of carbon, can reconcile climate mitigation, ecosystem protection, and sustainable resource use. In the future, it could also guide the responsible deployment of mCDR solutions outside the delineated and manageable coastal setting.

Table 1.Overview of the considered frameworks within the climate-ocean-biodiversity and nature protection policy domains.

Domain	Section	Framework	Page
Climate	3.1.1 Global climate frameworks	UNFCCC	29
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Ocean	3.2.1 Global ocean frameworks	London Protocol	40
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Table 2.Overview of the considered frameworks in the Addendum section.

Domain	Section	Framework	Page
Overarching framework	6.1 UN 2030 Agenda for Sustainable Development	UN 2030 Agenda for Sustainable Development	82
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Executive summary and policy recommendations

Current global climate action remains insufficient to achieve the Paris Agreement's objective of limiting warming to well below +2 °C. In response, increasing attention is being directed towards marine carbon dioxide removal (mCDR) as a complementary climate mitigation pathway. Scientific evidence suggests the ocean holds substantial, yet largely untapped, potential for carbon dioxide removal through both engineered (e.g. ocean alkalinty enhancement, ocean fertilisation) and nature-based mCDR approaches (creation and or restoration of blue carbon ecosystems like mangroves, seagrass or salt marshes). However, mCDR techniques remain characterised by significant uncertainties regarding their effectiveness, environmental impact, costs, durability, and societal acceptance.

At the same time, governance at the ocean-climate-biodiversity nexus is fragmented and insufficiently equipped to regulate mCDR. Our cross-framework analysis from a carbon-perspective touches upon key bottlenecks as well as entry points for making mCDR "policy-ready".

Climate governance frameworks set the rules for climate action, including monitoring, reporting and verification (MRV), carbon accounting, and carbon markets. Yet, with the partial exception of specific coastal blue carbon ecosystems, these frameworks currently lack applicability to marine systems. As a result, the carbon sink function of the open ocean and shelf seas remains largely excluded from formal climate accounting.

Ocean governance frameworks by contrast, focus primarily on spatial planning and the management of human activities, while they largely overlook marine carbon as a management target, limiting their suitability for governing carbon removal and accounting processes.

Biodiversity and nature conservation frameworks provide robust safeguards through protection, restoration, and the precautionary principle, particularly the obligation to avoid 'significant environmental harm'. While essential, these safeguards can constrain experimental in-situ research, especially on engineered mCDR. Moreover, the limited integration of quantitative marine carbon considerations within these frameworks restricts their capacity to assess climate benefits alongside biodiversity or pollution-focused conservation objectives.

Overall, no single policy framework is currently capable of operationalising and regulating ocean-based carbon removal. The development and integration of robust, science-based MRV systems capable of accurately quantifying and verifying marine carbon fluxes emerge as a critical precondition for enabling coherent governance, regulatory oversight and the potential integration of mCDR into carbon market mechanisms.

The BERNARDO project directly addresses this science-policy-industry gap by building to the scientific and methodological foundations required for future policy integration. Notably, it will deliver a detailed baseline marine carbon budget for a shelf sea (the Belgian North Sea). This quantification is based on state-of-the-art observations and methodologies and as such provides a robust basis for the development of MRV systems, as well as their application in carbon accounting frameworks, climate finance mechanisms, and life-cycle assessment frameworks.

Building on the policy analysis presented in this policy brief, BERNARDO identifies concrete entry points for policy uptake. These include a.o. the EU Carbon Removals and Carbon Farming (CRCF) Regulation which offers a testing ground for certification readiness, the EU Ocean Pact with its Ocean Eye initiative, where BERNARDO's scientific outputs can inform the integration of carbon considerations into future marine spatial planning or the Nature Restoration Regulation where the protection of marine carbon sinks is one of the key pillars. In addition, BERNARDO's findings open new avenues for incorporating climate-relevant carbon assessments into environmental impact assessments (EIAs) and permitting procedures within the Blue Economy context.

Taken together, the insights presented in this brief, combined with the results of the BERNARDO project, constitute important steps towards robust marine carbon accounting and the potential deployment of certified ocean-based carbon removal approaches. Such deployment will require a robust and integrated policy framework, aligned with sustainable blue economy objectives, environmental protection objectives, science-based marine climate action, and the effective protection of oceanic carbon sinks and the biodiversity supporting it.

Policy recommendations

Based on our carbon-focused assessment of existing climate, ocean, and biodiversity policy frameworks, supported by a screening of relevant scientific literature, we conclude that marine carbon will only become policy-relevant if monitoring, reporting and verification (MRV), governance structures, and carbon accounting frameworks become aligned.

We propose the following recommendations towards this objective:

1. Strengthen the scientific basis for MRV
Invest in research projects that address the remaining challenges preventing the development of sound MRV guidelines for marine carbon accounting and as such invest in evidence-based guidance on the management of marine carbon sinks and the assessment of mCDR.

2. Develop standardised marine MRV methodologies
Advance MRV approaches for marine carbon accounting that are aligned with the criteria of the EU's CRCF Regulation and consistent with the Intergovernmental Panel on Climate Change (IPCC) guidelines.

3. Establish integrative governance frameworks
Align climate, ocean and biodiversity frameworks to create a coherent governance structure that recognises the central role of marine carbon in the global ocean system and all its beneficiaries and provide a regulatory basis for transparent and reliable carbon accounting.

4. Integrate carbon into marine spatial planning and impact assessment
Embed carbon considerations into marine spatial planning (MSP) and environmental impact assessment (EIA) processes, for instance through emerging policy instruments such as the EU Ocean Pact/Act.

5. Align biodiversity safeguards with carbon accounting
Ensure that biodiversity protection frameworks are better aligned with carbon accounting approaches, enabling a balanced evaluation of ecological risks (particularly for engineered mCDR approaches) and the added value provided by nature (nature-based approaches) alongside climate or economic benefits.

6. Enable carefully governed pilot projects for engineered mCDR
In case the carbon removal potential and environmental impact of engineered mCDR are assessed with high confidence, and where appropriate regulatory frameworks ensure equity and environmental integrity, pilot-scale deployments under real-world conditions to assess the mitigation potential of engineered mCDR techniques may be considered.

Central to the above recommendations is the establishment of transparent and robust accounting mechanisms, grounded in scientifically credible MRV systems, to ensure a reliable quantification of marine carbon fluxes and mCDR contributions. A credible quantification of marine carbon is a prerequisite in realising an integrated climate-ocean-biodiversity governance architecture that fully values ocean carbon and is ready to support science-based marine climate mitigation, the protection of oceanic carbon sinks and sustainable blue growth.

[1] The four key challenges are: (1) accurate baseline determination of the marine carbon budget, (2) resolving the fate of the carbon conundrum and ensuring long-term carbon sequestration, (3) accounting for ecosystem interconnectedness and (4) accounting for the possibility of significantly harmful and irreversible outcomes with uncertain spatial or temporal scope.

1. Ocean-based carbon removals - a potential ally in the fight against climate change?

PROBLEM

Current and projected global climate action is insufficient to meet the target of the Paris Agreement to keep global warming below +2 °C, prompting the exploration of novel mitigating pathways like marine carbon removal techniques (mCDR). mCDR, however, combines significant promise with substantial risks and remains characterised by major knowledge gaps regarding its effectiveness, environmental impacts, costs, durability, and societal acceptance. Only nature-based mCDR techniques, like the creation or restoration of coastal blue carbon ecosystems (salt marshes, mangroves, seagrass), are considered relatively "policy ready", leaving other blue carbon ecosystems like e.g. shelf seas (sediments) or engineered mCDR-approaches outside accounting and regulatory frameworks.

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BERNARDO can contribute to solving this problem by delivering policy-relevant evidence on shelf sea carbon dynamics. It's output is directly relevant to support the development of robust monitoring, reporting and verification (MRV) and marine carbon accounting methodologies, instruments which are essential in assessing environmental and socio-economic implications of mCDR. In doing so, BERNARDO provides valuable stepping stones towards the integration of offshore blue carbon into climate-ocean-biodiversity governance frameworks and enables a widening of the scope of today's marine carbon accounting landscape.

1.1 The ocean-climate nexus

Covering approximately 72% of the Earth's surface, the ocean is vital for all life on earth and supports our society in terms of climate stability, economic development and human well-being (IPCC 2019, Stuchtey et al. 2020, Nash et al. 2022, Hoegh-Guldberg & Northrop 2023). Yet, the ocean system is increasingly disrupted by climate change leading to sea-level rise, acidification, biodiversity loss, deoxygenation, etc., altering marine ecosystems and the services they provide (IPCC 2019). Concurrently, the pivotal role of the ocean in regulating the global climate, predominantly through its capacity to absorb, store, and cycle carbon, has gained political and scientific significance (UNFCCC 2015, IPCC 2019, Hoegh-Guldberg et al. 2019, Hoegh-Guldberg & Northrop 2023, EU Ocean Pact ((COM (2025) 281) see **3.2.2 Regional and European frameworks, p. 49**), UN Sustainable Development Goal 13 & 14 (see **6.1 UN 2030 Agenda for Sustainable Development, p. 82**)). Observations and research have revealed that the ocean has a major climate buffering effect, by annually capturing about 25% of the anthropogenic CO_2-emissions and storing 90% of excess heat by global warming (IPCC 2019, IPCC 2023, Mengis et al. 2023, Siegel et al. 2023, Friedlingstein et al. 2025). This ocean-climate nexus has led to a growing uptake in science and policy on the potential of ocean-based climate strategies (ocean solutions, marine climate mitigation) resulting in the emergence of an international ocean-climate agenda (GESAMP 2019, Hoegh-Guldberg et al. 2019, Gattuso et al. 2021, Lebling et al. 2022, UNFCCC 2022, Hoegh-Guldberg & Northrop 2023, Howard et al. 2023, EU Ocean Pact, UN Sustainable Development Goal 13& 14).

1.2 Rising interest in ocean-based carbon removals

To minimise the duration and magnitude of global warming above +1.5 °C, strengthened and accelerated climate action can no longer be delayed (IPCC 2023). Nevertheless, scientific evidence underscores that the current trajectory of climate action falls short in achieving the climate targets set out in the Paris Agreement and fulfil the climate-related Sustainable Development Goals (Rogelj et al. 2016, IPCC 2019, IPCC 2023, Climate Action Tracker). In case of overshooting the global climate goal, the Earth risks crossing several earth system tipping points (ESPs), inducing abrupt, deep and irreversible harm to ecosystems and society (McKay et al. 2022, Lenton et al. 2025). As a result, the demand for effective, reliable and feasible approaches that permanently reduce atmospheric CO_2 concentrations is rapidly increasing (Fuss et al. 2016, Peters & Geden 2017, Lawrence et al. 2018, De Coninck & Revi 2019, IRENA 2020, IEA 2021, Macreadie et al. 2021, NASEM 2021, Schindler Murray et al. 2023, Johnson et al. 2024).

Terrestrial ecosystems and their carbon sink function have long been prioritised by policy makers. However, the growing interest in carbon dioxide removal techniques (CDR)[2] (Rogelj et al. 2019, Shukla et al 2022), whether driven by the inadequacy of emission-reduction efforts (Climate Action Tracker), the finite availability of terrestrial space and resources (Boysen et al. 2017), or the difficulty of mitigating hard-to-abate emissions from sectors like agriculture, cement, steel, aviation or maritime transport, has also catalysed the exploration of ocean-based negative emission opportunities (Dauwe et al. 2021, Mengis et al. 2023, Hoegh-Guldberg & Northrop 2023, IPCC 2023). In less than a decade, the ocean has emerged as the new "blue frontier" for carbon removal and permanent storage strategies (Nelleman et al. 2009, UNFCCC 2015, Gattuso et al. 2018, Krause-Jensen et al. 2018, GESAMP 2019, Hoegh-Guldberg et al. 2019, Dauwe et al. 2021, Gattuso et al. 2021, Hilmi et al. 2021, Macreadie et al. 2021, Claes et al. 2022, Boettcher et al. 2023, Hoegh-Guldberg & Northrop 2023, Schindler Murray et al. 2023, Johnson et al. 2024).

[2] The IPCC defines CDR as 'anthropogenic activities removing carbon (CO_2) from the atmosphere and durably storing it in geological, terrestrial or ocean reservoirs or in products with the specific exclusion of natural CO_2-uptake not directly caused by human activities (IPCC 2023).

1.2.1 Carbon removal through mCDR

In order to achieve ocean-based carbon removals, scientist have come up with a wide range of concepts that intervene in the ocean's carbon cycle to enhance its natural carbon capture and sequestration potential (Minx et al. 2018, GESAMP 2019, NASEM 2021). These techniques are commonly referred to as marine carbon dioxide removal techniques, in short mCDR. An mCDR action[3] is a carbon removal action that relies on technical solutions or human interference into natural processes to enhance carbon uptake and storage by the marine system, including enhancing biological productivity or altering ocean chemistry. According to this definition, two types of mCDR can be distinguished: (1) nature-based mCDR which concerns the creation, restoration and sustainable management of blue carbon ecosystems and (2) engineered mCDR which uses technical solutions (e.g. ocean alkalinity enhancement, artificial upwelling) to stimulate marine carbon capture and storage (GESAMP 2019, NASEM 2021, Gagern et al. 2022, Schindler Murray et al. 2023, Bach et al. 2024).

Since the last decade, interest in mCDR-technologies is surging. First and foremost because of their impressive theoretical carbon sink potential and the vast

> *" The challenge of mCDR is not solely technological, it is equally scientific, ethical, and political*

opportunities for upscaling, along with their potential capacity to provide cobenefits for biodiversity, food security, coastal protection, etc.

However, mCDR remains characterised by substantial uncertainties regarding efficiency, cost, environmental impacts, monitoring, reporting and verification requirements in the context of carbon crediting, societal acceptance, environmental justice and the adequacy of governance frameworks, all of which must be addressed before large-scale deployment for climate mitigation purposes can proceed (Gattuso et al. 2018, GESAMP 2019, Hoegh-Guldberg et al. 2019, Gattuso et al. 2021, NASEM 2021, Hoegh-Guldberg & Northrop 2023, Lebling et al. 2022, Williamson & Gattuso 2022, Smith et al. 2024, Simpson & Smart 2024, Webb et al. 2024).

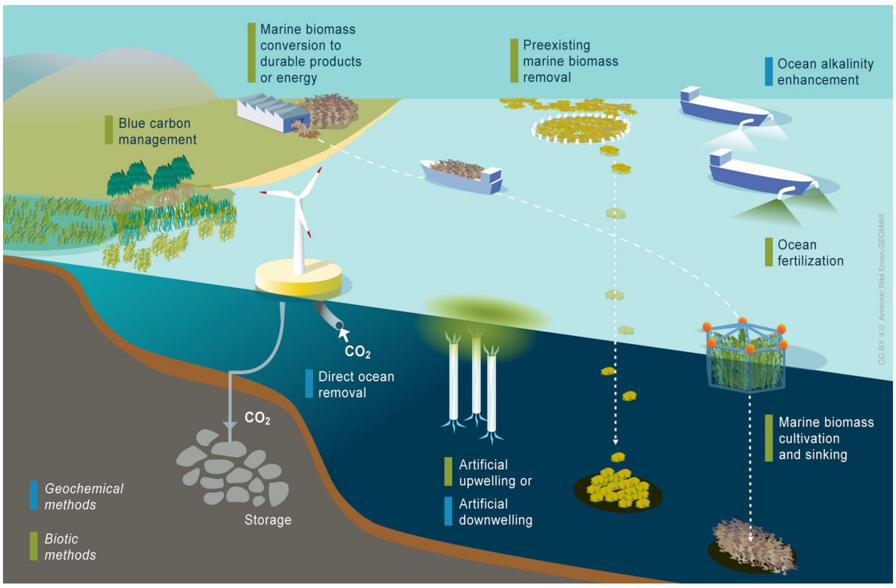

Figure 1. Schematic overview of typical marine CDR concepts (EMB 2025).

[3] Also often identified as 'Ocean-based negative emission technologies' (ONETs).

2. Why marine carbon isn't policy ready

2.1 Fragmented regulation

PROBLEM

The regulation of carbon and mCDR is constrained by fragmented and sectoral governance frameworks that fail to reflect the ocean's interconnected and transboundary nature. Climate, ocean and biodiversity policies remain poorly integrated, while existing regulatory frameworks are primarily designed to prevent harm rather than enable and regulate emerging climate solutions, such as mCDR. Today, only a subset of nature-based approaches (i.e. coastal blue carbon ecosystems) are considered "policy-ready" and hence are currently included in accounting and finance mechanisms. Other promising pathways, such as shelf sea sediments and engineered mCDR, remain excluded due to major uncertainties around effectiveness, permanence, environmental impacts, and societal acceptance. This governance gap creates legal uncertainty, delays responsible research and innovation, and risks uncoordinated or premature deployment, all while climate urgency intensifies pressure for actionable solutions.

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This policy brief provides a carbon-focused analysis of the readiness of current governance frameworks at the climate-ocean-biodiversity domain to regulate mCDR. In doing so, the BERNARDO project intends to inform on the need for a more coherent, balanced and integrated approach to policymaking, one that can simultaneously support sustainable blue growth, protect marine ecosystems, and enable effective marine climate mitigation in a fair and equitable way. Overall, the project bridges scientific insights to policy development and sustainability considerations, thereby contributing to responsible, science-based ocean-climate-biodiversity governance.

Despite the ocean's central role in the global climate system, current governance frameworks still treat ocean and climate policy as largely separate domains (Gallo et al. 2017, Spalding & de Ycaza 2020). Furthermore, the global ocean governance framework remains fragmented and sectoral, encompassing multiple institutional regimes with often appearing conflicting interest (e.g. human activities vs. nature conservation) (Stephenson et al. 2021, Boettcher et al. 2023, Röschel & Neuman 2023). In particular, today's governance frameworks struggle to account for the ocean's interconnected, transboundary and fluid nature, which calls for coherent, integrated approaches and sustained international collaboration (Boyes & Elliott 2014, Haas et al. 2021, Stephenson et al. 2021, Boettcher et al. 2023, Röschel & Neuman 2023). In addition, these frameworks are characterised by a lack of consideration of the interaction between the ocean and the atmosphere (van Doorn et al. 2024).

2.1.1 Regulation of nature-based mCDR

Today, only coastal blue carbon ecosystems (mangroves, salt marshes, seagrass ecosystems), with their high rate of carbon sequestration and long-term carbon storage potential are considered in international policy and carbon market frameworks (McLeod et al. 2011, Luisetti et al. 2020, Hilmi et al. 2021, Macreadie et al. 2022, Vanderklift et al. 2022, Hilmi et al. 2023, Schindler Murray et al. 2023, Dauwe et al. 2023). They are also the only marine ecosystems currently recognised in IPCC guidelines for national GHG-inventories. Although their inclusion remains voluntary, this recognition makes them the only marine ecosystem types included in Nationally Determined Contributions (NDCs) or long-term low-emission and development strategies (LT-LEDS) (Gallo et al. 2017, Schindler Murray et al. 2023, Simpson & Smart 2024, NDCs). Moreover, their carbon storage capacity is traded through carbon credits in both compliance and voluntary carbon markets (IPCC 2014, Dauwe et al. 2023). Discussions are ongoing whether to include other marine ecosystems, such as kelp forests, unvegetated tidal flats frameworks or even sediments of shelf seas, into carbon accounting frameworks. However, gaps in MRV (see **2.2 MRV barriers to carbon governance and accounting, p. 18**) prevent disclosure on major uncertainties regarding effectiveness and permanence which is why these systems are so far prevented from being incorporated into policy frameworks and climate-finance mechanisms (Krause-Jensen et al. 2018, Steven et al. 2019, Luisetti et al. 2020, Hilmi et al. 2021, Vanderklift et al. 2022, Dauwe et al. 2023, Van Dam et al. 2024, EMB 2025).

2.1.2 Regulation of engineered mCDR

The governance vacuum is more pronounced for mCDR approaches beyond coastal blue carbon restoration or creation. Since existing ocean and biodiversity policy frameworks are primarily designed to prevent environmental harm they are ill-equipped to address the novel challenges and opportunities posed by engineered mCDR (Scott 2013, Elsler et al.2022, Lebling et al. 2022, Palter et al 2023, Smith et al. 2024). In addition, the fragmented nature of the current global ocean governance landscape further complicates regulation (Röschel & Neuman 2023). This governance barrier results into legal uncertainty, increasing the risk engineered mCDR-projects proceed without the appropriate assessments while simultaneously delaying responsible research and experimentation necessary to rigorously evaluate engineered mCDR as a potential climate solution (Fuss et al. 2016, Brent et al. 2019, NASEM 2021, Williamson & Gattuso 2022, Lebling et al. 2022, Boettcher et al. 2023, Webb et al. 2023a, Web et al. 2023b, Webb et al. 2024, Smith et al. 2024). However, recent European initiatives, including the EU Carbon Removals and Carbon Farming Regulation (see **3.1.2 European climate frameworks p. 35**) and the Ocean Pact (see **3.2.2 Regional and European ocean frameworks p. 49**), represent initial steps towards breaking this impasse.

2.1.3 Balancing climate urgency with sound mCDR governance

Despite the major challenges and uncertainties highlighted above, the urgency of climate action has maintained political pressure to explore mCDR approaches (GESAMP 2019, Orlove et al. 2020, Boettcher et al. 2023, Hoegh-Guldberg & Northrop 2023). This momentum has intensified calls for adaptive, anticipatory governance and legislative frameworks that are practically implementable and capable of ensuring an effective and safe application of mCDR (Fridahl et al. 2023, Röschel & Neuman 2023, Johnson et al. 2024, Webb et al. 2024).

" Governance must be adaptive, address the uneven distribution of risks and benefits, and operate with social legitimacy

However, political decisions depend on a social license to operate and typically consider financial viability (Cooley et al. 2023, Bach et al. 2024). Neglecting these dimensions risks undermining transparency, legitimacy, and public trust, which are essential for the political and societal acceptance of marine based climate policies (Dooley et al. 2021, Cooley et al. 2023, Dauwe et al. 2025). Next to scientific robustness, successful mCDR governance must also be mindful of socio-economic objectives other than combatting climate change (e.g. food production, biodiversity conservation, equity, environmental justice, etc.) (Stephenson et al. 2021, Bennet 2022, Boettcher et al. 2023, Bach et al. 2024, Blue Herrings 2025). An exercise that becomes more difficult the more complex the mCDR method and the less certainty on carbon sequestration capacity and negative side-effects (Dooley et al. 2021, Cooley et al. 2023).

Furthermore, aside from the broader societal and policy perspective, mCDR is in itself a contentious strategy, as it risks undermining emission reduction efforts, potentially prolonging fossil fuel dependence while its environmental impact potentially compromises natural carbon sinks and reservoirs. In doing so, large-scale mCDR potentially conflicts with the objectives of the Paris Agreement, the Sustainable Development Goals and international biodiversity targets (Dooley et al 2021, Stephenson et al. 2021, Cooley et al. 2023, Fridahl et al. 2023, Boettcher et al. 2023, Röschel & Neuman 2023).

2.2 MRV barriers to carbon governance and carbon accounting

PROBLEM

Transparent and credible MRV systems are a prerequisite for the inclusion of carbon removals in climate policy and carbon markets. However, the quantification of net carbon removals remains challenging, particularly in distinguishing anthropogenic effects from natural variability. In addition, concepts like additionality, permanence and leakage are fundamental but contested concepts in the accounting of carbon removals.

The challenge of monitoring and verifying carbon sequestration is particularly compounded in the complex, open ocean system, where tracking the fate of the carbon remains one of the central scientific challenges, along with coping with the uncertainty of unintended consequences across spatial and temporal scales.

The forementioned scientific gaps pose a direct risk to the credibility and value of (ocean-based) carbon removal credits. Compounded with the absence of uniformly agreed methodologies and appropriate governance frameworks, MRV for mCDR today is not ready to support a climate-relevant scale-up of mCDR beyond the creation or restoration of blue carbon ecosystems. These challenges and uncertainties are reflected in Europe's precautionary approach to the exploration of engineered mCDR, which in practice results in a standstill between meaningful scientific progress and the development of the required regulatory frameworks.

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By developing and combining state of the art observation techniques, BERNARDO was able to produce a detailed carbon budget for the Belgian North Sea area. The realised advancements in the monitoring and quantification of carbon fluxes allowed for an improved detection of anthropogenic signals against natural variability and provide the tools to further explore the fate of the carbon and the durability of carbon in open marine systems. Hence, BERNARDO was able to achieve progress in several key MRV challenges like baseline definition, uncertainty management and system-wide impact of human activities. Therefore, the scientific results of BERNARDO can contribute strongly to the development of robust, scalable and policy relevant (IPCC) MRV systems. In doing so, BERNARDO makes a concrete contribution to the incorporation of offshore marine ecosystems into IPCC reporting, provides an evidence base for the governance of marine climate mitigation pathways like mCDR, and contributes to the development of robust marine carbon accounting and carbon markets mechanisms..

2.2.1 Stringent MRV requirements result in immature MRV systems

Monitoring, reporting and verification (MRV) of carbon removals and storage underpins the credibility of ocean-based carbon dioxide removal (mCDR) and is foundational to climate finance, carbon market mechanisms, sustainable economic development, and environmental governance. By ensuring transparency, traceability, and environmental integrity, robust MRV frameworks are indispensable for evaluating and managing CDR activities (Fuss et al. 2016, Smith et al. 2024, Van Dam et al. 2024, EMB 2025). They also stimulate scientific research and technological innovation towards the development and deployment of both nature-based and engineered CDR approaches (Van Dam et al. 2024, Smith et al. 2024).

Despite its central importance, MRV systems for most CDR techniques remain under development, with protocols still being designed, tested, and negotiated[4]. The level of methodological maturity varies considerably across approaches, with notable differences between nature-based and engineered mCDR, as well as among individual techniques. These disparities reflect underlying scientific uncertainties, methodological constraints, and evolving policy requirements (Smith et al. 2024).

The central objective of MRV is to determine the net amount of atmospheric CO_2 removed and durably stored over time. Achieving this demands robust quantification methodologies capable of capturing system-wide carbon dynamics under real-world conditions (Brander et al. 2021, Rogelj et al. 2023, Morganti et al. 2025). A key scientific challenge lies in distinguishing anthropogenic carbon fluxes from natural variability, an issue that remains the focus of ongoing research (Minx et al. 2018, Palter et al. 2023, EMB 2025, Morganti et al. 2025, BERNARDO project). In practice, MRV systems must balance accuracy, feasibility, and cost. This trade-off is particularly pronounced for engineered mCDR approaches operating in open and dynamic systems like the marine environment, where monitoring is inherently complex and resource-intensive (Smith et al. 2024, EMB 2025).

Persistent scientific knowledge gaps continue to undermine confidence in CDR and delay its integration into climate policy and carbon markets. In the European context, a precautionary approach to implementation and testing has limited the uptake of CDR, with policy integration only expected to follow once robust governance frameworks underpinned by reliable MRV are in place (Röschel & Neuman 2023, Smith et al. 2024, Simpson & Smart 2024, Webb et al. 2024, EU Ocean Pact (COM (2025) 281), EU CRCF Regulation (Regulation (EU) 2024/3012) (see **3.1.2 European climate frameworks p. 35**)). Across most CDR methods, further research is required to improve the accuracy of carbon accounting, particularly in relation to lifecycle assessments and model-based estimations for greenhouse gas budgeting (Mengis et al. 2023, Smith et al. 2024). The absence of specific guidance from the IPCC on MRV for emerging engineered mCDR approaches constitutes a significant gap in this regard (Smith et al. 2024). Future MRV systems will also need to be adaptable to the local context while ensuring consistency across spatial scales, accounting frameworks, and governance levels (Smith et al. 2024, Morganti et al. 2025). Conceptual clarity on MRV however is a key starting point.

2.2.2 Conceptual clarity and complex challenges

Four core principles require consistent definition and application to ensure robust MRV (Minx et al. 2018, Mengis et al. 2023, Bach et al. 2024, Smith et al. 2024, Morganti et al. 2025):

- Durability refers to the capacity of a carbon reservoir to retain stored carbon over time without re-release to the atmosphere. It is to be distinguished from permanence, which denotes the duration of storage.
- Double counting encompasses double issuance (crediting under multiple schemes), double use (using the same credit more than once), and double claiming (multiple entities claiming the same removal without appropriate accounting alignment).
- Quantification concerns the accurate measurement of net atmospheric carbon removal, typically expressed in tonnes of CO_2 equivalent (tCO_{2eq}).

[4] In addition to carbon accounting with the aim to generate carbon credits, governments, researchers and credit buyers are exploring to develop and apply MRV-systems that cover environmental impacts (e.g. changes in biodiversity, water, soil and air quality or land availability) and social benefits (e.g. job creation) (ICVM Core Carbon Principles, World Economic Forum).

“ MRV bridges marine carbon science to climate policy

- Additionality requires that carbon removals exceed what would have occurred under baseline conditions.

These principles raise a series of unresolved policy and methodological questions that are critical for advancing MRV. These include (non-exhaustive): what constitutes sufficiently permanent storage; how temporary removals should be treated within national and corporate climate strategies; what level of monitoring is proportionate for low-risk storage pathways; how to operationalise greenhouse gas accounting across scales, including the incorporation of voluntary market activities within national inventories; how to implement safeguards against double counting, such as the application of equitable corresponding adjustments; how to quantify removals in open and poorly bounded systems like the ocean; what levels of uncertainty are acceptable for different policy applications; and how can additionality be robustly demonstrated (Mengis et al. 2023, Smith et al. 2024).

These challenges are amplified in the marine environment. The ocean's scale, heterogeneity, and connectivity complicate the development of MRV systems that are both scientifically rigorous and operationally feasible. Without such systems, reliable quantification and certification of marine carbon removals remain unattainable, limiting their integration into policy frameworks and carbon markets (Mengis et al. 2023, Bach et al. 2024, Smith et al. 2024, Morganti et al. 2025).

Four interrelated challenges are particularly important:

- First, establishing accurate baselines for the marine carbon budget is inherently difficult due to high spatial and temporal variability (Minx et al. 2018, Mengis et al. 2023);
- Second, resolving the “fate of carbon” conundrum. Determining where and whether captured carbon is durably sequestered or returned to the atmosphere remains a major scientific uncertainty (Van Dam et al. 2024, Morganti et al. 2025);
- Third, marine ecosystems are highly interconnected, meaning that interventions in one location may generate unintended biogeochemical or ecological responses elsewhere (Paschen et al. 2021);
- Finally, there is a non-negligible risk of unintended, potentially irreversible environmental impacts, the spatial and temporal extent of which may be uncertain (GESAMP 2019, Dooley et al. 2021, Simpson & Smart 2024).

Addressing these challenges is a prerequisite for developing credible MRV systems for marine carbon accounting and, by extension, enabling a responsible inclusion of mCDR in climate policy and market-based mechanisms (Minx et al. 2018, Paschen et al. 2021, Mengis et al. 2023, Bach et al. 2024, Simpson & Smart 2024, Van Dam et al. 2024, EMB 2025, Morganti et al. 2025).

2.3 Barriers to marine carbon accounting

PROBLEM

Marine carbon accounting is a precondition to unlock the full potential of ocean-based climate mitigation. By providing the quantitative backbone to MRV, carbon markets, and policy evaluation, it forms the bridge between the ocean's conceptual mitigation potential to operational mCDR at scale. However, the ocean remains insufficiently captured in existing accounting frameworks as current systems largely fail to account for the complexity, variability, and uncertainty associated with marine carbon fluxes, particularly beyond easier to study coastal blue carbon ecosystems.

Credible marine carbon accounting relies on robust MRV for generating high-quality carbon credits, supporting national GHG inventories, and enabling participation in carbon markets. Despite its central role, MRV for marine carbon accounting remains greatly underdeveloped. Existing IPCC guidelines provide methodologies for terrestrial systems and coastal blue carbon ecosystems, but these do not extend to the open ocean or cater to engineered mCDR approaches. Driven by increasing climate urgency, this gap has led to a proliferation of heterogeneous MRV protocols, often developed within the voluntary carbon market by actors that also provide carbon credits, thereby increasing the risk of bias.

For marine carbon to become policy-relevant, carbon accounting systems must evolve to address the previously identified gaps in MRV. Second, governance frameworks must integrate carbon (accounting) into broader ocean management instruments, including marine spatial planning, environmental impact assessment, and permitting processes. Third, certification systems must ensure environmental integrity by thoroughly addressing permanence, leakage, additionality, and ecological impacts, while also recognising co-benefits.

In this context, policy initiatives such as the EU CRCF Regulation and ongoing developments under the UNFCCC Article 6 provide important emerging entry points. However, their effectiveness will depend on the availability of useful scientific data and science-based integrative accounting methodologies.

BERNARDO

As a science-industry ICON-project, BERNARDO's work packages are structured in such a way that they generate both fundamentally and methodologically robust knowledge on the monitoring of carbon fluxes, as well as insights into how these can be valorised within the contexts of the Blue Economy, climate finance, environmental impact assessments, and sustainable ocean governance. As such, the project is optimally positioned to take significant steps towards closing critical knowledge gaps across multiple domains related to marine carbon accounting.

2.3.1 Carbon accounting is crucial but flawed

As the aim of MRV is to enable robust carbon accounting, an MRV system relies on the accurate quantification of carbon fluxes. When these quantifications meet established quality criteria and align to recognised certification guidelines, carbon removals through for instance CDR can be validated and issued as certified carbon credits (Verra, Plan Vivo, Gold Standard, IVCM, VCMI). This final step, the certification of real carbon removals constitutes a foundational pillar of climate governance and carbon market mechanisms (Stephan & Paterson 2012, Fridahl et al. 2023, Mengis et al. 2023, Johnson et al. 2024, Paris Agreement Article 6 (see **3.1.1 Global climate frameworks p. 30**)). By translating greenhouse gas (GHG) emissions and removals into standardised, quantifiable units (CO_{2eq}), the operationalisation of climate targets, the trading of carbon through carbon markets, and the monitoring of progress under international agreements becomes possible.

Carbon accounting can be undertaken at the project, corporate or national level. The two most used applications are: (1) national greenhouse gas inventories under the UNFCCC (see **3.1.1 Global climate frameworks p. 29**) and (2) the voluntary carbon market[5] which guides project-level accounting (Dauwe et al. 2023, Smith et al. 2024). However, both compliance and voluntary carbon markets have been under severe scrutiny with doubts on their robustness and integrity. Common shortcomings include double counting of emission reductions, an overestimation of climate benefits, an incorrect focus on carbon capture instead of sequestration, poor financial flows to local communities, and unintended environmental and social impacts such as monoculture afforestation (Nesshöver et al. 2017, Schneider et al. 2019, Seddon et al. 2020, Williams & Gattuso 2022, Mengis et al. 2023). Empirical assessments further suggest that a substantial share of issued credits does not represent real or additional atmospheric CO_2 reductions, further undermining trust in carbon markets (Probst et al. 2024)[6]. A major shortcoming of the certification process is its focus on procedural compliance instead of an actual monitoring of carbon removals (Smith et al. 2024).

An important barrier in the marine context is the fact that no IPCC guidance[7] on MRV is provided for CDR methods that rely on biogeochemical alterations of the ocean's carbon sink capacity (engineered mCDR)[8]. This lack of guidance, often results in uncoordinated MRV development happening at the project level within the context of the VCM. A process which is usually conducted by the same party that issues credits, warranting a degree of caution with respect to objectivity and transparency (Green 2011, IOSCO 2024). A screening of existing protocols conducted in late 2023 by Smith et al. (2024) identified over a hundred MRV-protocols, spanning 16 different CDR methods[9]. Only three of these protocols handled engineered mCDR and all were developed within the VCM context. This lack of protocols can likely be explained by the difficulty in quantifying the carbon impact of human interventions in the open ocean system.

Another limitation of current carbon accounting approaches is their narrow focus on carbon quantities. Most crediting mechanisms value projects solely based on the volume of carbon sequestered, without accounting for broader ecosystem services or socio-economic co-benefits (Milon & Alvarez 2019a,b, Hilmi et al. 2021). This omission is particularly problematic in marine systems, where the ocean's carbon sink capacity is intrinsically linked to biodiversity, food security, and coastal protection (Hilmi et al. 2021, Elsler et al. 2022). Not accounting for these co-benefits potentially leads to suboptimal or even harmful outcomes. For instance, engineered mCDR interventions may create trade-offs between climate mitigation and other ecosystem services, potentially extending beyond jurisdictional boundaries (GESAMP 2019, Röschel & Neumann 2023). Conversely, incorporating co-benefits into

[5] Currently, the Integrity Council for the Voluntary Carbon Market (ICVM) and the Voluntary Carbon Markets Integrity Initiative (VCMI) are established bodies that aim to improve the quality of carbon credits and promote best practices within the VCM (e.g. ICVM's Core Carbon Principles or VCMI's Claims Code of Practice).

[6] Based on a rigorous screening of 2.346 mitigation projects, equaling a total of 1 billion tonnes of CO_{2eq}, less than 16% of issued credits constituted real emission reductions (Probst et al. 2024).

[7] For an overview on which CDR-techniques IPCC-protocols exist, see Smith et al. (2024).

[8] The current scientific knowledge limits marine carbon accounting to three vegetated coastal habitats: mangroves, salt marshes and seagrass ecosystems (Howard et al. 2023).

[9] For nature-based mCDR national GHG-inventory guidelines exist through the IPCC supplement on wetlands (IPCC 2014, Vanderklift et al. 2022).

carbon accounting frameworks could enhance the attractiveness and societal legitimacy of marine carbon projects, particularly in voluntary markets this approach may have a positive effect on the market price (Johnson et al. 2024). The above considerations underscore the need for improved and integrated accounting frameworks that move beyond single-metric carbon accounting towards a more holistic valuation of marine ecosystems (Stephenson et al. 2021, Mengis et al 2023, Röschel & Neumann 2023, Boettcher & Brent 2024, Webb et al. 2024).

2.3.2 Environmental-economic accounting

A promising way forward towards a more integrative valuation of marine ecosystems is provided by novel environmental-economic accounting frameworks like the System of Environmental-Economic Accounting - Ecosystem Accounting[10] (SEEA-EA) (UN SEEA-EA, UN 2021, Dauwe et al. 2023). This mechanism provides a structured methodology to link ecological processes with economic systems. By adopting an ecosystem services perspective, SEEA-EA enables the integration of biophysical metrics (e.g. carbon fluxes, nutrient cycling, O_2 production) with monetary valuation, thereby facilitating more holistic policy-relevant assessments (Cavalletti et al. 2020, Grilli et al. 2022, Dauwe et al. 2023). For marine ecosystems, such approaches offer a pathway to embed carbon within a broader ecosystem-based management framework. However, the application of the SEEA-EA accounting system remains very limited due to a lack of useful data, methodological uncertainty, and the absence of standardised protocols for marine carbon accounting. For that reason, the UN advocates for research projects focusing on closing these uncertainties (UN 2019, UN 2021, UN SEEA-EA).

2.3.3 UNFCCC's Article 6 and EU's CRCF Regulation

Internationally, carbon accounting is embedded within the governance structures of the UNFCCC and the Paris Agreement. For instance, Article 6 establishes mechanisms for international cooperation through carbon markets, including the transfer of internationally transferred mitigation outcomes (ITMOs)[11,12] and the development of a centralised crediting mechanism (Article 6.4) (Granziera et al. 2025). These mechanisms are intended to improve cost-effectiveness and support countries to achieve their Nationally Determined Contributions (NDCs) (Article 6 Paris Agreement, see **3.1.1 Global climate frameworks p. 30**).

However, the application of Article 6 to mCDR remains highly uncertain. The absence of agreed MRV methodologies, unclear accounting rules for removals, and risks of double counting have so far prevented consensus on a uniform framework. At the same time, VCMs are increasingly financing carbon removal innovation. To respond to this proliferation, the EU has taken steps to strengthen the integrity of VCMs through the Carbon Removal and Carbon Farming Regulation (Regulation (EU) 2024/3012) (see **3.1.2 European climate frameworks p. 35**), which introduces common certification rules for high-quality carbon removals and as such offer a reliable pathway for carbon removal projects into the regulated carbon market.

While developments within UNFCCC Article 6 and Europe's CRCF Regulation demonstrate advancements towards credible carbon accounting, marine carbon removals are not yet fully integrated into both frameworks. Their integration hinges on the availability of robust scientific data, profound systemic knowledge and proofed MRV and accounting methodologies. Ultimately, credible marine carbon accounting is a precondition for unlocking the full potential of ocean-based climate mitigation and a crucial instrument to evaluate ecologic-economic considerations. By providing the quantitative backbone to MRV, carbon markets, and policy evaluation, marine carbon accounting hence forms the crucial bridge between the ocean's conceptual mitigation potential to operational mCDR at scale.

[10] Ecosystem accounts under SEEA-EA deliver spatially explicit and policy-relevant information across four core dimensions: ecosystem extent, ecosystem condition, ecosystem service flows, and ecosystem asset values. When consistently monitored over time, these accounts can reveal trends in ecosystem health, support early identification of pressures, and inform targeted management interventions (Hein et al. 2015, Barbier et al. 2017).

[11] 1 ITMO = 1 carbon credit = 1 ton CO_{2eq}

[12] Next to the trading of ITMOs, the UNFCCC provides a framework for other climate finance mechanisms that have different ways of implementation (e.g. grants, loans, bond, private investments, insurances) (Article 6 Paris Agreement, Green Climate Fund).

3. Analysis of the climate-ocean-biodiversity governance landscape for mCDR

mCDR techniques are regulated by a fragmented set of frameworks across the climate, ocean and biodiversity policy domains (Röschel & Neumann et al. 2023). The frameworks currently in place differ quite substantially in objectives, scope, legal status, etc. resulting in both regulatory overlaps and gaps. Based on our analysis of the policy frameworks, a clear governance gap, particularly for engineered mCDR could be identified. Where climate frameworks incentivise carbon removal and put a lot of focus on carbon accounting, the marine integration is underdeveloped. Ocean and biodiversity frameworks are generally strong in managing anthropogenic use and environmental impact, but they constrain useful progress of research and innovation into mCDR. Improving the alignment between marine carbon accounting, environmental impacts and biodiversity protection into current or future policy frameworks will therefor be critical if a reliable and safe contribution of mCDR to the global climate mitigation strategy is considered.

Table 3. Key insights on strengths and weaknesses of climate-ocean-biodiversity frameworks based on wider policy analysis.

Policy domain	Strengths	Weaknesses
Climate	Climate frameworks set out clear climate targets and are the driving force behind developments in rule-based carbon accounting, MRV and carbon markets.	The marine scope is limited to coastal blue carbon ecosystems.
Ocean	Ocean frameworks are strong in managing marine spatial use and the human impact through concepts like ecosystem-based management, good environmental status and marine spatial planning.	Carbon as a key element connecting various regulating and providing ecosystem services is rarely explicitly considered in ocean governance.
Biodiversity and nature protection	Biodiversity frameworks generally follow a precautionary approach when it comes to (engineered) mCDR according to the 'do not significant harm' principle. Hence they provide strong safeguards for environmental protection and restoration.	The absence of carbon metrics when valuing biodiversity results in unbalanced evaluation of ecological importance vs. climate or economic benefits

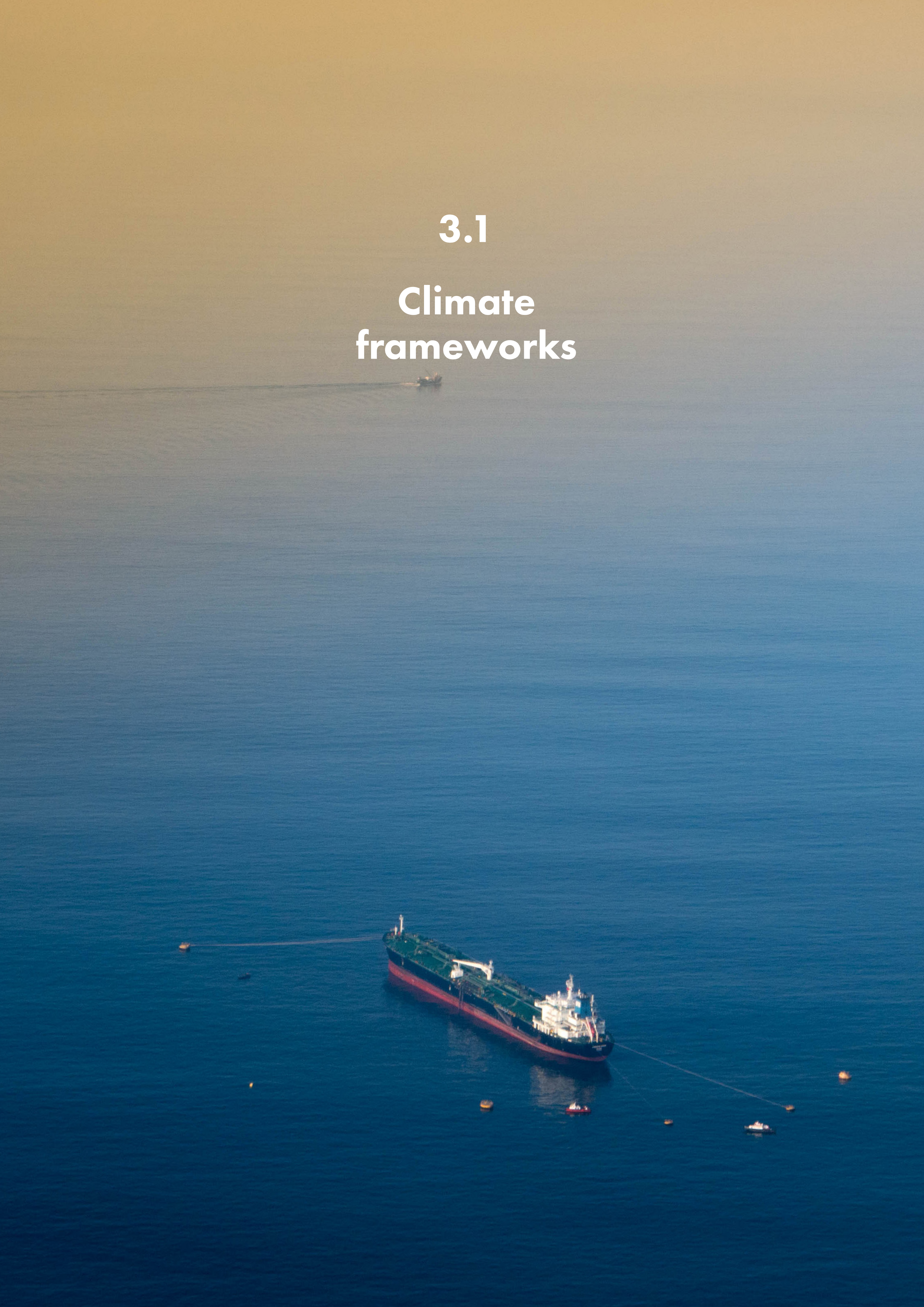
Table 4. Comparative assessment of key climate-ocean and biodiversity policy frameworks relevant to mCDR.

Framework	Domain	Focus	Core objective	Relevance for mCDR	Direct/ Explicit relevance	mCDR types	Geographic scope	Legal status
Paris Agreement	Climate	Target setting	Limit global warming to well below 2°C, pursuing 1.5°C	No MRV rules for engineered mCDR; inclusion limited to nature-based (blue carbon) CDR	Y	nature-based	Global	Binding target setting and reporting, but flexible implementation through NDCs
LULUCF Regulation	Climate	Carbon accounting	Account for emissions and removals from land-use and forestry	Marine ecosystems beyond coastal blue carbon are currently excluded from the Regulation	Y	nature-based (terrestrial focus)	EU	Binding
CRCF Regulation	Climate	Carbon certification	Establish a robust carbon removal certification framework	All mCDR in case of robust MRV	Y	nature-based, engineered, CO_2-storage	EU	Binding
London Protocol	Ocean	Pollution control	Prevent marine pollution by dumping	Directly regulates iron fertilisation; subseabed CO_2-storage allowed	Y	engineered, CO_2-storage	Global	Binding (provisions evolving)
UNCLOS	Ocean	Governance	Main legal framework for managing human use and environmental protection	Provides general and overarching obligations on sustainable use and environmental protection	N	nature-based, engineered, CO_2-storage	Global	Binding
High Seas Treaty	Ocean + Biodiversity	Biodiversity protection	Protect biodiversity in areas beyond national jurisdiction	Demands EIA for activities with expected significant impact on high seas ecosystems	N	nature-based, engineered, CO_2-storage	Global (High Seas)	Binding
OSPAR Convention	Ocean	Environmental protection	Protect the marine environment of the North East Atlantic	Indirect by adhering to precautionary principle; allows CO_2 storage	N	nature-based, engineered, CO_2-storage	North-East Atlantic	Binding
Ocean Pact	Ocean	Governance	Holistic policy strategy promoting a sustainable blue economy and healthy ocean	Supports nature-based solutions; promotes R&I into mCDR; precautionary approach to engineered mCDR	Y	nature-based, engineered, CO_2-storage	EU	Non-binding (yet)
Marine Strategy Framework Directive	Ocean	Environmental protection	Achieve good environmental status of EU's marine waters	Environmental obligations constrain mCDR	N	nature-based, engineered, CO_2-storage	EU	Binding
Water Framework Directive	Coastal and inland waters	Environmental protection	Achieve good ecological and good chemical status of EU's inland and coastal (≤1 nm) waters	Controls pollution affecting coastal mCDR deployment	N	nature-based; engineered	EU (inland + coastal (≤1 nm) waters)	Binding
Maritime Spatial Planning Directive	Ocean	Spatial planning; impact management	Coordinate the use of marine space	Not explicit, must comply with ecosystem-based planning approach	N	nature-based, engineered, CO_2-storage	EU	Binding
EIA Directive	Environmental governance	Impact management	Assess the environmental impact of human activities	Applies to all mCDR projects with a potential impact on the marine environment	Y	nature-based, engineered, CO_2-storage	EU	Binding

Framework	Domain	Focus	Core objective	Relevance for mCDR	Direct/ Explicit relevance	mCDR types	Geographic scope	Legal status
Convention on Biological Diversity	Biodiversity	Conservation, sustainable use, benefit sharing	(i) the conservation of biological diversity, (ii) the sustainable use of its components and (iii) the fair and equitable sharing of the benefits from the use of genetic resources	Moratorium on engineered mCDR; supports nature-based solutions	Y	nature-based; engineered	Global	Binding
Kunming-Montreal Global Biodiversity Framework	Biodiversity	Conservation, protection, climate-biodiversity synergies	Protect and restore 30% of ecosystems by 2030	Reinforce nature-based solutions for mutual climate-biodiversity benefits; moratorium on engineered mCDR	Y	nature-based; engineered	Global	Non-binding (under CBD)
Ramsar Convention	Biodiversity	Conservation, wise use	A framework for the protection and wise use of wetlands and their resources	Promotes the conservation and restoration of coastal blue carbon ecosystems	Y	nature-based	Global	Binding
Nature Restoration Regulation	Biodiversity	Restoration	Restore degraded ecosystems in the EU (20% by 2030)	The carbon sink potential of blue carbon ecosystems are considered as a reason for conservation and restoration	Y	nature-based	EU	Binding
Habitats Directive	Biodiversity	Conservation	Protect valuable habitats and species within 'sites of community importance'	Strict assessments for activities in protected areas	Y	nature-based; engineered	EU	Binding

3.1

Climate frameworks



PROBLEM

Persistent knowledge gaps in marine carbon fluxes, stocks and permanence of storage has so far challenged the inclusion of marine carbon and marine carbon mitigation strategies into climate frameworks, particularly for ecosystems beyond coastal blue carbon. The absence of IPCC-approved MRV protocols has not only delayed policy uptake, it also impacts the uptake of marine carbon in carbon markets and climate finance mechanisms. However, first steps that pursue closing this gap are taken, for instance by the EU's CRCF Regulation and its QU.A.L.ITY criteria that seek to enable carbon certification for both nature-based and engineered marine carbon removals.

KEY TAKEAWAYS

- The Paris Agreement establishes a global mitigation target, but allows national flexibility through NDC's.
- Countries to the Agreement are required to report on GHG balances using IPCC guidelines.
- IPCC GHG-reporting guidelines are absent for marine ecosystems beyond coastal blue carbon ecosystems (mangroves, salt marshes, seagrass), limiting policy uptake of other marine carbon sequestering ecosystems.
- Scientific uncertainties around quantification, durability, and environmental impacts remain key barriers to the integration of mCDR into climate policy and carbon markets.
- Article 6 of the Paris Agreement allows for the bilateral trading of carbon credits, but relies on external parties for carbon verification. It provides flexibility to carbon crediting trading entities on how to arrange the trade.
- Initial steps are underway at the international (UNFCCC) and EU level (CRCF Regulation, revision of LULUCF Regulation) to develop science-based MRV methodologies that live up to current IPCC standards which could, in the future, provide a basis for the certification of high-quality carbon removals and credible carbon trading of marine carbon removals from nature-based and engineered approaches.

BERNARDO

BERNARDO applies the most advanced, comprehensive, and scientifically validated methodology for determining marine carbon fluxes. This approach is extensively documented with a view to validation within the current United Nations accounting frameworks or IPCC framework. Concretely, by reducing uncertainty in marine carbon processes, the project provides valuable insights for the development of reliable and accurate MRV protocols and carbon accounting practices, which offer a pathway towards a credible integration of marine carbon into climate frameworks (e.g. the LULUCF Regulation, NDCs) and carbon market mechanisms.

3.1.1 Global climate frameworks

UNFCCC

Within The United Nations Framework Convention on Climate Change (UNFCCC), Climate change is labelled as a "common concern of humankind". The UNFCCC, adopted in 1992 at the Earth Summit in Rio de Janeiro, serves as the foundational treaty for international climate negotiations and cooperation. Its objective is to stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the global climate system (UNFCCC 1992).

Parties to the Convention are required to track their national progress in reducing net greenhouse gas (GHG) emissions (Article 4(a)) through the national GHG inventory instrument. In this regard, they have to follow standardised accounting methodologies and reporting formats provided by the Intergovernmental Panel on Climate Change (IPCC). These inventories are intended to systematically account for greenhouse gas emissions by sources and removals by sinks across all sectors of a country's economy. Emissions and removals of seven naturally occurring greenhouse gases[13] are covered: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorinated compounds (PFCs), sulfurhexafluoride (SF_6) and nitrotrifluoride (NF_3). The UNFCCC provides relatively detailed guidance for measuring and reporting direct CO_{2eq} emissions and CO_{2eq} reductions (UNFCCC MRV framework). The applied MRV framework is grounded in transparency and verified GHG-reductions and was reinforced under Article 6 of the Paris Agreement, which governs cooperative approaches (COP26 2021).

Regarding marine ecosystems, the UNFCCC recognises the climate mitigation potential of the ocean, with particular emphasis on the integration of coastal blue carbon ecosystems into Nationally Determined Contributions (NDCs, see further). Because of their effective mitigation and adaptation potential, most regulatory attention to date has focused on mangroves, tidal marshes, and seagrass meadows (Nellemann et al. 2009, Herr & Landis 2016, Lecerf et al. 2021) which culminated in the release of the 2013 Wetlands Supplement to the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2014). The latter supplement provides methodological guidance for countries seeking to account[14] for the greenhouse gas balance associated with the management of these coastal ecosystems in their national GHG inventories[15]. As such, these guidelines provide an incentive for their protection and restoration and enable their inclusion in NDCs (Herr & Landis 2016, Li & Liu 2023, The Blue Carbon Initiative, Simpson & Smart 2024). However, persistent knowledge gaps in marine carbon fluxes and storage, compounded by the absence of standardised MRV protocols for marine carbon sequestration has resulted in a situation where Parties cannot yet incorporate marine carbon sinks beyond coastal blue carbon ecosystems into formal national climate commitments (Luisetti et al. 2020, Hilmi et al. 2023).

[13] To allow for a common standard to account for emissions other than CO_2 (e.g. methane, nitrous oxide, etc.) each GHG is assigned a 'global warming potential' based on the amount of warming expected over a certain time period (usually 100 years) relative to carbon dioxide (IPCC 1990, Shine et al. 2005). This is used to calculate the CO_2-equivalent (CO_{2eq})

[14] Coastal wetlands are addressed within the land use, land-use change and forestry category, which, since 2006, has been merged with agriculture into the broader reporting sector known as 'Agriculture, Forestry, and Other Land Use', AFOLU.

[15] Over 60 countries have included blue carbon ecosystem in their NDCs as a kind of emission reduction action (2020 cycle) (Macreadie et al. 2021).

Paris Agreement

Core objective: Limit global warming to well below 2°C, pursuing 1.5°C

Geographic scope
Global

Legal status
Binding target setting and reporting, but flexible implementation through NDcs

Focus
Target setting

Carbon mentioned
Yes

Relevance for mCDR
Countries can decide on their climate strategy through NDCs, however no MRV-guidelines exist for engineered mCDR excluding these techniques from GHG-inventory reporting. MRV-guidelines for carbon sequestration by coastal blue carbon ecosystems are however available.

mCDR types
Nature-based mCDR

The Paris Agreement[16] is a subsidiary, legally binding treaty[17] under the UNFCCC that defines specific targets and mechanisms to reduce climate change. It builds upon the UNFCCC framework, by demanding more rigorous and targeted climate action, enhancing transparency, comparability among GHG-inventories, and fostering continuous improvement in national climate efforts. It was adopted by 195 Parties[18] at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015. The Agreement entered into force on 4 November 2016. Its overarching goal is to limit the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels.

The Paris Agreement does not set out specific emission reduction targets, nor does it recommend certain climate strategies or regulates any single sector. Parties do however have an obligation to pursue the set out goals and report on their climate progress. Article 13(7) (a) and (b) requires parties to submit a national inventory report on anthropogenic GHG-emissions by sources and removals by sinks using IPCC guidelines (IPCC 2019). The use of IPCC methodologies is mandatory to guarantee comparability and scientific robustness. Today, guidelines and methodologies for MRV of marine carbon fluxes beyond coastal blue carbon ecosystems and accounting for engineered mCDR are lacking, but some progress is expected during the next IPCC cycle (IPCC 2025- Chapter 15).

The MRV framework is provided by the Enhanced Transparency Framework (ETF). The ETF is designed to support the credibility and proceedings of the Paris Agreement by guiding countries on the reporting of their GHG-emissions, track progress on their nationally determined contributions (NDCs), the

[16] The Paris Agreement superseded the Kyoto Protocol (1992), which still formally exists but without binding emission reduction targets. The final commitment period ended in December 2020.

[17] Only the procedural commitments are binding, the emission reduction targets are self-determined by the contracting Parties with just a commitment to "pursue" the climate goal of +2 °C warming.

[18] Currently (April 2026) 194 Parties remain after the withdrawal of the United States of America in January 2025.

> ***"The Enhanced Transparency Framework transforms reporting into a mechanism for accountability and trust***

impacts of climate change and adaptation efforts, etc. (World Resources Institute). The ETF further provides technical expert reviews of reported information along with a multilateral peer review process through which countries can pose questions to one another. As a unified framework, the ETF offers flexibility to developing countries with respect to reporting frequency and the level of detail, depending on their capacities (Perugini et al. 2021, Shapovalova 2024).

From 2024 onwards the ETF requires all countries to submit a Biennial Transparency Report (BTR) with up-to-date GHG inventories, progress on NDCs and efforts towards mitigation and adaptation. Every five years, the information gathered through the ETF feeds into the 'Global Stocktake' which evaluates the global progress towards the collective long-term climate goals.

In addition to reporting requirements, parties are obliged to describe how they will reach the Paris goals in NDCs (Paris Agreement Articles 2 and 3). These NDCs run on a five-year cycle, where each new NDC has to communicate greater ambition compared to the previous NDC, considering the country's capacity and national circumstances. The NDCs[19] allow flexibility to the states to define the nature and scope of their commitments, including mitigation, adaptation, resilience priorities and long-term low-emissions planning based on their national context. While the NDC demonstrates national commitments and targets at a high level, it is informed and underpinned by a series of national reports, such as national adaptation plans (NAPs), national inventory reports (technical details of the national GHG inventory), BTRs[20] and national biodiversity strategy and action plans (NBSAPs) (Hoegh-Guldberg & Northrop 2023).

Article 6

Article 6 of the Paris Agreement determines how countries and businesses can collaborate on climate change mitigation and adaptation by means of trading carbon credits. Two articles under Article 6 are of relevance to CDR. Article 6.2 provides guidance on trading carbon emission reduction and removal credits, while Article 6.4, which in essence is an update of the Kyoto protocol's Clean Development Mechanism (CDM), seeks to provide a standardised and centralised carbon crediting mechanism for projects that reduce GHG-emissions or remove atmospheric CO_2. Despite the majority of the rules for implementation and types of removals of Article 6.4 were agreed upon during COP26, the implementation has not yet received sufficient approval (Granziera et al. 2025). In the meantime the ICVCM and VCMI guidelines remain a possible foundation for the national regulation of CDR.

[19] Detailed guidance on how to include blue carbon elements into NDCs is given by The Blue Carbon's Initiative: 'Guidelines for Blue Carbon and Nationally Determined Contributions' (Thomas et al. 2023).

[20] The biennial transparency reports provide a more detailed account of indicators and comparable metrics for mitigation action, and start to capture adaptation co-benefits.

[21] Currently, Article 6.2 allows countries to cooperate under loose arrangements that can be defined bilaterally and guided by methodologies from the VCM. This includes how countries set project baselines and determine additionality and what social and environmental minimum standards they apply. There are currently no limitations on the types of units that can be traded (gases, sectors, methodologies) as long as they comply with the MRV rules of Article 6.2. A corresponding adjustment mechanism is put in place to avoid double counting of carbon credits (Granziera et al. 2025, Florence School of Regulation Article 6, Environmental Defense Fund 2023).

[22] Notably decisions on liability and long-term monitoring requirements in removal projects have been postponed, leaving gaps that jeopardise environmental integrity (Environmental Defense Fund 2023).

3.1.2 European climate frameworks

Fit for 55 package

Anchored in the European Green Deal (COM (2019) 640) and the binding targets as set under the European Climate Law (July 2021), Europe's fit for 55 package[23] prompted the revision and expansion of a whole suite of legislative instruments[24] aimed at accelerating GHG reductions across the EU. These instruments are interlinked and specifically designed to ensure that the energy transition is fair, green and competitive and responsibility is shared evenly across different sectors and Member States.

At the core of the package lies Directive 2003/87/EC on the EU emissions trading system (the ETS Directive), Regulation (EU) 2018/842 (the Effort-Sharing Regulation, ESR), and Regulation (EU) 2018/841 (LULUCF Regulation). All three set binding limits and targets on GHG emissions and removals. They act by capping and pricing emissions (ETS Directive), assigning national reduction targets for non-ETS sectors (ESR Regulation), and setting binding carbon-removal targets for terrestrial carbon sinks (LULUCF Regulation). This approach sets them apart from the other Fit for 55 instruments that focus on regulating and prescribing new technologies or standards for energy use, fuels, efficiency, infrastructure, etc.

To ensure coherence across its different climate policy instruments, the EU has created a system of equivalence linking the ETS, the ESR, and LULUCF. Operationally, this implies that one tonne of CO_{2eq} is defined and quantified in a consistent manner across the different legislations. This equivalence allows the transfer of credits between sectors within the LULUCF Regulation and the ESR Regulation. The equivalence approach also provides flexibility and clear rules to governments and businesses as action in one sector, can support compliance in another.

To maintain focus on the regulation of carbon removals through mCDR, only the LULUCF Regulation will be discussed in detail within the main text, while the ESR and ETS are addressed in Addendum (see **6.2.2 European emission reduction frameworks p. 88 ESR, p. 89 ETS**).

[23] Europe has agreed to reduce GHG-emission levels by 55% by 2030 compared to 1990 levels followed by climate neutrality in 2050.

[24] 13 proposals got revised and six new legislative proposals were developed and adopted.

LULUCF Regulation

Core objective: Accounting for human-induced emissions and removals resulting from changes in terrestrial carbon sinks.

Geographic scope
EU

Legal status
Binding

Focus
Carbon accounting

Carbon mentioned
Yes

Relevance for mCDR
Marine ecosystems beyond coastal blue carbon ecosystems and engineered-mCDR are currently not included in the LULUCF accounting framework.

mCDR types
Nature-based mCDR

The LULUCF Regulation (Regulation (EU) 2018/841) is an EU law, which sets out rules on how Member States (MS) need to account for GHG-emissions and GHG removals within the land use, land use change and forestry sector. Under LULUCF, each MS is assigned specific carbon removal targets by natural sinks, which are accounted for through the issuance of land use credits[25] (Böttcher et al. 2019). Focusing on terrestrial carbon sinks, the regulation applies the 'no debit' rule, meaning emissions resulting from human activities in terrestrial ecosystems that act as a carbon sink cannot exceed the amount of GHG they capture[26]. In case emission limits are not respected, MS must take action to balance emissions (e.g. by planting trees or transferring emission credits), aiming for at least a net-zero impact of their activities.

From 2026 onwards, the revised LULUCF Regulation sets stricter accounting principles and removal targets, with an EU-wide target of 310 $MtCO_{2eq}$ removals by 2030 and the requirement to halt declining trends in LULUCF net GHG-removals[27,28]. The adapted regulation demands a rigorous and transparent tracking of emissions and removals, with the possibility of penalties should MS violate the regulation (Jensen 2023). The regulation ensures consistency with categories and reporting requirements under the UNFCCC and with the guidelines provided by the IPCC. On this accounting and reporting basis, MS are required to integrate land use considerations into their National Energy and Climate Plans (NECPs) and Common Agricultural (CAP) Strategic Plans, thereby operationalising the targets set out in the revised LULUCF Regulation and the Effort Sharing Regulation (ESR) (see **6.2.2 European CCS frameworks p. 92**).

[25] All member states can use up to 262 million credits from the land use sector (131 million credits in each of the periods 2021-2025 and 2026-2030) to meet their national agricultural emissions targets. Countries whose agricultural sector constitutes a big share of its emission, can emit more.

[26] Considering the long time it takes for the effects of mitigation actions under LULUCF to materialise, a standard transition period of 20 years applies to areas converted by means of deforestation or afforestation.

[27] Climate neutrality from the land sector followed by negative emissions has to be realised from 2035 onwards.

[28] How to achieve this goal has to be communicated through National Climate and Energy Plans. These plans are mandated by the Regulation on the Governance of the Energy Union and Climate Action (Regulation (EU) 2018/1999) to help reaching the intermediate 2030-climate goals. The Regulation sets common rules for planning, reporting and monitoring while also outlining the monitoring mechanism to ensure the EU's compliance with international commitments under the Paris Agreement and the UNFCCC.

LULUCF in the marine context

The LULUCF Regulation primarily focuses on terrestrial ecosystems such as forests, croplands, grasslands, and wetlands, requiring MS to track and balance GHG emissions and carbon removals from these systems to meet EU climate targets (Fridahl et al. 2023). From 2026 onwards the accounting obligations for wetlands become mandatory aligned with UNFCCC practice, but this obligation does not cover coastal wetlands which contain the coastal blue carbon ecosystems. Currently, the reporting of GHG-fluxes from coastal blue carbon ecosystems using the guidelines as provided in the 2013 IPCC Wetland Supplement (IPCC 2014) is authorised, but so far remains voluntary, leaving a potentially significant gap in Europe's GHG tracking and regulation.

Within the revised LULUCF Regulation under the "Fit for 55" package, accounting for CO_2 removals in marine ecosystems beyond coastal blue carbon ecosystems remains a future possibility (post-2035), provided a science-based monitoring methodology aligned with UNFCCC and IPCC standards and ensuring robust and accurate data becomes available (Jensen 2023). The policy group of JPI Oceans' Blue Carbon Knowledge Hub recently provided a detailed analysis of the pathways and opportunities for integrating blue carbon ecosystems into the LULUCF Regulation (Lindemann et al. 2026). Should feasibility be confirmed, regulatory changes to the LULUCF Regulation will oblige MS to also monitor and report aquatic GHG fluxes and integrate these into their climate strategies.

EU Carbon Removals and Carbon Farming (CRCF) Regulation

Core objective: Provide a harmonised, high quality carbon certification framework to scale-up climate action and avoid greenwashing.

Geographic scope
EU

Legal status
Binding

Focus
Carbon certification

Carbon mentioned
Yes

Relevance for mCDR
All activities that result in permanent and safe carbon sequestration are in principle within scope, provided adequate MRV is guaranteed.

mCDR types
CO_2-storage, nature-based mCDR, engineered mCDR

Today, one of the most important funding streams driving innovation into carbon removal approaches are voluntary carbon markets (VCMs), where carbon credits are traded between buyers (emitters) and sellers (suppliers) (Carbon Credits.com, Dauwe et al. 2023). To stimulate investments in innovative carbon-removal techniques while safeguarding the quality of carbon credits, the EU has recently taken major steps to build a robust and transparent European Voluntary Carbon Market framework. A cornerstone of this effort is the new Carbon Removal and Carbon Farming Regulation (Regulation (EU) 2024/3012), which sets out common rules for the certification of high-quality carbon removals across Europe. The regulation constitutes the first government-led legal framework enabling the integration of carbon removal projects into a regulated carbon market, aimed at bolstering EU's climate ambition and ensuring high-quality verification standards. The Regulation applies to three different concepts of carbon removal: permanent carbon removal, carbon[29] farming (with a focus on agriculture and forestry)[30] and carbon storage in products[31]. With this Regulation, the EU provides the world's first government-led legal framework to enable the transition of carbon removal projects into a regulated market.

The CRCF is designed to support the EU's climate objectives as accepted under the Climate Law (Fit for 55 Package, see **3.1.2 European climate frameworks p. 35**). The framework supports the EU's long-term ambition to generate negative emissions after 2050, with specific intermediate targets such as the 310 million tonnes of CO_2 equivalent net removals by 2030 under the LULUCF Regulation (Regulation (EU) 2018/841) or the national targets set out in the Effort Sharing Regulation (Regulation (EU)2018/842)(Fit for 55 Package, see **6.2.2 European frameworks p. 88**). The overarching goal is to ensure that carbon removals within the EU are of high quality and transparently verified. To achieve this, the framework mandates third-party verification and the publication of certification data in a centralised EU

[29] Any practice or process that, under normal circumstances and using appropriate management practices, captures and stores atmospheric or biogenic carbon for at least 200 years, including permanently chemically bound carbon in products.

[30] Any practice or process carried out over an activity period of at least five years, related to the management of a terrestrial or coastal environment and resulting in the capture and temporary storage of atmospheric or biogenic carbon in biogenic carbon pools, or in the reduction of soil emissions.

[31] Any practice or process that captures and stores atmospheric or biogenic carbon for at least 35 years in long-lasting products, allows on-site monitoring of the carbon stored and is certified throughout the monitoring period.

> *"The CRCF establishes the first government-led framework for certifying high-quality carbon removals*

registry. In the initial phase, certified removals can only contribute to the EU's nationally determined contributions (NDCs).

For its integration into EU's climate policy[32], the Commission will develop detailed certification methodologies and technical rules for a wide range of carbon removal activities, by means of delegated and implementing acts that have to ensure consistency across MS. According to the regulation (article 8), the Commission will prioritise the development of methodologies for activities that are the most technologically mature, provide the largest cobenefits, and have existing EU legislation. Certified credits must comply with the four "QU.A.L.ITY" pillars: 1. Quantification against a baseline; 2. Additionality; 3. Long-term storage (at least 200 years for permanent carbon removals, 35 years for storage in products and five years for carbon farming) and 4. Sustainability based on the 'Do No Significant Harm' screening criteria of the Taxonomy Regulation (Regulation (EU) 2020/852). In a future step, the Commission is considering methodologies under the CRCF for additional permanent carbon removal activities, including marine pathways such as ocean alkalinity enhancement and direct ocean capture with carbon storage (EU Carbon Removals and Carbon Farming, Regulation (EU) 2024/3012). If successful, this would provide a major milestone towards reliable and sustainable marine climate mitigation through mCDR.

As a first step towards implementation, the Commission introduced Implementing Regulation (EU) 2025/2358 providing transparency standards for certification schemes along with rules for the appointment and supervision of certification bodies and audit processes. Subsequently, in early 2026, the Commission adopted the first Delegated Acts which set out detailed and tailored certification methodologies for a set of permanent carbon removal activities: Direct Air Capture with Carbon Storage (DACCS), Biogenic emissions Capture with Carbon Storage (BioCSS), Biochar Carbon Removal (BCR)) and carbon farming actions (agriculture and agroforestry, peatland rewetting, and afforestation).

In the longer term, the EU intends to explore if and how to align with the UN's international carbon market mechanism (Article 6) and connect with its ETS and ESR frameworks, in doing so contributing to a more coherent and interoperable carbon market structure (Regulation (EU) 2024/3012, The Carbon Gap, Martirosian et al. 2025).

Marine carbon credits under the CRCF Regulation?

After the first set of Delegated Acts, the EU intends to explore certification of ocean alkalinity enhancement and enhanced rock weathering activities (EU Carbon Removals and Carbon Farming, Regulation (EU) 2024/3012). However, without certification to prove carbon is stored safely and permanently in the expected quantities, mCDR cannot be integrated into EU's climate policy frameworks or carbon markets. Therefore, the immediate focus is on the development of fit for purpose MRV practices[33], which in turn have to be supported by robust scientific evidence and a comprehensive understanding of the methods used (Mengis et al. 2023, Van Dam et al. 2024, EMB 2025). A challenge which is anchored in and driven by the recently adopted Ocean Pact and its Ocean Eye initiative (COM (2025) 281 (see

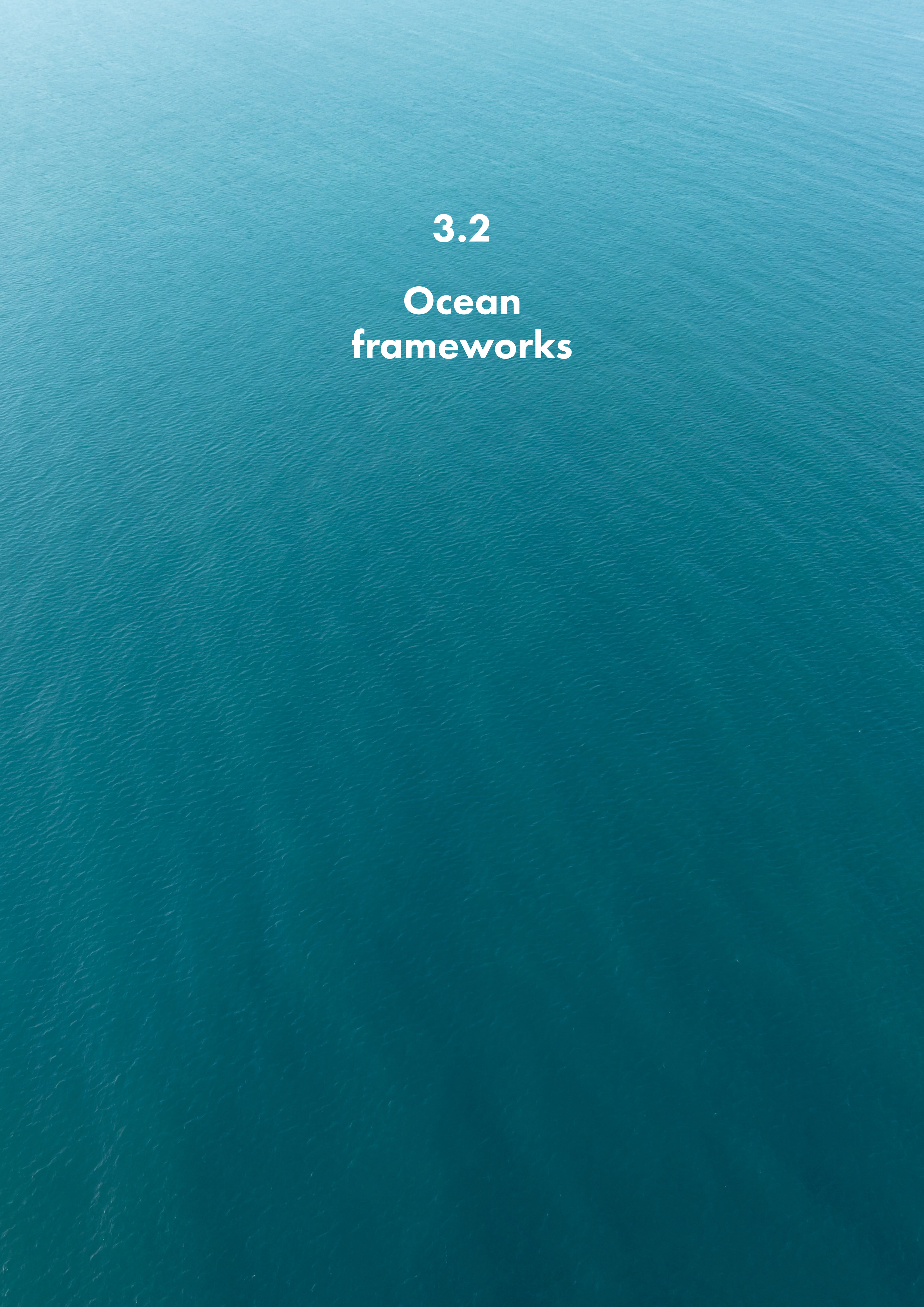
[32] In November 2025, Member States agreed on a legally binding 2040 target of 90% reduction in GHG-emissions relative to 1990 with a domestic target of 85% and up to 5% of international carbon credits.

[33] MRV should align to global developments in carbon monitoring and reporting, be based on the latest scientific insights and as such be dynamic to incorporate the latest insights and evolutions.

3.2.2 Regional and European ocean frameworks p. 49), JPI Oceans 2025). Without rigorous standards and safety provisions underpinning certification, a large scale-up of mCDR to support emission reduction efforts and carbon-negative emissions post 2050 will not be possible, while effective MRV will open the door to commercial-scale mCDR in European marine waters. In other words, the CRCF Regulation may be seen as a policy instrument that could help guide decision-making between engineered mCDR and marine protection, which traditionally is grounded in the precautionary principle.

From a broader perspective, all activities that result in long-term carbon storage in marine and coastal ecosystems are in principle within the scope of the CRCF Regulation, whether they qualify as permanent carbon removals or as carbon farming practices when they relate to the sustainable management of marine and coastal environments. All activities implemented under the Regulation do however have to comply with the QU.A.L. ITY criteria and respect the overarching requirement to avoid significant harm to the environment and, where possible, generate cobenefits. This includes contributing positively, or at least not causing significant harm, to:

- climate change mitigation and adaptation;
- the protection and restoration of biodiversity and ecosystems (including soil health and the avoidance of land degradation);
- the sustainable use and protection of water and marine resources;
- the transition to a circular economy (including the efficient use of sustainably sourced bio-based materials);
- pollution prevention and control.



3.2

Ocean frameworks

PROBLEM

Ocean governance frameworks are primarily committed to protecting the environment while pursuing a sustainable approach to the management of human activities, rather than managing the ocean from the perspective of a climate-regulating system. As a result, the ocean's carbon sink capacity is insufficiently captured by current frameworks and therefore ocean frameworks are considered to be largely inadequate to regulate ocean-based climate interventions like engineered mCDR.

KEY TAKEAWAYS

- Most ocean frameworks are impact-focused, aiming at preventing significant harmful environmental impacts, rather than enable ocean-based climate interventions.
- The transboundary and fluid nature of the ocean, while acknowledged, requires deep coordinated approaches across sectors and scales.
- The London Protocol is currently the only global instrument directly regulating scientific iron fertilisation experiments and allows for sub-seabed CO_2-storage. Beyond the LP, no dedicated pathways for engineered mCDR implementation or field research exist, leaving a regulatory vacuum.
- Broader legal structures like UNCLOS establish a general obligation to take care of the environment, while regional instrument like OSPAR and the MSFD impose the precautionary principle to avoid significant environmental harm.
- Environmental impact assessments, marine spatial planning and dedicated permitting procedures can act as potential entry points for mCDR governance, but demand adaptation to account for carbon accounting, potential side-effects and long-term impacts.
- Ocean governance frameworks do not yet explicitly incorporate carbon accounting or MRV requirements, substantially reducing their usefulness to support carbon market mechanisms, ocean-based climate strategies or climate financing models like blue bonds.
- Recently, increasing policy attention to the ocean-climate nexus (EU Ocean Pact, UN Ocean Decade, OSPAR NEAES 2030, etc.) signals a shift towards more integrated and climate-centered ocean governance, however due to the lack of profound systemic knowledge and MRV procedures operationalisation remains very limited.

BERNARDO

BERNARDO contributes to ocean governance by providing a measurement-based, spatially explicit marine carbon baseline that can be integrated into MSP, EIA, and permitting processes. This enables policymakers to incorporate carbon as a decision variable in ocean management, enabling an improved system-based climate strategy, targeted protection of important carbon sinks and supporting evidence-based sustainable blue growth.

The London Protocol

Core objective: The prevention of pollution by dumping in the ocean

Geographic scope
Global

Legal status
Binding

Focus
Pollution control by dumping

Carbon mentioned
Yes

Relevance for mCDR
Only marine regulatory framework to date that directly regulates a type of engineered mCDR. The Protocol applies a (non-ratified) ban on iron fertilisation, with an exception for small-scale scientific research. The potential inclusion of other mCDR-approaches is under review. The Protocol does allow for sub-seabed geological storage of carbon.

mCDR types
Engineered mCDR, CO_2 storage

The London Protocol (LP 1996) of the London Convention (LC) on the Prevention of Marine Pollution by Dumping Wastes and Other Matter requires Contracting Parties to prevent the pollution of the global ocean by dumping, i.e. the deliberate disposal, of any wastes or other matters that "may create hazards to human health, harm living resources and marine life, damage amenities or interferes with other legitimate uses of the sea" (Art. 1 and 3).

The LC and LP currently provide the only explicit international legal framework for governing mCDR techniques that qualify as marine geoengineering and are considered as 'ocean dumping' (GESAMP 2019, Röschel & Neuman 2023). All forms of mCDR- that are considered dumping are prohibited under Article 3 of the Protocol, except for strictly controlled small-scale scientific research on iron fertilisation (Annex 4). The most recent Amendment to the Protocol (Resolution LP.4(8) (2013)) prevents the placement of matter into the sea for marine geoengineering purposes unless the specific technique is listed and authorised through a permit-based system. However, the Amendment has not yet entered into force. In response, some Parties have begun exploring its provisional application, which may give rise to legally binding obligations to implement the Amendment, in whole or partly, between consenting States (UN 2005, VanderZwaag & Mahamah 2024, Webb et al. 2024). Today, only ocean fertilisation is listed (Annex 4), meaning it may not be conducted except for legitimate, small-scale scientific research with robust oversight and after successfully completing a two-step approval process (Resolution LP.4(8), GESAMP 2019, Webb et al. 2024). Commercial or large-scale interventions for climate mitigating purposes remain forbidden.

Currently, a process is underway to carefully evaluate the possibility of adding further types of marine geoengineering approaches to the LP, leaving room for future regulation of mCDR-techniques using dumping techniques (Hilmi et al. 2023, Röschel & Neuman 2023, LC44/LP 17). However, in 2023 Parties to the Convention released a statement, acknowledging that "each of the four marine geoengineering techniques prioritised for evaluation has the potential for deleterious effects that are widespread, long-lasting or severe; and there is considerable uncertainty regarding their effects on the marine environment, *“Only dedicated framework to regulate mCDR approaches using dumping techniques*

human health, and on other uses of the ocean” (LC45/LP 18). Considering the current level of scientific uncertainty and perceived risks, Parties to the Convention affirm that all activities using mCDR-techniques other than legitimate scientific research should be strongly deferred and always warrant an environmental impact assessment (EIA) (see **3.2.2 Regional and European ocean frameworks p. 57**).

In addition to the regulation of mCDR, the LC also permits the storage of carbon dioxide coming from carbon capture processes in sub-seabed geological formations (

, Vivian & Del Savio 2024, see further **6.3.2 EU Carbon Capture and Storage Directive p. 92**).

United Nations Convention on the Law of the Sea (UNCLOS)

Core objective: Foundational legal framework guiding the international governance, protection, management, and sustainable use of the ocean and its resources.

Geographic scope
Global

Legal status
Binding

Focus
Governance

Carbon mentioned
Yes

Relevance for mCDR
UNCLOS legally anchors the responsibility of the international community for environmental stewardship and the sustainable use of the ocean. However, it does not authorise, manages or guides climate intervention through mCDR.

mCDR types
Nature-based mCDR, engineered mCDR, CO_2-storage

At the heart of international ocean governance lies the United Nations Convention on the Law of the Sea (UNCLOS 1982). As a foundational legal instrument, UNCLOS provides the legal basis for the use, conservation, and protection of the marine environment and maritime rights. It is complemented by a range of global and regional agreements with thematic or geographic mandates (Sands et al. 2018).

While UNCLOS predates contemporary concerns about carbon dioxide removal strategies, several of its provisions remain directly relevant for assessing the governance of emerging ocean-based climate interventions such as mCDR (Elsler et al. 2022, Röschel & Neuman 2023). As a fundamental principle, the environmental perspective of UNCLOS seeks to ensure the protection of the marine environment (including the High Seas) and its marine biological resources. It obliges States to take all necessary measures - either individually or jointly - to protect and preserve the marine environment (Art. 192) and to prevent, reduce, and control pollution from any source (Art. 194(1)). Although the Convention does not explicitly refer to marine carbon dioxide removal, these stipulations offer important baseline obligations that govern such activities indirectly.

Several articles within UNCLOS do however appear particularly pertinent to the majority of engineered mCDR techniques. For instance, Article 195 prohibits the transfer of pollution from one environmental domain to another, while Article 196 requires States to prevent harmful pollution arising from technologies under their jurisdiction or control. Together, these provisions extend State responsibility to emerging ocean-based interventions. UNCLOS also recognises the interconnectedness of ocean and atmospheric processes. Three provisions make explicit reference to this interaction: Article 194(3)(a) on pollution from or through the atmosphere, Article 212 on the prevention of atmospheric pollution, and Article 222 on pollution from or through the atmosphere. While these references are limited in scope, they offer a legal entry point for addressing the climate dimensions of certain mCDR interventions.

UNCLOS further grants coastal States sovereign rights over natural resources and related activities within their Exclusive Economic Zones (EEZs) (Art. 56). These rights are however constrained by obligations relating to the conservation

“ Activities must avoid significant harm to the environment

of living resources (Arts. 61-62) and the protection of the marine environment (Arts. 192-194), all of which are directly relevant to mCDR practices such as macroalgae cultivation or subsurface carbon storage. In all cases, the exercise of sovereign rights remains subject to the duty to avoid "significant" harm to the marine environment and to respect the rights and obligations of other States (Scott 2013).

Concerning procedural responsibilities, UNCLOS requires States to monitor, assess and report on the potential effects of all activities that can cause harm to the marine environment (Art. 204 and 206), both within and beyond national jurisdiction. De facto requiring States to conduct an Environmental Impact Assessment (EIA) (see **3.2.2 Regional and European ocean frameworks p. 57**). While not specified in detail what information should be reported, UNCLOS does call for international cooperation in monitoring, environmental assessment, and information exchange, particularly in relation to activities with potential transboundary or global effects.

To conclude, UNCLOS does not prohibit mCDR, however it does not provide an adequate regulatory framework for it either. Its general obligations on pollution prevention, technology use, and international cooperation can however be viewed as a "governance baseline" that applies to both research and deployment of engineered mCDR techniques in particular. This perspective has been reinforced by judicial bodies such as the International Tribunal for the Law of the Sea (ITLOS), which advocates the precautionary principle and compliance with UNCLOS in relation to marine carbon dioxiode removals.

High Seas Treaty - Biodiversity Beyond National Jurisdiction Agreement

Core objective: Halt biodiversity decline in the High Seas

Geographic scope
Global (ABNJ)[35]

Legal status
Binding

Focus
Governance

Carbon mentioned
Yes

Relevance for mCDR
Obligation to conduct rigorous environmental impact assessments for activities that can result in significant damage to the biodiversity in the High Seas.

mCDR types
Nature-based mCDR, engineered mCDR, CO_2-storage

Adopted in 2023, the Agreement under UNCLOS on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction - in short the BBNJ Agreement - sets binding rules for the protection of the High Seas[36]. Through this Agreement, which lays out a more holistic and cooperative approach to biodiversity governance (Gaebel et al. 2025), the international community intends to stop the degradation of the marine environment and the loss of biodiversity in the High Seas. As such, the Agreement provides the legal framework which closes existing governance gaps that have long characterised this remote area of the global ocean.

Next to halting biodiversity loss, the Agreement also provides an opportunity to address climate change and its impact on the ocean. From this perspective the Agreement creates the legal conditions necessary for designating marine protected areas (MPAs) in the High Seas, and thus plays a pivotal role in meeting the target of safeguarding at least 30% of the planet by 2030 (see **3.3.1 Global biodiversity frameworks p. 61**). In addition, it aims for a more integrative management of human activities in areas beyond national jurisdiction (ABNJ). However, a key challenge now lies in translating the legal commitments into operational mechanisms (Gaebel et al. 2025).

From an mCDR-perspective, the obligation to conduct environmental impact assessments (EIAs) to inform on all the environmental implications for a planned activity (Article 27-39) is of particular interest (Craik & Gu 2023, Curry & Müller 2023, Li & Liu 2023, Boettcher & Brent 2024). Building on the EIA provisions under UNCLOS, the Agreement states the following: "when a planned activity may have more than a minor or transitory effect on the marine environment, or the effects of the activity are unknown or poorly understood, a Party is required to conduct a screening of the activity" (BBNJ Art. 30(1)). This screening should be sufficiently detailed and consider the duration, location, and intensity of the activity. The scope of the activities ranges from: activities that happen within ABNJ, those that take place in waters of national jurisdiction but with potential spillover effects into ABNJ and activities that are covered by frameworks or bodies already in place. The EIA should also take cumulative effects into account and include relevant economic, social, cultural

[35] Areas beyond national jurisdiction.

[36] The Agreement deals with four key issues: (i) marine genetic resources, including the fair and equitable sharing of benefits; (ii) measures such as area-based management tools, including MPAs; (iii) environmental impact assessments; (IV) capacity building and the transfer of marine technology.

“ Clearing House Mechanism as a potential entry point to assess mCDR approaches

and human health aspect using the best available science and scientific information and, where available, relevant traditional knowledge of Indigenous Peoples and local communities (BBNJ Art. 31(1)(ii)). Moreover, EIAs should be developed in a way that activities are assessed and conducted to prevent, mitigate and manage significant adverse impacts for the purpose of protecting and preserving the marine environment (Art. 27 (b)). In contrast to the rather general and less prescriptive obligations set out under UNCLOS (Part XII-XIII) (see **3.2.1 Global ocean frameworks p. 42)** or the Convention on Biological Diversity (Art. 14) (see **3.3.1 Global biodiversity frameworks p. 60**), Part IV of the BBNJ Agreement establishes clear processes, thresholds and other requirements necessary for conducting and reporting of EIAs (Mandai & De Souza 2021, Craik & Gu 2023, Bodansky 2024).

The responsibility whether or not to allow a certain activity lies with the States. Once authorised, monitoring of all potential effects (ecological, economic, cultural, social, health, cumulative impact) is mandatory - including the monitoring of effects occurring in areas of national jurisdiction. Reporting of monitoring results happens through periodic reports, disclosed through the Clearing House Mechanism (CHM) (Art. 33 (5), Art. 36 (2)) (Boettcher & Brent 2024, Gaebel et al. 2025, High Seas Alliance 2025, Veiga & Marcos 2026). This CHM can be considered as a centralised, digital open access data, knowledge, and information repository for parties involved in a given policy framework. In this capacity, the CHM supports regulatory compliance, provenance tracking, and transparency for marine activities in ABNJ assisting in the successful implementation and monitoring of the BBNJ Agreement (Gaebel et al. 2025, High Seas Alliance 2025, Veiga & Marcos 2026). As the CHM promotes knowledge pluralism by enabling input of different knowledge types, both academic and indigenous and local communities' knowledge, during the assessment, approval and monitorings phase it provides an entry point to a holistic assessment and management of mCDR approaches (Boetcher & Brent 2024).

OSPAR Convention

Core objective: Preserving a healthy, resilient marine environment with regulated marine activities in the NE-Atlantic.

Geographic scope
NE Atlantic

Legal status
Binding

Focus
Environmental protection

Carbon mentioned
Yes

Relevance for mCDR
The protection of marine carbon sinks and avoiding significant pollution and harmful effects on biodiversity (precautionary principle). Geological CO_2-storage is allowed.

mCDR types
Nature-based mCDR, engineered mCDR, CO_2-storage

The OSPAR Convention (1992) constitutes a comprehensive framework for the protection of the marine environment of the North-East Atlantic Ocean (including the North Sea). It is adopted by 15 national governments and the EU. The OSPAR Convention contains a broad set of provisions for the protection of the marine environment, organised into six thematic work areas (OSPAR Work Areas). These provisions include agreements on quality assessments and on protecting and conserving ecosystems and biological diversity. The work of the OSPAR Commission is guided by the ecosystem approach, applying integrated management to ensure that human activities are adapted to the complex and dynamic nature of marine ecosystems. This is supported by an obligation of contracting parties to apply the precautionary and polluter pays principle and the use of best available techniques (BAT) and best environmental practice (BEP), including clean technology.

The implementation of the OSPAR Convention until 2030 is described in the North-East Atlantic Environment Strategy (NEAES) 2030 (NEAES 2030, OSPAR 2021). It sets out collective strategic objectives (SO's) reflecting OSPAR's vision to address the triple challenge facing the ocean today: biodiversity loss, pollution and climate change. These SO's are to be achieved through a set of operational objectives which are translated into national implementation plans (Implementation Plan 2030)[37]. The implementation of the NEAES is part of OSPAR's contribution to the achievement of the United Nations 2030 Agenda for Sustainable Development (see **6.1 UN 2030 Agenda for Sustainable Development**, **p.82**) and the targets set within the Marine Strategy Framework Directive (MSFD) (see **3.2.2 Regional and European ocean frameworks p. 51**).

Climate mitigation and adaptation

The NEAES 2030 strives towards a North-East Atlantic Ocean that is resilient to climate change and acidification (SO 10, SO 11, SO 12). A coordinated long-term monitoring programme for ocean acidification variables will be developed by 2025 (SO 10.01) (not available at time of writing (June 2026))

[37] In the NEAES 2030 these themes are approached under four themes: clean seas, biologically diverse seas, productive and sustainably used seas, and seas resilient to climate change and ocean acidification.

along with regular assessments (starting in 2023 and every six years thereafter) of the current and projected impacts of climate change and ocean acidification in the OSPAR maritime area (SO 10.03). These assessments need to inform national and international actions and ensure that the impacts of ocean acidification and climate change are systematically taken into account in relevant OSPAR indicators and assessments (SO 10.02). Adaptation strategies are stipulated in SO 11.

OSPAR and mCDR

The NEAES 2030 also contains several strategic objectives that are relevant in the context of mCDR:

- SO 1 connects to engineered mCDR techniques as it seeks to limit the input of nutrients, which may be artificially added to temporarily enhance carbon uptake, to levels that avoid adverse effects on the marine environment.
- SO2 focuses more broadly on preventing pollution by hazardous substances.
- SO5 and SO6 align with nature-based mCDR approaches as they aim to conserve and restore marine biodiversity and ecosystems, thereby safeguarding ecosystem functions and enhancing resilience to climate change and ocean acidification.
- SO 12 addresses the mitigation of climate change and ocean acidification by focusing on the preservation of natural carbon sinks and stocks:
    - SO 12.01 aims to develop a regional approach for the implementation of measures to protect and restore key blue carbon ecosystems, such as seagrass beds, kelp forests, and salt marshes.
    - S 12.02 states that, from 2025 onwards, OSPAR will include carbon storage potential as a criterion in the designation of marine protected areas and in the review of the OSPAR 'List of Threatened and/or Declining Species and Habitats'.
    - S 12.03 will review the effectiveness of carbon measurements to ensure that carbon dioxide streams from all pathways (biogenic, industrial, and abiotic) are permanently retained in carbon stocks and do not lead to significant adverse consequences for the marine environment, human health, or legitimate uses of the maritime area.

Furthermore, when examining the OSPAR Convention from an mCDR perspective, the precautionary principle is mandated. Contracting Parties are to take all necessary steps to prevent or eliminate pollution by dumping (Article 4) and from offshore source (Article 5), but exceptions apply (see Annex II and III).

Strong international engagement

OSPAR positions itself as a central platform, tying up regional marine governance with the wider global ocean agenda. This is apparent by the strong international engagement to advance the protection of the marine environment and the sustainable use of ocean resources (International Cooperation).

At the global level, OSPAR engages with several key multilateral environmental agreements that promote nature conservation and the sustainable use of marine resources: e.g. in 2018 OSPAR signed a MoU with the International Maritime Organization (IMO) to strengthen regional cooperation under the London Convention and London Protocol. OSPAR also collaborates closely with the Convention on Biological Diversity (CBD) (see **3.3.1 Global biodiversity frameworks p. 60**).

A clear example of this collaboration is the identification by OSPAR and subsequent recognition by the CBD of numerous Ecologically or Biologically Significant Areas (EBSAs) in the North-East Atlantic. Furthermore, acting as a regional cooperation platform for the implementation of Sustainable Development Goal 14 (SDG 14) (see **6.1 UN 2030 Agenda for Sustainable Development, p. 85**), OSPAR integrates the United Nations Sustainable Development Goals (SDGs) into its programmes, measures, and actions. Adding to this, OSPAR strives to strengthen ties with the United Nations Environment Programme (UNEP) and its Regional Seas Programme (see **6.4.1 International frameworks, p. 96**), regional conventions and action plans, and with other transboundary organisations to address common challenges for the ocean

From a climate-focused perspective, OSPAR supports the implementation of the United Nations Framework Convention on Climate Change (UNFCCC) (see **3.1.1 Global climate frameworks p. 29**) and the UN Decade of Ocean Science for Sustainable Development (UNDOSSD) (see **6.4.1 International frameworks p. 100**).

" Management is guided by the ecosystem approach

Specifically for EU's marine waters, OSPAR provides the coordination platform within the Marine Strategy Framework Directive (MSFD see **3.2.2 Regional and European ocean frameworks p. 51**) to its Contracting Parties that are EU Member States, supporting them in aligning all elements of their marine environmental strategies. This includes facilitating cooperation in defining and achieving Good Environmental Status (GES) in accordance with Articles 5 and 6 of the MSFD Directive (Directive 2008/56/EC).

EU Ocean Pact

Core objective: Identifies 6 priority areas towards a healthy, well-managed, safe marine environment supporting a competitive but sustainable blue economy.

Geographic scope
EU

Legal status
Non-binding

Focus
Governance

Carbon mentioned
Yes

Relevance for mCDR
Explicit acknowledgement of the ocean's carbon sink capacity. Supportive of nature-based mCDR. Precautionary principle applied for engineered mCDR. Strong emphasis on research and innovation into MRV to explore potential future implementation of engineered mCDR.

mCDR types
Nature-based mCDR, engineered mCDR, CO_2-storage

During the UN Ocean Conference in Nice (2025), the European Commission presented the 'Ocean Pact' (COM (2025) 281). The Ocean Pact introduces a holistic approach across all marine policy areas and aims to consolidate Europe's leadership in ocean policies grounded in observational evidence and scientific knowledge. As a single reference framework, the Pact aims to streamline coordination processes, simplify reporting and provide a unified implementation strategy for existing legislations in order to achieve an effective and coherent realisation of their policy goals. A central aim of the Pact is to better address major global challenges like climate change, pollution, the overexploitation of natural resources while simultaneously addressing security threats. To realise this ambition, six priority areas were identified:

- protecting and restoring ocean health;
- boosting sustainable competitiveness of the blue economy;
- supporting coastal, island communities and outermost regions;
- advancing ocean research, knowledge, skills and innovation;
- enhancing maritime security and defence as a prerequisite;
- strengthening EU ocean diplomacy and international rules-based governance.

To increase the efficiency of planning, decision-making, and the implementation of actions designed to meet these objectives, the EU foresees the revision and strengthening of its existing marine policy frameworks. Particular attention will be devoted to enhancing coherence in the adoption, monitoring, and enforcement of measures across EU, regional, national, and local governance levels. As a strategic tool to serve the priorities of the Ocean Pact, the Commission will prioritise the revision of the current Marine Spatial Planning Directive (Directive 2014/89/EU see **3.2.2 Regional and European ocean frameworks p. 56**). This revision needs to improve cross-sectoral coordination and strengthen sea basin approaches. This strengthened and modernised Spatial Planning Directive will be a key instrument towards an "Ocean Act" by 2027.

The Ocean Pact and climate action

The Ocean Pact acknowledges the vital climate regulating role of the ocean and views the ocean as an ally in the fight against climate change. The Pact explicitly values the ocean's carbon sink capacity, underscoring the contribution of protected and restored ecosystems to the mitigation of climate warming. Therefore, the Commission will support Member States in the planning and execution of measures to restore degraded habitats and in doing so comply with the Nature Restoration Regulation (Regulation (EU) 2024/1991) that mandates that all ecosystems in need for restoration benefit from restoration efforts by 2050 (see **3.3.2. European biodiversity frameworks p. 64**). In addition, the Commission is supportive of coastal communities building new business models that provide benefits to nature and people. Next to the protection and restoration of marine carbon sinks, the EU puts stronger emphasis on the decarbonisation of the blue economy by accelerating the deployment of clean blue technologies, supporting business models that preserve or restore ocean ecosystems and biodiversity, for instance through nature-based solutions and carbon-negative products and by creating enabling conditions for clean, sustainable blue growth. Strengthening offshore wind and ocean energy are considered key steps to deliver affordable energy and improve energy security in the EU (COM (2025) 281, COM (2020) 741).

Despite providing clear entry points for nature-based mCDR, the Ocean Pact adheres to the precautionary principle regarding engineered mCDR. The need for a robust scientific knowledge base to support these approaches, along with a careful assessment of their associated risks and impacts, is a priority before this type of marine climate mitigation can be seriously considered as an effective climate pathway (COM (2025) 281, JOIN (2022) 28).

Strengthening ocean observation and science-policy exchange

To support the goals of the Ocean Pact and progress its climate ambitions, the EU launched the OceanEye initiative. Constituting Europe's ocean observation initiative, OceanEye will undertake action to merge two of the EU's main marine data services, EMODnet and the Copernicus Marine Service. The OceanEye also builds upon the European Digital Twin of the Ocean (EDITO), a centralised near real-time virtual representation of the ocean available to all. Through the OceanEye the EU aims to foster cutting-edge ocean observation technology infrastructure, thereby supporting international efforts in ocean observation and protection like the Global Ocean Observing System (GOOS). To support ocean research and innovation, the EU also foresees the establishment of an Ocean R&I Strategy to coordinate investments, create a European network of ocean testing sites, and enhance the development and deployment of innovative marine monitoring systems (EU Ocean Pact, JPI Oceans 2025).

In addition, in order to strengthen ocean science-policy knowledge exchange that leads to actionable, evidence-based decision making, the EU supported the development of the International Platform for Ocean Sustainability (IPOS) concept. The IPOS platform is designed to support a swift and inclusive fulfilment of international ocean commitments both at national and regional scales.

Together, the above measures could deliver a decisive leap towards strengthening the MRV systems required to move towards credible carbon accounting and a more quantitative and reliable assessment of the potential and risks of (engineered) mCDR.

[38] All actions have to adhere to the following four guidelines: pollution should be tackled by a source-to-sea approach, the precautionary principle should always be applied, science is fundamental to policy making and an ecosystem-based approach is central to safeguard ocean health and sustainability.

Marine Strategy Framework Directive (MSFD)

Core objective: Achieving and safeguarding Good Environmental Status of Europe's marine and coastal waters.

Geographic scope
EU

Legal status
Binding

Focus
Environmental protection

Carbon mentioned
Yes

Relevance for mCDR
Contains several provisions that have to ensure anthropogenic pressures remain within sustainable environmental limits.

mCDR types
Nature-based mCDR, engineered mCDR, CO_2-storage

The EU Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC) establishes the holistic legislative framework for the environmental protection of European marine waters. It requires Member States (MS) to take all necessary measures to reach and maintain a 'good environmental status' (GES) of its marine ecosystems (including the seabed and subsoil) and to sustainably manage the marine resources on which economic and social activities depend. It is the key contributor to the Ocean Pact's ocean health pillar (see **3.2.2 Regional and European ocean frameworks p. 49**) and directly contributes to the ambitions of the Biodiversity Strategy for 2030 (see **3.3.2 European biodiversity frameworks p. 63**) and the Zero Pollution action plan. MSFD's targets are supported by Directives like the Birds (Directive 2009/147/EC), Habitats Directive (Council Directive 92/43/EEC) and EU's Nature Restoration Regulation (Regulation (EU) 2024/1991) (see **3.3.2 European biodiversity frameworks p. 64**). Internationally, the MSFD is a cornerstone to deliver on its global commitment to protect the marine environment and pursue a sustainable approach to ocean management. Achieving GES directly contributes to the targets of instruments like: UNCLOS (see **3.2.1 Global ocean frameworks p. 42**), the Convention on Biological Diversity (see **3.3.1 Global biodiversity frameworks p. 60**), the 2030 UN Agenda for Sustainable Development (e.g. SDG14 Life Below Water) (see **6.1 UN 2030 Agenda for Sustainable Development, p. 82**) and indirectly the High Seas Treaty (see **3.2.1 Global ocean frameworks p. 44**) (Ni Longphuirt et al. 2025). The MSFD is therefore widely considered the EU's overarching framework for marine environmental governance, offering a transparent and harmonised legislative foundation that aligns cross-sectoral policies and ensures coherence, coordination, and mutual reinforcement with other EU legislation and international commitments.

Good Environmental Status (GES)

GES under the MSFD is defined through 11 qualitative descriptors (Article 9, Annex I), for which Member States must develop regionally appropriate indicators and associated targets (Commission Decision (EU) 2017/848). These indicators[39], together with a dedicated monitoring programme and a programme of measures, form the core of a Member State's marine strategy, outlining how environmental deterioration will be prevented and, where feasible, degraded marine ecosystems restored (Degraer et al. 2023). Marine strategies are prepared and revised on a six-year cycle, ensuring regular assessment, adaptation, and alignment with evolving scientific knowledge and policy priorities (WISE Marine Implementation of MSFD). Management of human activities within this framework follows an ecosystem-based approach, aiming to ensure that anthropogenic pressures remain within sustainable environmental limits while supporting the achievement of GES. The coordination is operationalised through established regional cooperation structures, most notably the four Regional Sea Conventions (OSPAR (see **3.2.2 Regional and European ocean frameworks, p. 46**), HELCOM, Barcelona[40], and Bucharest), which provide institutional platforms for joint action among EU Member States and neighbouring countries sharing marine waters.

MSFD and mCDR

Scientific research has demonstrated that the natural carbon sink capacity of marine ecosystems increases when they are in a good environmental condition (Sala et al. 2021). Hence, achieving GES directly supports several climate mitigating benefits which can be realised through nature-based mCDR (Christianson et al. 2022, Claes et al. 2022, Simpson & Smart 2024). Hence, the protection and restoration of these ecosystems directly contributes to international commitments like the UN Sustainability Goals (see **6.1 UN 2030 Agenda for Sustainable Development p. 82**) or the implementation of the EU's Nature Restoration Regulation (see **3.3.2 European biodiversity frameworks p. 64**). However, despite their importance, blue carbon ecosystems remain poorly integrated into the implementation of the MSFD. Therefore a call to develop a unified and strengthened approach to the management of blue carbon at EU level via the MSFD framework was recently communicated in a JPI Oceans policy brief (Ní Longphuirt et al. 2025). Improvements in this area may be achieved through the recently developed 'Blue Carbon Roadmap' which sets out a framework for improving the mapping, monitoring, and management of coastal blue carbon ecosystems across the EU (Wartman et al. 2025). Being aligned with the EU's broader climate and environmental policy architecture, (European Green Deal and the Biodiversity Strategy for 2030) the roadmap is meant to support policymakers, stakeholders, and the scientific community in strengthening blue carbon governance and sustainable management in support of EU's climate, biodiversity, and sustainability targets. The roadmap provides targeted actions to address critical knowledge gaps, enhance data availability, and enable the integration of blue carbon ecosystems into carbon and natural capital markets.

Concerning engineered-mCDR activities, the following stipulations of the MSFD are of interest:

- Article 1(1). States shall prevent and reduce inputs in the marine environment, with a view to phasing out pollution[41], so as to ensure that there are no significant impacts on or risks to marine biodiversity, marine ecosystems, human health or legitimate uses of the sea.
- Article 2 (1). The MSFD applies to all marine waters as defined in Article 3(1) - which includes the coastal waters, seabed and subsoil - and shall take account of the transboundary effects on the quality of the marine environment of third States in the same marine region or subregion.

[39] To support coherent indicator development, the EU provides targeted guidance through a technical report, descriptor-specific scientific opinions, and Commission Decision (EU) 2017/848, which defines the criteria, methodological standards, and required monitoring and assessment methods for achieving GES. These instruments enable Member States to set threshold values, design robust monitoring systems, and ensure regional and EU-wide consistency, thereby underpinning the harmonised and scientifically rigorous implementation of the MSFD.

[40] Officially the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean and its Protocols.

[41] According to Article 3(8) 'pollution' means the direct or indirect introduction into the marine environment, as a result of human activity, of substances or energy, including human-induced marine underwater noise, which results or is likely to result in deleterious effects such as harm to living resources and marine ecosystems, including loss of biodiversity, hazards to human health, the hindering of marine activities, including fishing, tourism and recreation and other legitimate uses of the sea, impairment of the quality for use of sea water and reduction of amenities or, in general, impairment of the sustainable use of marine goods and services.

- Article 13(3). Member States have to ensure that measures are cost-effective and technically feasible, and shall carry out impact assessments, including cost-benefit analyses, prior to the introduction of any new measure and consider to the best of their abilities the socio-economic impact of any measure.
- Provision 13. By acknowledging the transboundary nature of the marine environment, Member States should cooperate to ensure the coordinated development of marine strategies for each marine region or subregion. Since marine regions or subregions are shared both with other Member States and with third countries, Member States should make every effort to ensure close coordination with all Member States and third countries concerned.

Regarding the descriptors, the relevant descriptors are listed in table 3.

Concerning the pressures and impacts from human activities to be monitored (Annex III), the following can be connected to engineered mCDR activities:

- The contamination by hazardous substances;
- The systematic and/or intentional release of substances;
- Nutrient and organic matter enrichment.

To conclude, the MSFD recommends the monitoring of a set of physical and chemical features (Annex III), such as the spatial and temporal distribution of nutrients and oxygen, as well as pH and pCO_2 profiles. All these variables are directly relevant for assessing the effectiveness and impacts of mCDR.

Table 5. MSFD descriptors with specific relevance for mCDR-techniques.

Descriptor	Description
D1	Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions.
D4	All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity.
D5	Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters.
D6	Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected.
D8	Concentrations of contaminants are at levels not giving rise to pollution effects.
D11	Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.

Water Framework Directive (WFD)

Core objective: Preventing the deterioration of Europe's inland and coastal waters (≤ 1 nm). Achieving Good Ecological Status (GES) and Good Chemical Status (GCS)

Geographic scope
EU

Legal status
Binding

Focus
Coastal and inland waters

Carbon mentioned
Yes

Relevance for mCDR
Indirect regulation by controlling pollutant inputs to ensure GES and GCS of coastal waters

mCDR types
Nature-based mCDR, engineered mCDR

The EU's Water Framework Directive (WFD) (Directive 2000/60/EC) is the main European law for water protection. It requires Member States to protect all inland, transitional[42], and coastal[43] surface waters, as well as groundwater bodies, and to restore them in cases where environmental quality standards (EQS) for specific pollutants are exceeded. The Directive is implemented via management plans at river basin level (RBMPs) and Programmes of Measures (PoMs), which account for the interconnectedness of water bodies and ensure international cooperation. RBMPs have a 6-year cycle after which they are revised. Their effectiveness and progress towards the WFD targets is tracked in Implementation Reports.

Article 4 of the WFD has to ensure European surface waters and ground water bodies reach a good ecological and good chemical status (GES & GCS). The elements to be monitored to assess GES are listed in Annex V. These elements include pollutants of national or local concern, for which Member States must set and meet environmental quality standards (EQS) (Environmental Quality Standards Directive (Directive 2008/105/EC)). The elements to be monitored to reach GCS are listed in Annex X and comprise a list of so called 'priority substances', including 'priority hazardous substances'. A proposal to revise and expand this list was adopted in October 2022 to increase efforts to protect EU citizen and nature and increase consistency with existing policy provisions like the EU Biodiversity Strategy for 2030 (COM (2020) 380) and the Zero Pollution Action plan (COM (2021) 400). The different variables to be assessed are listed in Annex V[44], which among others include nutrient conditions, salinity and components that are discharged in sufficient quantity in the water column.

[42] Bodies of partly saline surface water in the vicinity to the coast, but which are heavily influenced by freshwater flows.

[43] Coastal water means surface water on the landward side of a line, every point of which is at a distance of one nautical mile (1 nm) on the seaward side from the nearest point of the baseline (low waterline) from which the breadth of territorial waters is measured, extending where appropriate up to the outer limit of transitional waters.

[44] To evaluate GES, the following variables are screened: composition, abundance and biomass of phytoplankton; composition and abundance of other aquatic flora; composition and abundance of benthic invertebrate fauna; hydromorphological elements supporting the biological elements; morphological conditions; depth variation; structure and substrate of the coastal seabed; structure of the intertidal zone; tidal regime; direction of dominant currents; wave exposure; chemical and physico-chemical elements supporting the biological elements; transparency; thermal conditions; oxygenation conditions; salinity; nutrient conditions; specific pollutants; pollution by all priority substances identified as being discharged into the water body; pollution by other substances identified as being discharged in significant quantities into the body of water.

> *“Preventing pollution and avoiding ecosystem degradation are core principles guiding EU marine policy*

Concerning the coastal environment the WFD acknowledges the potential impact of the quality of inland waters to estuaries and the coastal environment, hence the inclusion of coastal waters (≤ 1 nm) to the WFD.

In the context of mCDR, engineered mCDR-techniques like ocean alkalinity enhancement or related electrochemical approaches, can be deployed in coastal zones, where they potentially alter the chemical conditions (GESAMP 2019), in which case they fall within the scope of the WFD. Although mCDR is not explicitly included in the WFD, any deployment of mCDR in coastal waters within the geographical range of the Directive (1 nm for GES and 12 nm for Good Chemical Status (GCS)) would therefore be required to comply with EQS and environmental assessment obligations, ensuring that no deterioration of the ecological or chemical status of the water body occurs.

Maritime Spatial Planning Directive

Core objective: The spatial organisation of human activities at sea to allow a sustainable use of marine resources and blue growth.

Geographic scope
EU

Legal status
Binding

Focus
Spatial planning, impact management

Carbon mentioned
No

Relevance for mCDR
Provides a framework for the spatial delineation of nature conservation and restoration measures, as well as for offshore CO_2 storage. In the future, the Directive could also be used to organise the spatial deployment of engineered mCDR implementation.

mCDR types
Nature-based mCDR, engineered mCDR, CO_2 storage

Drawing on the provisions of the United Nations Convention on the Law of the Sea (UNCLOS 1982) (see **3.2.1 Global ocean frameworks p. 42**) and building on foundational frameworks such as the Integrated Maritime Policy, as well as key studies like '*Marine Spatial Planning: A Step-by-Step Approach towards Ecosystem-based Management*' (Ehler & Douvere 2009), the EU recognised the need for national marine spatial planning. This was motivated by the dual objective of optimising the spatial organisation of human activities in the marine area to advance sustainable blue growth, while simultaneously integrating environmental protection as articulated in the eleven descriptors of the MSFD (Directive 2008/56/EC). This recognition culminated in the adoption of the MSP Directive (Directive 2014/89/EU), with Belgium among the first EU Member States to implement it. For a more comprehensive overview of the history behind EU's MSP Directive, the progress made and the lessons learned, see COM (2022) 185, the European Maritime Spatial Planning Platform and the study of Zaucha et al. (2025).

Some key elements embedded in the MSP Directive and to which coastal states must consistently devote sufficient attention to, include climate change, the ecosystem-based approach, societal impacts, and coherence with other decisions and provisions across different governance levels. The Directive provides a framework for the spatial delineation of nature conservation and restoration measures, as well as for offshore CO_2 storage. In the future, the Directive could also be used to organise the spatial deployment of engineered mCDR.

Environmental Impact Assessment Directive[45]

Core objective: Consideration of environmental concerns for major public or private projects

Geographic scope
EU

Legal status
Binding

Focus
Impact management

Carbon mentioned
Greenhouse gases

Relevance for mCDR
Obligation to conduct rigorous environmental impact assessments for activities that can affect the (marine) environment

mCDR types
Nature-based mCDR, engineered mCDR, CO_2 storage

The European Environmental Impact Assessment Directive (Directive 2011/92/EU), amended by Directive 2014/52/EU ensures the consideration of environmental concerns[46] before the start of major construction or development projects. As such, the EIA Directive acts as one of the key instrument to ensure marine activities do not compromise environmental targets such as the "Good Environmental Status" under the MSFD (see **3.2.2 Regional and European ocean frameworks p. 51**). The obligation to conduct an EIA is also established in different international ocean treaties, such as UNCLOS Art. 206 and the Convention on Biological Diversity (Art. 14 (a)).

Determining whether an EIA is required often balances on vague and context-dependent interpretations of what constitutes a 'major' or 'significant' impact[47]. For mCDR activities, EIAs can produce the baseline environmental data necessary to quantify anthropogenic removals over time and evaluate additionality, given that EIAs involve both ex ante assessment and ongoing monitoring throughout the project lifetime. The data generated through EIA processes can therefore serve as an essential input to the development of robust monitoring, reporting, and verification (MRV) frameworks for mCDR activities (Van Dam et al. 2024, EMB 2025).

Concerning climate change, recommendation 13 of the Directive states that it is appropriate to assess the impact of projects on greenhouse gas emissions and evaluate their vulnerability to climate change. Furthermore, EIAs should also account for accidents and disasters by climate change in accordance with the best available scientific knowledge.

[45] Although the EIA-Directive is not a marine-specific directive, it is considered here because of its direct relevance on the management of impacts caused by anthropogenic use of marine space and resources.

[46] The EIA should evaluate all possible direct and indirect impacts of the project on a wide range of factors, such as: population and human health, biodiversity, land, soil, water, air, climate, landscape, material assets and cultural heritage. When an EIA is required, the public must be informed and the developer must provide an opportunity for concerns to be expressed.

[47] The International Law Commission (UN 2005) states that hazardous activities with potential significant transboundary effects must be assessable through factual and objective criteria.

3.3

Biodiversity and nature conservation frameworks

PROBLEM

Biodiversity and nature conservation frameworks prioritise ecosystem conservation and restoration and do not systematically or explicitly integrate the climate mitigating capabilities of marine ecosystems. Despite clear connections, potential trade-offs between carbon sequestration and ecosystem integrity and health is insufficiently understood, creating both opportunities and tensions to align biodiversity objectives with, in particular, engineered mCDR approaches.

KEY TAKEAWAYS

- Biodiversity frameworks are generally guided by the precautionary principle, prioritising ecosystem integrity, resilience, and restoration.
- Coastal blue carbon ecosystems (salt marshes, seagrasses, mangroves) are recognised for bridging climate mitigation, adaptation and biodiversity conservation and are relatively well integrated into biodiversity and conservation frameworks, but the governance landscape isn't aligned on issues and solutions.
- Non-coastal ecosystems like shelf ecosystems remain largely excluded from biodiversity-climate policy integration, despite their carbon stocks potentially being of substantial importance to the marine carbon balance and hence its implications for climate regulation. Here, the focus lies on knowledge building, rather than management for resilience, adaptation or mitigating purposes.
- Biodiversity protection frameworks impose strict safeguards, often by following the precautionary principle, which constrain research and deployment of engineered mCDR approaches.
- Most biodiversity frameworks consider the management, conservation and restoration of marine ecosystems from the perspective of adaptation or resilience to climate change, however the recent EU Nature Restoration Regulation and the Kunming-Montreal Biodiversity Framework explicitly value the role of marine ecosystems as carbon sinks for protection and restoration purposes.
- Current frameworks lack MRV systems that capture both carbon fluxes and biodiversity status, limiting a direct evaluation of co-benefits and potential risks of climate intervention through mCDR.
- Increasing emphasis on ecosystem-based management and restoration economies creates an entry point to align biodiversity and climate targets but don't provide governance pathways for engineered interventions.

BERNARDO

BERNARDO supports the integration of biodiversity and climate policy by enabling quantitative, science-based assessments of carbon-ecosystem interactions. By its holistic study of the marine carbon cycle and assessment of the carbon impact of different use cases, BERNARDO contributes to the development of science-based environmental safeguards, co-benefit frameworks, and nature-inclusive carbon accounting.

Convention on Biological Diversity

Core objective: The objectives are threefold: (i) the conservation of biological diversity, (ii) the sustainable use of its components and (iii) the fair and equitable sharing of the benefits from the use of genetic resources.

Geographic scope
Global

Legal status
Binding

Focus
Conservation, sustainable use, benefit sharing

Carbon mentioned?
In CoP Decisions

Relevance for mCDR
Parties to the Convention are required to apply the precautionary approach when it comes to (engineered) mCDR. A moratorium decision was adopted in 2010 (Decision X/33). The restoration of blue carbon ecosystems as a NbS supporting climate change mitigation and adaptation however is supported, providing any negative impact to marine biodiversity is kept to a minimum.

mCDR types
Nature-based mCDR, engineered mCDR

The Convention on Biological Diversity (CBD) (Rio 1992) is one of the key international instruments driving the wider global sustainability movement. It is a nearly universally adopted (196 Parties) biodiversity framework with three main goals: the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits from the use of genetic resources. Through Article 14 Parties to the CBD are obliged to assess, prevent, and respond to activities that may harm biodiversity, whether in territorial waters or in waters beyond national jurisdiction and calls on the Parties to look into suitable ways to address liability and take compensating measures when necessary (CBD Article 14, Mandai & De Souza 2021).

Concerning engineered mCDR, the CBD aligns with the position of the LC/LP (see **3.2.1 Global ocean frameworks p. 40**) and urges its members to adopt the precautionary approach and respect customary international maritime law (UNCLOS (see **3.2.1 Global ocean frameworks p. 42**)). Additionally, acknowledging the risk of transboundary effects, the substantial scientific uncertainty and the lack of regulatory control, Decision X/33 (2010) establishes a moratorium on all climate-related geoengineering activities that may harm biodiversity pending sufficient scientific guarantees and comprehensive risk assessments addressing environmental, social, economic, and cultural impacts (Vanderzwaag & Mahamah 2024). Conversely, conserving and restoring carbon-rich ecosystems like coastal blue carbon ecosystems is endorsed by the COP of the CBD (Kunming-Montreal Global Biodiversity Framework, He & Cao 2026, Blue Carbon Policy Framework).

Kunming-Montreal Global Biodiversity Framework

Core objective: Operationalisation of the CBD. Contains commitment to conserve and restore at least 30% of degraded marine and terrestrial areas by 2030.

Geographic scope
Global

Legal status
Non-binding
(policy framework under CBD)

Focus
Conservation, restoration and climate-biodiversity synergies

Carbon mentioned
No

Relevance for mCDR
Engineered mCDR remains constrained by former COP decisions. Supports the restoration and protection of marine ecosystems with important ecosystem services

mCDR types
Nature-based mCDR, engineered mCDR

The most recent agreement under the CBD is the Kunming-Montreal Global Biodiversity Framework (GBF) (COP 15, December 2022), which builds on the preceding Aichi Targets[48] (2010-2020). It provides a bold, science-driven framework to guide global biodiversity policy and action by 2030 and 2050 and is aligned with the Sustainable Development Goals. The new framework contains the landmark commitment to conserve and restore at least 30% of degraded terrestrial and marine areas (a.o. blue carbon ecosystems) by 2030 - the so called "30 by 30" target.

Within the context of climate change two GBF-targets are particularly relevant:

- Target 8 calls for keeping the impact of climate change and ocean acidification on biodiversity to a minimum and points to actions, including nature-based solutions and/or ecosystem-based approaches to mitigate harmful climate impacts and deliver net positive outcomes for both climate and biodiversity.
- Target 11 supports nature-based solutions to help restore, maintain and enhance nature's contributions to people, including ecosystem services and functions.

To monitor the progress towards its objectives and ensure transparency and accountability, MRV frameworks will be established (UN COP 17 2025). In addition, the GBF will seek to stimulate global coordination on reaching its goals and connect closely to the UN Decade of Ecosystem Restoration (2021-2030) (see **6.4.1 International frameworks p. 99**).

[48] A set of 20 global biodiversity targets agreed upon by the CBD in 2010 for the period 2010-2020.

RAMSAR Convention

Core objective: The protection and wise use of wetlands and their resources

Geographic scope
Global

Legal status
Binding

Focus
Conservation and wise use of wetlands

Carbon mentioned
No

Relevance for mCDR
The conservation, restoration and sustainable management of coastal blue carbon ecosystems is promoted (Resolution XII. 14)

mCDR types
Nature-based mCDR

The RAMSAR Convention is the intergovernmental treaty that provides a global framework for the conservation and wise use of wetlands[49] and their resources (Ramsar Convention 1971, List of Wetlands of International Importance). The framework aims at international cooperation and sets international conservations standards. As such, Contracting Parties are obliged to cooperate in case a water system is shared or wetlands cross national borders (Transboundary Wetlands of International Importance) (Article 5).

Central to the Convention is the "wise use" principle (Art. 3.1), meaning Contracting Parties have to ensure wetlands are used sustainably without losing their ecosystem services and ecological character. To fulfill this commitment Contracting Parties are required to develop national integrated management and conservation plans that cover site inventarisation, monitoring, research, training and public education and develop the necessary policies and legislation for effective implementation. Assistance on how to implement the wise-use principle is provided by a set of guidelines (Annex A Resolution IX.1, Ramsar Convention Secretariat 2010).

Globally, there are 151 countries within the Ramsar Convention that have at least one coastal blue carbon ecosystem and 71 of them have all three types (tidal marshes, seagrass and mangroves) (RAMSAR, Convention on Wetlands 2025). The conservation, restoration and sustainable management of coastal blue carbon ecosystems, and their recognition as effective nature-based solutions to climate change and sea level rise, is considered a priority for Contracting Parties within the Ramsar Convention as evident by a variety of Resolutions (e.g., VIII.4, X.24, XIII.14). As such, these resolutions respond to the United Nations General Assembly (UNGA) Resolution on Oceans and the law of the Sea (Resolution A/RES/71/257) and scientific calls that emphasise the restoration and protection of blue carbon ecosystems as a key climate priority (Herr and Landis 2016, Gattuso et al. 2018, Macreadie et al. 2021, Convention on Wetlands 2025). Within that vein, the Ramsar Convention is also a member of the International Partnership for Blue Carbon (IPBC, IPBC 2023). A partnership that aims to build awareness on blue carbon ecosystems and promote their protection and sustainable management, connecting governments, research institutes and NGO's.

[49] Wetland areas are defined as: marshes, fens, peatlands or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres (Art. 1).

3.3.2 European biodiversity frameworks

EU Biodiversity Strategy for 2030

Within the framework of the EU Green Deal (COM(2019) 640) the EU launched its Biodiversity Strategy for 2030 'Bringing nature back into our lives' (COM (2020) 380). The strategy aims to halt Europe's biodiversity decline and set it on a path to recovery by 2030, thereby supporting key international initiatives like the Kunming-Montreal Global Biodiversity Framework (see **3.3.1 Global biodiversity frameworks p. 61**), the 2030 Agenda for Sustainable Development (see **6.1 UN 2030 Agenda for Sustainable Development p. 82**) and the Paris Agreement on Climate Change (Paris 2015) (see **3.1.1 Global climate frameworks p. 30**). The Strategy calls for the large-scale protection and restoration of Europe's degraded ecosystems, a strengthening and expanding of existing protected areas (e.g. expanding the Natura 2000 network) and making nature more resilient to impacts from climate, people and economic activities. The Strategy establishes three concrete protection commitments[50] and fourteen restoration commitments[51].

To reach its goals the Strategy depends on action by citizens, businesses, social partners and research and knowledge institutions. All actions are to be evaluated by the Commissions' better regulations tools[52] (EC Better Regulation, EC Better Regulation guidelines and toolbox, Dauwe et al. 2025) to ensure that all relevant environmental, social and economic impacts are appropriately considered in line with the 'do no harm principle' - in essence giving nature a more central role in decision making. The Strategy also intends to improve existing governance frameworks to ensure a better tracking and a full and effective implementation of EU legislation and in that manner tackle previous, less effective conservation and restoration efforts[53] under pre-existing nature strategies and action plans (SWD (2016) 472).

EU's biodiversity strategy is underpinned by the recognition that tackling the biodiversity and climate crises requires an integrated approach. It frames nature as an important ally to address climate change as reflected in the statement "Nature regulates the climate, and nature-based solutions, such as protecting and restoring wetlands, peatlands and coastal ecosystems, or sustainably managing marine areas, forests, grasslands and agricultural soils, will be essential for emission reduction and climate adaptation". In addition, the Strategy acknowledges that investing in natural capital, e.g. carbon-rich ecosystems, has clear economic and societal benefits (COM (2020) 380).

Marine ecosystems

The Biodiversity Strategy labels marine ecosystems as vital, but threatened ecosystems for societal welfare and wellbeing and calls for more and stronger action for protection and restoration. Marine resources must be used sustainably with zero-tolerance for illegal, unreported and unregulated (IUU) practices. In this regard, the full implementation and enforcement of ecosystem-based (management) legislation like the EU's Common Fisheries Policy, the Marine Strategy Framework Directive (see **3.2.2 Regional and European ocean frameworks p. 51**) and the Birds and Habitats Directives (see **3.3.2 European biodiversity frameworks p. 67**) are essential. To achieve this, Member States have to develop national marine spatial plans (Spatial Planning Directive (Directive 2014/89/EU), see **3.2.2 Regional and European ocean frameworks p. 56**) that encompass all maritime sectors and activities and include area-based conservation-management measures. The EU will also work with partner countries and regional organisations to protect and sustainably manage vulnerable marine ecosystems and species, particularly in biodiversity hotspots and areas beyond national jurisdiction.

[50] Ensure that at least 30% of the EU's land and sea areas are legally protected, and connect these areas through ecological corridors forming a Trans-European Nature Network; (2) place at least one-third of all EU protected areas under strict protection (= 10% protected areas under strict protection), including all remaining primary and old-growth forests; (3) guarantee that all protected areas are managed effectively, with clear conservation objectives, defined measures, and appropriate monitoring.

[51] Commitment 1 requires the restoration of 'significant areas' of degraded carbon rich ecosystems and Commitment 13 aims to significantly reduce human impacts on sensitive species and habitats, including those to the seabed.

[52] Based on the call of the 'Better Regulation Communication (COM (2019) 178) for evidence-informed decision making, a strong approach to stakeholder consultation, burden reduction and the analysis of key impacts and the integration of strategic foresight.

[53] Main complaints/issues were the lack of requirements for Member States to have biodiversity restoration plans, the common lack of clear or binding targets and timelines and no definition or criteria on restoration or the sustainable use of ecosystems. There is also no requirement to comprehensively map, monitor or assess ecosystem services, health or restoration efforts. These issues are exacerbated by the gaps in implementation that prevent the existing legislation from achieving its objectives.

Nature Restoration Regulation

Core objective: By 2030 20% of EU's degraded ecosystems have to be restored or under restoration. This target increases for all degraded ecosystems by 2050.

Geographic scope
EU

Legal status
Binding

Focus
Restoration

Carbon mentioned
Yes

Relevance for mCDR
Prioritises the protection and restoration of (marine) carbon rich ecosystems with high sequestration potential, hence explicitly linking nature conservation and restoration to climate mitigation.

mCDR types
Nature-based mCDR

Recognising that most of Europe's natural environment is degraded and that existing protection measures are insufficient[54] to address the biodiversity crisis, the EU adopted the Nature Restoration Regulation in 2024 (NRR, also commonly referred to as the Nature Restoration Law) (Regulation (EU) 2024/1991). The NRR is a key element of Europe's Biodiversity Strategy for 2030, intended to strengthen the level of implementation of existing conservation and restoration legislation within clear deadlines and legally binding restoration targets for ecosystems, habitats and species. It seeks a sustained recovery of degraded areas, transforming them into biodiverse and resilient ecosystems that contribute to the EU's climate mitigation and adaptation objectives and meet several international commitments. By 2030, at least 20% of the EU's degraded land and sea areas should be under restoration, with efforts extending to all ecosystems in need of restoration by 2050. In particular ecosystems that act as important carbon sinks and reduce the impact of natural disasters will be targeted as they are considered fundamental to tackle the current climate-biodiversity crisis. The NRR foresees many synergies among nature-based carbon removal activities, particularly carbon farming, and nature restoration measures. In this context, the recent CRCF Regulation (see **3.1.2 European climate frameworks p. 35**) will provide an incentive to achieve the NRR's restoration targets.

Concerning NRR's implementation, MS are required to draft Nature Restoration Plans by mid-2026 which have to include a description of the required monitoring and reporting actions. In case ecosystems cross national boundaries, as is often the case in the marine context, the MS concerned are required to make every effort to maximise the coherence of their restoration plans across the relevant ecosystems (Article 18). Regular progress reports will be drafted by the European Environment Agency (EEA).

Through the NRR, the EU aims to capitalise on the well-documented evidence that investments in nature yield substantially higher financial returns than the costs associated with restoration (UNEP 2025). This approach draws upon the ecosystem accounting framework developed under the United Nations System of Environmental-Economic Accounting - Ecosystem Accounting (SEEA-EA) (Dauwe et al. 2023), which integrates data on habitats, landscapes, and the extent and condition of ecosystem services with corresponding economic dimensions.

[54] A fitness check conducted by the EC (SWD (2016) 472) concluded insufficient progress in the implementation and monitoring of the Habitats and Birds Directive, resulting in an Action Plan (2017) to accelerate progress.

" The NRR aligns biodiversity restoration with marine climate mitigation

Fulfilling international biodiversity and climate requirements

Through the NRR, the EU delivers on the long-term strategic vision adopted by the Parties to the Convention on Biological Diversity (Decision X/2 Strategic Plan for Biodiversity 2011-2020) (see **3.3.1 Global biodiversity frameworks p. 60**) which envisions biodiversity is "to be valued, conserved restored and wisely used by 2050, maintaining ecosystem services, thereby sustaining a healthy planet and providing benefits for all". The NRR also further advances action-driven global targets e.g. target 1, 2 and 11 of the Kunming-Montreal Global Biodiversity Framework (see **3.3.1 Global biodiversity frameworks p. 61**) and goals 14.2, 15.1, 15.2 and 15.3 of the UN Sustainable Development Goals (see **6.1 UN 2030 Agenda for Sustainable Development p. 82**), which call for the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services.

Besides meeting international biodiversity commitments, the NRR is also instrumental in fulfilling the obligations established under the European Climate Law (Regulation 2021/1119). This Regulation not only underscores the importance of nature-based opportunities for climate mitigation, it also mandates the enhancement of nature's capacity to support societal adaptation to the impacts of climate change. This recognition of nature-based solutions is further echoed in COM (2021) 82, *Forging a Climate-Resilient Europe - The New EU Strategy on Adaptation to Climate Change.*

Marine restoration targets

Article 5 of the NRR sets out the guidelines and conditions for the restoration of marine ecosystems, which can be grouped into seven habitat type groups (Annex II): 1. seagrass beds; 2.macroalgal forests; 3. shellfish beds; 4. maerl beds; 5. sponge, coral and coralligenous beds; 6. vents and seeps; 7. soft sediments above 1000 m depth. Deepsea environments are not explicitly represented (SERE 2023). In summary, it states that by 2030 at least 30% of ecosystems belonging to group 1-6 which are not in good ecological state need to be under restoration. This target rises to 60% by 2040 and at least 90% by 2050. In addition, MS must take action to restore areas where these types have been lost as a result of human activities until they achieve a 'favourable reference area'[55] by 2050. This reference area should be determined with consideration of historical records of habitat distribution as well as projected changes in environmental conditions arising from climate change (Regulation (EU) 2024/1991).

With regard to the marine restoration targets for group 7 habitats, the shelf sediments above 1,000 m depth[56] - which are directly relevant to the BERNARDO project - the NRR is more focused on condition improvement than on strict re-establishment of lost area. For bottom sediment, the EU requires Member States to base their actions on the best available knowledge of habitat extent and condition, while progressively improving monitoring and assessment over time. National Restoration Plans due in 2026 must include baseline information on the distribution and condition of these habitats, including

[55] "The total area of a habitat type in a given biogeographical or marine region at national level that is considered the minimum necessary to ensure the long-term viability of the habitat type and its typical species or typical species composition, and all the significant ecological variations of that habitat type in its natural range, and which is composed of the current area of the habitat type and, if that area is not sufficient for the long-term viability of the habitat type and its typical species or typical species composition, the additional area necessary for the re-establishment of the habitat type; where the habitat type concerned is listed in Annex I to Directive 92/43/EEC, such re-establishment contributes to reaching favourable conservation status for a habitat and, in marine ecosystems, such re-establishment contributes to achieving or maintaining good environmental status".

[56] Partly a consequence of the reduced feasibility of an effective monitoring of the impact of measures with depth (SWD (2022) 167).

areas not in good condition and identifying existing data gaps. In the long-term, the NRR intends for group 7 habitats to be re-established and restored where lost or degraded, with site-specific measures ensuring ecological coherence and connectivity (Regulation (EU) 2024/1991).

From the above, it is clear the NRR sets out the restoration of marine habitats that are known carbon sinks and entail climate mitigating benefits. Areas designated as Natura 2000 sites will be given priority until 2030. Regarding its implementation, the EU expects MS to pursue a coherent implementation and alignment of measures to meet the objectives and requirements established under other European frameworks for the protection of the marine environment.

In addition, the NRR allows greater flexibility in the restoration of marine habitat types compared to the Habitats Directive (see **3.3.2 European biodiversity frameworks p. 67**). For instance, the NRR enables the implementation of targeted, small-scale restoration actions of certain ecological (sub)types of benthic habitats that are not listed in Annex I of the Habitats Directive but instead are recognised within the European Nature Information System (EUNIS) and considered under the Marine Strategy Framework Directive (MSFD) (see **3.2.2 Regional and European ocean frameworks p. 51**, Directive 2008/56/EC).

Habitats Directive

Core objective: The protection of a predetermined list of habitats and species

Geographic scope
EU

Legal status
Binding

Focus
Conservation

Carbon mentioned
No

Relevance for mCDR
Does not mention mCDR, however engineered mCDR activities in or close to 'special areas of conservation' require an 'appropriate assessment procedure'. Nature-based mCDR is indirectly allowedhab

mCDR types
Nature-based mCDR, engineered mCDR

The Habitats Directive (Council Directive 92/43/EEC), together with the Birds Directive (Directive 2009/147/EC) is one of the key pillars of EU's biodiversity protection policy. Together, they make the Natura 2000 network of protected nature areas. The Habitats Directive sets out the protection and recovery of a vast number of species and habitat types. The selection of so called 'Sites of Community Importance' (SCI) (Article 2) is done by the EC, assisted by the MS, the European Environment Agency (EEA) and scientific experts. Once a SCI is designated, MS have six years to turn them into 'Special Areas of Conservation' (SAC) and start with the implementation of protective and restorative measures to bring populations or habitats back into a 'favourable' conservation status (Article 1). An update, based on a set of scientifically underpinned indicators, on the conservation status is subsequently due every six years (Article 17) after which a composite report is drafted by the Commission, the 'State of Nature' reports. An SCI-status however, does not prohibit human activities in the area of interest. In case any plan or project that is not related to the management of the site is likely to impact it, an 'appropriate assessment' has to be undertaken (Article 6 (3)). The competent authority can allow the activity after it has determined the integrity of the site will not be adversely affected. If, a negative impact cannot be ruled out and the project has to proceed because of imperative reasons of overriding public interest, the MS are obliged to take all necessary compensatory measures (Article 6 (4)).

Concerning the protection of marine habitats, Annex I lists several coastal and halophylic habitat types that are eligible to the designation of SAC. It concerns six habitat groups[57] that are further divided into several subtypes. For some of these habitat types, the Commission provides management models to assist site managers in their preparation of site-specific management plans.

[57] Open sea and tidal areas, sea cliffs and shingle or stony beaches, Atlantic and continental salt marshes and salt meadows, Mediterranean and thermos-Atlantic salt marshes and salt meadows, salt and gypsum inland steppes, boreal Baltic archipelago, coastal and land upheaval areas.

4. Conclusion

4.1 Three interrelated bottlenecks

This policy brief assesses whether marine carbon is "policy-ready" within the current ocean-climate-biodiversity governance landscape. Our analysis demonstrates that, despite the ocean's central role in regulating the global climate and supporting the blue economy, marine carbon as a connecting element remains structurally underrepresented in policy and accounting frameworks and is therefore poorly operationalised in climate strategies, accounting frameworks or in the evaluation of environmental-economic implications of human activities.

Three interdependent bottlenecks underpin the current underrepresentation: fragmented laws and regulations (Elsler et al. 2022, Webb et al. 2023, Röschel & Neuman 2023), inadequate monitoring, reporting and verification (MRV) systems (Mengis et al. 2023, Bach et al. 2024, EMB 2025), and the absence of robust and widely accepted marine carbon accounting frameworks (Brander et al. 2021, Dauwe et al. 2023, Mengis et al. 2023, Johnson et al. 2024, Van Dam et al. 2024).

4.2 Boundless ocean challenges enabling MRV

This poor consideration of the central position of marine carbon challenges an adequate approach to the governance of ocean-based climate action. This is particularly true for emerging concepts like marine carbon removal, a.k.a. mCDR, which is increasingly considered as a complementary pathway to mitigate residual emissions, and achieve net-zero targets beyond 2050 (Boyes & Elliott 2014, Röschel & Neuman 2023, Webb et al. 2023, Webb 2024, Johnson et al. 2024). However, most mCDR-concepts remains characterised by considerable knowledge gaps in effectiveness, durability and environmental impacts and are largely untested in real-life conditions. Moreover, scientific evidence suggests that all mCDR-approaches are likely to produce transboundary effects on ocean ecosystems and coastal communities, further complicating their governance and potential deployment (GESAMP 2019, Macreadie et al. 2022, Minx et al. 2022, Morganti et al. 2025).

Despite major uncertainties on effectiveness and impact, the prominence of mCDR in the global climate science-policy landscape is growing, pushed by an increasing urgency for impactful climate mitigating pathways (GESAMP 2019, Boettcher et al. 2023, Fridahl et al. 2023, Hoegh-Guldberg & Northrop 2023, Johnson et al. 2024). It is therefore pertinent that integrative and adaptive policy frameworks, which are able to balance the urgency of carbon removal to safeguarding the ocean's ecosystems and their ecosystem services, are developed (Stephenson et al. 2021, Lebling et al. 2022, Röschel & Neuman 2023, Webb 2024).

4.3 Nature-based vs. engineered mCDR

This tension between climate urgency and poor scientific and governance readiness feeds a growing regulatory mismatch. On the one hand, climate frameworks like Article 6 of the Paris Agreement or Europe's LULUCF Regulation (Regulation (EU) 2023/839) and CRCF Regulation (Regulation (EU) 2024/3012) increasingly recognise the value of carbon removals and seek to expand carbon accounting capabilities and carbon markets. On the other hand, ocean and biodiversity frameworks prioritise and evolve to improve environmental quality and ecosystem resilience. As a result, no single climate-ocean-biodiversity framework today is capable of regulating and evaluating mCDR (Röschel & Neuman 2023).

> *"Marine carbon should be considered as a cross-cutting element linking climate, ocean and biodiversity policies*

This mismatch however, is less pronounced for nature-based mCDR approaches such as the restoration or creation of coastal blue carbon ecosystems (salt marshes, seagrass, mangroves). Because restoration efforts can be fully implemented within a country's territorial waters, and thus only require localised and less costly monitoring efforts, coastal blue carbon ecosystems are explicitly promoted under strategic frameworks such as the Kunming-Montreal Global Biodiversity Framework and the EU's Nature Restoration Regulation. Moreover, their carbon removal potential can be systematically assessed to a sufficiently high degree of confidence, allowing their inclusion in national climate strategies, GHG inventories under the IPCC and the trading of carbon credits through carbon market mechanisms (ICVCM Core Carbon Principles, IPCC 2014, Macreadie et al. 2022, Schindler Murray et al. 2023, Watanabe et al. 2023, Bach et al. 2024, Simpson & Smart 2024)[58]. However, the inclusion of these systems in multiple global regulatory frameworks has so far resulted in unaligned governance, inconsistent definitions, and uneven implementation, thereby limiting their effectiveness in delivering climate and biodiversity outcomes (Ni Longphuirt et al. 2025, He & Cao 2026). Although, global initiatives like the International Partnership for Blue Carbon (IPBC) and the International Policy Framework for Blue Carbon Ecosystems represent concerted efforts in tackling these challenges.

Engineered mCDR approaches, while potentially offering greater mitigation capacity than nature-based options, entail significant monitoring challenges that drive up costs and contribute to persistent scientific uncertainties, thereby complicating their regulation and governance (Mengis et al. 2023, Palter et al. 2023, Röschel & Neuman 2023, Morganti et al. 2025). Therefore, international regulatory instruments generally apply the precautionary principle when it comes to engineered mCDR. The one legal framework regulating some forms of engineered mCDR, the London Protocol, prohibits the dumping of substances into the ocean and only allows for small-scale scientific research on iron fertilisation. Conversely, the subsea geological storage of carbon is allowed under the Protocol and under the OSPAR Convention, but large-scale deployment is hampered by the prohibition on trans-national transportation of captured CO_2.

4.4 Value and challenges of MRV

The aforementioned challenges make it clear that a responsible integration of carbon, and by extension mCDR, in governance frameworks, hinges on credible MRV practices that are able to track carbon through the marine system (also known as fate of the carbon) and quantify changes in carbon sequestration processes (additionality and permanence) and biota. However, the strong complexity and heterogeneity of marine biogeochemical and ecological processes in time and space, together with strong signal dispersion typical for open, dynamic marine systems, render current MRV protocols inadequate to assess human-driven CO_2 removal and environmental impacts. These challenges are compounded by the absence of standardised methodologies and IPCC guidance for offshore and engineered mCDR approaches, resulting in fragmented and often inconsistent MRV protocols. Without credible MRV grounded in standardised indicators, metrics, and baselines, the quantification and verification of additional and permanent carbon removal fails. This compromises the inclusion of marine carbon into greenhouse gas inventories, the evaluation of mCDR as a realistic climate mitigating pathway and the inclusion of marine carbon into certification schemes and carbon

[58] Contrary to other carbon sinks further offshore, like for instance shelf sediments (Luisetti et al. 2020, Dauwe et al. 2023).

market or climate finance mechanisms (Mengis et al. 2023, Bach et al. 2024, Smith et al. 2024, Van Dam et al. 2024, EMB 2025, Morganti et al. 2025). In other words, without credible accounting, marine carbon cannot be considered as a reliable policy variable in any of the three major policy domains.

4.5 Towards integrated governance

In order to close this gap, a transition from fragmented, sectoral governance towards a coherent and integrated governance architecture that recognises the ocean as a shared global interest and common heritage is recommended. Such an approach should be grounded in principles of equity, fairness, and transparent benefit-sharing, as reflected in recent developments such as the High Seas Treaty (see Section **3.2.1 Global ocean frameworks, p. 44**) (Minx et al. 2018, Bennett 2022, Elsler et al. 2022, Röschel & Neumann 2023, Webb et al. 2023, Van Dam et al. 2024, Webb 2024). To remain effective, this governance architecture must be adaptive to evolving scientific insights, technological developments, and shifting economic and geopolitical realities, and should be co-developed through collaboration between policymakers, scientists, industry actors, and civil society to ensure fairness and increase uptake (Lebling et al. 2022, Macreadie et al. 2022, Johnson et al. 2024).

Concretely, policy frameworks must extend beyond a narrow-centered perspective and account for the broader suite of socio-economic and ecological co-benefits of marine systems, including biodiversity conservation, food provision, and coastal protection - for instance through mechanism like the UN SEEA-EA framework (Herr et al. 2017, Hilmi et al. 2021, Grilli et al. 2022, Dauwe et al. 2023, Röschel & Neumann 2023). This implies aligning climate mitigation objectives with ocean governance and biodiversity protection, while recognising and valuing marine carbon as a cross-cutting element linking these domains (Hilmi et al. 2021, Elsler et al. 2022, Johnson et al. 2024).

Cautious early entry points for such integration are starting to emerge. At the European level, initiatives such as the CRCF Regulation, the revision of the LULUCF Regulation, the Nature Restoration Regulation and the Ocean Pact create opportunities to develop certification mechanisms, integrate carbon considerations into marine spatial planning, and stimulate research and innovation into holistic ocean observation. Internationally, ongoing developments under the UNFCCC, including evolving Article 6 mechanisms, signal a gradual shift towards more comprehensive and standardised carbon accounting systems, although marine applications remain limited to date.

> ***"Future ocean-based climate action depends on bridging fragmented governance, MRV and carbon accounting***

4.6 BERNARDO's contribution

By establishing a detailed marine carbon budget for a shelf sea (the Belgian North Sea), BERNARDO provides a scientifically robust baseline for understanding marine carbon dynamics and distinguishing signals from common anthropogenic user functions (e.g. dredging, aquaculture, etc.) from natural variability. The results of BERNARDO also offer direct policy relevance as its methodologies and datasets provide a solid foundation for the development of novel MRV systems, support the advancement of transparent and credible marine carbon accounting, and create entry points for integrating carbon into policy instruments such as marine spatial planning, environmental impact assessments, and carbon certification frameworks. BERNARDO hence demonstrates how targeted science-industry collaboration can unlock innovations in policy, industry and emerging environmental-economic accounting frameworks, and in doing so provide valuable tools to guide the transition towards a sustainable future for the ocean and the people who depend on it.

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6. Addendum

UN 2030 Agenda for Sustainable Development

Core objective: Achieving the 17 sustainable development goals by 2030 while leaving no-one behind

Geographic scope
Global

Legal status
Non-binding

Focus
Sustainable development

Carbon mentioned
Yes

Relevance for mCDR
Pushes for the realisation of the Paris climate goals, but not at the expense of environmental degradation.

The protection and restoration of blue carbon ecosystems is primarily supported from a climate adaptation perspective.

mCDR types
Nature-based mCDR

In 2015, the international community adopted Transforming Our World: the UN 2030 Agenda for Sustainable Development. The plan articulates the commitment to collectively build a world without poverty by 2030, find sustainable and inclusive development solutions and ensure everyone's human rights without leaving anyone behind. The Agenda formulated 17 Sustainable Development Goals (SDGs) and 169 targets. These targets are interconnected, balancing economic, social and environmental elements to the overarching sustainability target. Together with the Paris Agreement on Climate Change (see **3.1.1 Global climate frameworks p. 30**) the Agenda is one of the key global frameworks for international cooperation on sustainable development. However, at the same time, the goals of both frameworks should be regarded more as a declaration of intent rather than a roadmap specifying how the objectives should or could be achieved. This rather non-committal approach has a.o. contributed to uneven progress and indications that intensified efforts will be required to achieve all targets in time by 2030 (Sustainable Development Report 2025, Our World in Data - SDG tracker).

Marine climate action and protection through the SDGs

The Agenda recognises climate change as one of the most serious threats to sustainable development. Therefore, the Agenda addresses climate change and its harmful consequences in a dedicated climate-SDG: SDG 13 - *take urgent action to combat climate change and its impacts*. Its objectives tackle both mitigation and adaptation with a focus on strengthening resilience to climate-related hazards and natural disasters by ensuring that mitigation and adaptation measures are effectively integrated into national policies, strategies, and planning processes, thereby actively supporting the realisation of the targets of the Paris Agreement (see **3.1.1 Global climate frameworks p. 30**). SDG 13 also calls to strengthen education, awareness, and institutional capacity for climate action and aims to build planning and management capacity in least developed countries and small island developing states, with attention to women, youth, and marginalised groups[59].

[59] To assist in carrying out these actions, developed countries pledge to provide vulnerable countries with the necessary financial resources, for instance through the annual mobilisation of 100 billion dollar and the Green Climate Fund.

“ Multiple SDGs are connected through coastal blue carbon ecosystems

In addition to a major climate focus, the international community recognises that sustainable social and economic development relies on healthy and sustainably managed natural resources, both terrestrial and marine.

The marine environment is addressed by SDG 14 Life below water: Conserve and sustainably use the oceans, seas and marine resources for sustainable development, calling for the implementation of paragraph 158 of "The future we want" (Declaration UN Sustainable Development Conference Rio 2012). SDG 14 also promotes marine science and technological development to the benefit of ocean health and society. Particularly relevant from a climate perspective are SDG 14.2 and SDG 14.3. SDG 14.2 focuses on the sustainable management and protection of marine and coastal ecosystems and for increased restoration efforts to achieve healthy, resilient and productive ecosystems. SDG 14.3 aims to minimise the impact of ocean acidification, including through improved scientific cooperation.

SDG-linking blue carbon ecosystems

However, SDG 13 and SDG 14 cannot be viewed or approached in isolation to the other SDGs (SDGs, Griggs et al. 2014). Particularly coastal blue carbon ecosystems (mangroves, salt marshes, seagrass ecosystems) illustrate this connection (Hoegh-Guldberg & Northrop 2023), as they are situated at the land-sea interface with a tendency to provide a variety of ecosystem services (e.g. carbon sequestration, bottom stabilisation, wave attenuation, food production, etc.), therefore receiving much attention within the United Nations' 2030 Agenda for Sustainable Development as a nature-based solution (NbS) (SDG 14, UNEP 2021, Schindler Murray et al. 2023). As such, they can be linked to SDG 1.5, aiming to reduce the exposure and vulnerability of the world's poor to climate-related extreme events, or SDG 2.4, focusing on strengthening the resilience of the worlds food production systems to climate change. Additionally, SDG 6 *Clean Water and Sanitation*, through target 6.6, is also relevant as it seeks to protect and restore water-related ecosystems.

IMO Net Zero Framework

Core objective: Moving international maritime transport to climate neutrality by 2050

Geographic scope
Global

Legal status
Non-binding (yet)

Focus
Emission reduction

Carbon mentioned
Yes

Maritime transport accounts for approximately 2% of global anthropogenic greenhouse gas emissions and thus contributes significantly to climate change (IMO, IPCC 2023). Emissions from the maritime transport sector are regulated at the international level by the International Maritime Organization (IMO), whose legal framework is grounded in the United Nations Convention on the Law of the Sea (UNCLOS 1982) (see **3.2.1 International ocean frameworks p. 42**). UNCLOS obliges states to prevent, reduce, and control marine pollution, including pollution from or through the atmosphere. In parallel, global climate commitments such as the Paris Agreement (see **3.1.1 Global climate frameworks, p. 30**), while not setting sector-specific targets, have created international momentum and pressure towards a gradual tightening of emission standards for all greenhouse gases associated with maritime transport (primarily CO_2, CH_4, and N_2O).

The IMO's decarbonisation strategy is set out in the (draft) IMO Net Zero framework (2025), which is the regulatory response to the objectives delineated in the 2023 IMO Strategy on the Reduction of GHG Emissions from Ships. This Net Zero framework seeks to provide a legally binding framework within which the transition to net-zero emissions by around 2050 is to be achieved[60,61]. In practice, the maritime sector intends to decarbonise by combining gradually more stringent emission limits with a pricing and reward mechanism. However, a vote to set the concrete measures and targets was postponed in October 2025, resulting in continued uncertainty regarding the eventual measures and targets. Once agreed upon, the regulation could enter into force as early as 1 March 2028 and would govern approximately 85% of emissions from international shipping[62]. Upon acceptance, the Net-Zero Framework would be incorporated into Annex VI of the MARPOL Convention[63] on the prevention of air pollution and energy efficiency of ships.

[60] Emissions are based on a greenhouse gas fuel intensity (GFI) metric defined as how much greenhouse gases are emitted for one unit of energy from well (source) to wake (combustion at the ship). Ships are obliged to reduce their GFI over time and in case of excesses, buy 'remedial units' to balance its deficit. Ships using zero or near-zero technologies can be financially rewarded.

[61] The framework applies to ships of the international trading fleet from over 5,000 GT.

[62] Proceeds flow to the IMO Net-Zero Fund and be used to further the greening of the maritime sector.

[63] The International Convention for the Prevention of Pollution from Ships (MARPOL) was adopted by the IMO in 1973 (MARPOL 73/78). Initially focusing on oil pollution from shipping (MARPOL Protocol 1978), the Convention continuously expanded to include different forms of pollution related to maritime activities. MARPOL Annex VI, adopted in 2005, establishes limits on air pollutants from ships such as sulphur oxides (SOx), nitrogen oxides (NOx), and particulate matter. It also prohibits the use of ozone-depleting substances, regulates shipboard incineration and sets standards for fuel oil quality. In 2011, it has been expanded to include measures addressing greenhouse gas emissions, notably the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII) (IMO).

FuelEU Maritime Regulation

Core objective: Reduce the GHG intensity of maritime shipping in the EU

Geographic scope
EU

Legal status
Binding

Focus
Reduction of GHG intensity

Carbon mentioned
Yes

In the EU, emissions from maritime transport are incorporated into the Emissions Trading System (EU ETS, see **6.2.2 European frameworks, p. 89**), implying that ships calling at European ports have to monitor and report their emissions and purchase and surrender EU allowances for each tonne of reported CO_2 emission. From January 1 2026 this is extended to methane (CH_4) and nitrous oxide (N_2O). Despite having a clear regulatory framework and short-term financial impact it is considered to be unlikely the ETS system will enforce sufficient incentives to substantially shift the consumption towards renewable fuels (e.g. methanol, hydrogen, ammonia). Therefore, the FuelEU Maritime Regulation (Regulation (EU) 2023/1805) was developed to promote the use of renewable, low-carbon fuels and clean energy technologies in ships. The regulation requires vessels above 5,000 tonnes calling at European ports to reduce their GHG-intensity by 80% by 2050 and connect to onshore power supply while moored (unless they use another zero-emission technology). This target-based approach enables ship-specific or operation-specific greening strategies.

Methane Regulation

Core objective: Reducing anthropogenic methane emission in Europe and abroad

Geographic scope
Global

Legal status
Binding

Focus
Methane emissions

Carbon mentioned
CH_4

Methane (CH_4) is the second most important greenhouse gas after CO_2. It's warming potential however, is substantially higher with CH_4 estimated to be 82,5 times more potent over a 20 year period. On the contrary, the atmospheric residence time is about 10-12 years compared to hundreds of years for CO_2 (EC Methane emissions). Hence, abating CH_4 is considered as a quick win for the global climate. It is estimated that reducing methane emissions by 45% by 2030 could avert approximately 0,3 °C of warming by 2045 (IPCC 2023). At the international level, methane emission reduction efforts fit within the overarching pledge of the Paris Agreement to reduce greenhouse gas (GHG) emissions.

In the EU, the reduction of methane emissions are part of the GHG reduction targets as agreed under the Climate Law (Regulation (EU) 2021/1119). To specifically address methane emissions, the EU adopted the Regulation (EU) 2024/1787 which implements the Methane Strategy (COM (2020) 663) under the broader EU Green Deal framework (EC Methane emissions).

This Regulation sets out specific rules on:

- Methane emissions monitoring and reporting across upstream, midstream, and downstream operations.
- Regular leak detection and repair (LDAR) obligations for infrastructure operators.
- Ban on routine venting and flaring of methane.
- Methane import transparency rules, including reporting for third-country exporters.
- Creation of global methane monitoring tool and a methane transparency database based on satellite data.

For its implementation, the Commission will provide technical rules on the measurement and reporting methodologies, leak detection and repair frequency and technology requirements along with templates for importers' emission inventories. The targeted improved transparency on emissions aims to push a reduction in CH_4 emissions both in Europe and across global supply chains. In addition, progressively more stringent requirements on methane intensity[64], are designed to push exporting countries into applying the European MRV standards.

[64] The ratio of methane emitted per unit of fuel produced. No detailed methodology, nor targets are currently available.

> *"Mitigating methane emissions is a quick win for the global climate*

Starting in 2026/27, methane emissions in the European Union will be governed simultaneously by two distinct policy instruments: the EU Methane Regulation and the market-based Emissions Trading System (ETS) (see **6.2.2 European frameworks p. 89**). Both instruments apply to methane released across the extraction, transportation and end-use phases of fossil fuel supply chains. These parallel regulatory frameworks however, result in a set of inconsistencies[65].

[65] Three main inconsistencies arise from the parallel application of the EU Methane Regulation and the EU ETS. First, gaps in policy scope mean that several methane sources associated with LNG shipping such as boil-off gas, fugitives and vents during loading, unloading and transport risk remaining unregulated. Second, the two instruments employ divergent approaches to MRV: the Methane Regulation prioritises direct measurement, whereas the ETS relies largely on calculation-based methods and default emission factors, raising uncertainty regarding methane estimates with direct financial implications. Third, differences persist in the Global Warming Potential values used to convert methane to CO_2-equivalent.

Effort Sharing Regulation (ESR)

Core objective: Annual binding GHG emission targets in non-ETS sectors for 2021-2030

Geographic scope
EU

Legal status
Binding

Focus
Emission reduction

Carbon mentioned
Yes

The Effort Sharing Regulation (Regulation (EU) 2023/857) sets binding national targets for emissions reductions in sectors (e.g. agriculture, small industries, buildings, waste, road transport, etc.) that are not covered by the EU's Emission Trading System (ETS, see **6.2.2 European frameworks p. 89**). Recognising differences in national emission levels, and capacities of countries to reduce emissions, state-specific targets are set that take GDP per capita and cost-efficiency into account. Overall, a 40% emissions reduction has to be realised by 2030 compared to 2005 levels.

The system works on the premise that the agricultural sector has limited capacity to reduce emissions, and as such the ESR contributes to stronger climate action in the LULUCF sector (Böttcher et al. 2019, Chiocchetti et al. 2023). In practice, an internal offsetting mechanism allows MS to balance their agricultural emissions by using carbon removal units from LULUCF based mitigation measures to meet their ESR targets. Conversely, if the LULUCF sector fails to achieve its carbon removal goals, countries can adjust by reducing or cancelling a portion of their annual emission allowances under the ESR (Böttcher et al. 2019). Critics argue that this approach weakens the climate efforts by relying too heavily on uncertain carbon storage in the LULUCF sector rather than on concrete emission reductions measures (Brandt & Trunk 2016, Chiocchetti et al. 2023).

Emission Trading System (ETS)

Core objective: Establish a cap-and-trade system to reduce GHG emissions from energy-intensive industries, aviation and power production

Geographic scope
EU

Legal status
Binding

Focus
Emission trading

Carbon mentioned
Yes

Europe's Emissions Trading System (ETS) is a cap-and-trade system to reduce carbon emission via a carbon market approach as allowed under Article 6[66] of the Paris Agreement (see **3.1.1 Global climate frameworks p. 30**). It follows the 'polluter-pays principle' and currently covers circa 40% of all of Europe's GHG emissions, It's focus lies on abating emissions from major CO_2-polluting industries (e.g. power plants, aviation, energy- intensive industry), including the maritime sector[67] (included from 2024) (Scope of EU ETS, Reducing emissions from the shipping sector, Brandt & Trunk 2016). The target is to reduce GHG-emissions from ETS-sectors by 61% by 2030 compared to 2005 levels. The revenue from the EU ETS mainly flows to national budgets, and MS are required to use all of it to finance investments in renewable energy, energy efficiency, and low-carbon technologies. In addition, part of the EU ETS revenue supports low-carbon innovation and the broader energy transition across the EU through the Innovation Fund and the Modernisation Fund, or supports potentially vulnerable communities through the Social Climate Fund. The ETS systems allows to link with cap-and-trade systems worldwide. Hence, buyers or sellers in one system can buy or sell carbon credits from another system for compliance purposes (EC International carbon market). The ETS system imposes strong requirements on monitoring, reporting and verification (MRV). The annual MRV compliance cycle has to be robust, transparent, consistent and accurate and comes with a suite of regulations preventing market abuse (EC MRV).

ETS and marine carbon credits

Carbon credits generated by carbon storage from coastal blue carbon ecosystems are not eligible for credits traded under the EU regulated ETS (EU ETS Phase 4). They are however explicitly considered for integration into the EU's new voluntary market mechanism, the CRCF Regulation (see **3.1.2 European climate frameworks p. 35**). The main barriers constraining the integration of marine carbon sequestration into regulated market mechanisms, while simultaneously remaining a contentious issue in voluntary markets, are the scientific uncertainties on durable carbon storage and the need for clear,

[66] Also establishes a framework for standardised carbon accounting rules.

[67] For all large ships of 5,000 gross tonnage and above entering EU ports.

“ The ETS operationalises the polluter pays principle through a carbon market approach

standardised requirements on MRV to allow robust carbon accounting practices (Van Dam et al. 2024, EMB 2025). A challenge the EU intends to improve by its recently developed Blue Carbon Roadmap (Wartman et al. 2025). This roadmap, which is fully aligned to EU's climate strategies, seeks to support the implementation of blue carbon ecosystems into carbon and natural capital markets by setting out a strategy to address the most pressing knowledge and data gaps.

6.3 Emission avoidance frameworks

6.3.1 International CCS frameworks

The carbon capture and storage technique is a technique where gaseous carbon from industry or the power sector gets captured before its release into the atmosphere whereafter it becomes permanently stored in impermeable geological formations[68] (IPCC 2005)[69]. The concept is particularly interesting to abate the climate impact of hard to electrify industrial activities like the steel, cement, metal and oil and gas industry (IEA 2011, IOGP 2019, Townsend et al. 2020, IEA 2019, IEA 2021). The IPCC considers CCS techniques[70] in its emission scenarios and acknowledges its potential in realising the climate targets of the Paris Agreement (IPCC 2019).

Advances in the international, regional and national law and regulations for CCS were triggered by the IPCC Special Report on Carbon Dioxide Capture and Storage (IPCC 2005). This Special Report explored legal and regulatory issues around geological storage of carbon with a special focus on the London Convention (see **3.2.1 Global ocean frameworks p. 40**) and the OSPAR Convention (see **3.2.2 Regional and European ocean framework p. 46**). Following the CCS report, the IPCC added CCS accounting guidelines in its 2006 'IPCC Guidelines for National Greenhouse Gas Inventories' (IPCC 2006)[71,72], providing a methodology for geological storage monitoring and reporting. The IPCC guidelines influenced several regulatory developments, and led to the inclusion of CCS into the Clean Development Mechanism (CDM)[72] of the UNFCCC Kyoto Protocol. This inclusion expanded the application of CCS as a tool to meet national emission targets to developing countries.

[68] Formations that are situated at 800 m depth or more where the pressure and temperature transform CO_2 into a dense phase gas or supercritical fluid (Marston & Moore 2008).

[69] In case carbon gets captured before it reaches the atmosphere, CCS is considered an emission avoidance strategy. If it is used in combination with Direct Air Capture (DACCS) or Bio-energy production (BECCS) it is considered as a CDR-technique.

[70] For a broader discussion of the CCS technique see Dauwe et al. (2021).

[71] These emission accounting guidelines form the basis for Annex I countries (developed countries) within the UNFCCC for their annual GHG-inventories.

[72] Where CO_2-emissions are captured from industrial processes or large combustion sources, emissions should be allocated to the sector generating the CO_2 unless it can be shown that the CO_2 is stored in properly monitored geological storage sites.

[73] The CDM was the first global environmental investment and credit scheme that provided standardised emission reduction credits that can be counted towards a country's Kyoto Protocol targets. A carbon credit could only be issued in case the projected emission reduction was real, measurable, verifiable and additional to what would have occurred without the CDR activity.

EU Carbon Capture and Storage Directive

Core objective: Regulating CCS in the EU

Geographic scope
EU

Legal status
Binding

Focus
CO_2 storage

Carbon mentioned
Yes

Relevance for mCDR
Allows for the geological storage of captured carbon within the EU, including in EEZ and continental shelves.

mCDR types
CO_2 storage

To address the lack of regulation, issues on property rights and long-term liability of stored CO_2 as identified by the Special Report on CCS (IPCC 2005), the EU developed the CCS Directive (Directive 2009/31/EC). The Directive provides the enabling legal framework for the safe geological storage of CO_2 while safeguarding the protection of the environment[74]. The directive was pivotal in transferring responsibility from the operator to the state once evidence of safe and permanent CO_2 storage is provided, thereby significantly endorsing the uptake of the technique (Article 17-18). The directive applies to all CO_2 storage in geological formations within the EU, starting from a projected storage volume of 105 tonnes of CO_2, and covers the entire lifetime of the storage sites.

Implementation of CCS in Europe

Prior to the European Green Deal (COM (2019) 640) CCS was stimulated through the inclusion of the CCS Directive into the ETS Directive (Directive 2003/87/EC)[75] (see **6.2.2 European frameworks p. 89**), effectively stimulating CCS through a carbon pricing mechanism[76]. In 2024, under the Carbon Removals and Carbon Farming Certification (CRCF) Regulation (see **3.1.2 European climate frameworks p. 35**), a voluntary carbon certification framework followed, allowing the certification of carbon by Carbon Capture and Utilisation (CCU).

Further steps to implement CCS in Europe were accelerated by the introduction of the EU Green Deal (COM (2019) 640). Within the framework of the Green Deal, the European Commission developed a new industrial strategy (COM(2020) 102)[77]. This strategy outlined a path towards a green, digital, and competitive European industrial landscape by 2050. This new industrial strategy builds on seven key pillars with the importance of CCS highlighted in the pillars related to the circular economy, industrial innovation, and carbon neutrality.

[74] CCS can proceed in case of no significant risk of CO_2 leakage or harm to public health or the environment, and that no effects arise that could compromise the safety of transport networks or storage sites.

[75] Currently amended by Directive (EU) 2023/959.

[76] According to Article 12 (3a), states don't need to surrender allowances in case emissions have been verified as captured and transported for the purpose of permanent storage and if all the provisions of the CCS Directive are met. Conversely, EU ETS allowances must be surrendered in the event of CO_2 leakage.

[77] Updated in 2021 in response to the Covid-crisis (European industrial strategy).

Of particular relevance was the Communication on Sustainable Carbon Cycles (COM(2021) 800) which listed key actions to support industrial capture, use and storage of CO_2, including the assessment of cross-border CO_2 infrastructure deployment needs at EU, regional and national levels.

Europe's industrial strategy was recently strengthened by the Green Deal Industrial Plan for the Net-Zero Age (COM(2023) 62). This plan seeks to transform the EU's industrial landscape by focusing strongly on modernisation and reducing emissions from energy-intensive sectors. The new industrial plan is supported a.o. by the Net Zero Industry Act (Regulation (EU) 2024/1735), a law which focuses on the development and implementation of technologies that can quickly and substantially help cut emissions, especially those net-zero solutions with proven technology and that can be brought to scale in the short term. The regulation sets a legally binding EU target to achieve at least 50 million tonnes per year of CO_2 storage capacity by 2030, which, according to the impact assessment on the EU recommended climate target for 2040, has to expand to 280 million tonnes by 2040 (SWD (2024) 63)[78]. Guidance on how to reach these targets are communicated by the Communication on Industrial Carbon Management (COM(2024) 62, Industrial Carbon Management). This communication expresses the EU's desire to develop an integrated internal carbon market that encompasses all components of the value chain and outlines actions to boost investments into industrial carbon management technologies. A critical element in achieving this objective is the establishment of a robust carbon accounting framework for the utilisation of captured CO_2 as a resource in industrial processes.

To effectively facilitate CCS, a whole array of Amendments were introduced in: the Water Framework Directive (Directive 2000/60/EC, see **3.2.2 Regional and European ocean frameworks p. 54**), the Waste Framework Directive (Directive 2008/98/EC) and the Regulation on the Supervision and Control of Shipments of Waste (Regulation (EU) 2024/1157). Moreover, to support the monitoring and reporting of CO_2-emissions resulting from leaks during the capture, transport and storage of CO_2 the EU developed a set of guidance documents.

CCS in Marine Treaties

London Protocol

The London Protocol prohibits the dumping of all wastes and other matter into the sea or storage in the seabed and subsoil, unless those specified in Annex I of the Protocol, in which case permitting, regulation and monitoring are required. Hence, in its original form the London Protocol prohibits CCS with offshore storage.

However, driven by increasing concern about the effects of rising atmospheric CO_2 on ocean health, and in response to the IPCC Special Report on CCS (IPCC 2005), an international expert group evaluated the potential impacts of CCS on the marine environment. The group concluded that risks from subsea carbon storage are localised and relatively minor compared with the impacts of climate change and that potential negative effects can be effectively managed through suitable guidelines and oversight (IMO). Subsequently, in 2006 Annex I of the Protocol was amended to permit CCS with offshore carbon storage in sub-seabed geological formations on the condition that the disposal overwhelmingly consisted of CO_2. Relying on previously released IPCC reports, two Guideline Documents to the Amendment were issued providing the framework for the environmental impact assessment process: the 'Risk Assessment and Management Framework for CO_2 sequestration in Sub-seabed Geological Structures' (RAMF (LC/SG-CO2 1/7, annex 3)) and the 'Specific Guidelines for Assessment of CO_2 Streams for Disposal into Sub-Seabed Geological Formation' (WAG) (LC 34/15, annex 8) (IMO 2006, IMO).

However, despite this enabling Amendment, Article 6 of the LP, prohibits the transfer of waste between countries for dumping or incineration at sea, and as such effectively prevents countries without CCS storage capacity from making use of the provisions of the Amendment. This restriction was eventually removed in 2009 by the IMO (Resolution LP.3(4)) but to this day still awaits ratification. This barrier was later removed in 2019 by Resolution LP.5(14) which stipulated that EU Member States willing to deploy CCS are required to notify the IMO of their intentions and have to cooperate with each other and non-EU partners (notably Norway

[78] EU programs like the Innovation Fund, financed partly by the Emissions Trading System (ETS), are put forward as the main tool to support future CCS projects.

> *"Cross-border CCS cooperation is dependent on bilateral and multilateral agreements on environmental objectives, permitting, and monitoring*

and the United Kingdom) through bilateral or multilateral agreements that set environmental objectives, permitting conditions, and monitoring obligations for CCS to proceed (Carbstrat, IMO)

OSPAR

Acknowledging the harmful impact of high atmospheric CO_2-levels on the ocean's carbon chemistry, the OSPAR Committee instructed a technical and environmental review process into the storage of CO_2 in subsea geological formations (OSPAR 2006). Following the London Protocol's RAMF, OSPAR developed a tailored and refined Framework for Risk Assessment and Management of CO_2-streams in Geological Formations (FRAM) (OSPAR 2007). Subsequently, OSPAR amended Annex II (regulation of dumping) and Annex III (prevention and elimination of offshore pollution) to allow CCS relying on offshore reservoirs (OSPAR Decision 2007/02). Different to the LP Amendments, OSPAR included the provision that CO_2 storage should be permanent and must not lead to adverse consequences for the marine environment, its users and human health.

Further details on CCS's legal and regulatory framework under OSPAR and the London Protocol are provided by Dixon et al. (2015).

Sendai Framework for Disaster Risk Reduction

Core objective: Reduce the risk and impact of major disasters by a.o. enhancing preparedness and investing in effective responses.

Geographic scope
Global

Legal status
Non-binding

Focus
Disiaster resilience

Carbon mentioned
No

Relevance for mCDR
Promotion of nature-based solutions to reduce the risk and impact of natural disasters.

mCDR types
Nature-based mCDR

The Sendai Framework for Disaster Risk Reduction (DRR) 2015-2030 (Sendai Framework) is the UN policy framework guiding global disaster risk reduction efforts until 2030 (UNDRR). It can be considered as today's global strategy to reduce disaster risk. The framework sets out seven concrete targets revolved around four priorities for action: understanding disaster risk, strengthening governance, investing in resilience and enhancing preparedness for effective response and recovery and to "Build Back Better" (Monitoring Sendai Framework). The Sendai Framework calls upon the entire UN system to work together in a coordinated manner around DRR and support countries in building resilience. The framework is coordinated and monitored by the United Nations Office for Disaster Risk Reduction (UNDRR) which developed the UN Plan of Action on Disaster Risk Reduction for Resilience: Towards a Risk informed and Integrated Approach to Sustainable Development to assist Member States in the implementation of the Sendai Framework. The Action Plan serves as the UN's contribution to ensure a risk-informed approach to the achievement of the 2030 Agenda (UNDRR 2030 Agenda).

The Sendai Framework promotes working with nature to reduce disaster risk while keeping ecosystems healthy and resilient and protecting the people. It provides guidance and entry points for the design, implementation, and reporting of nature-based actions that strengthen disaster risk reduction and increase resilience. A vision towards resilience the framework shares with the more recent Kunming-Montreal Global Biodiversity Framework (see **3.3.1 Global biodiversity framework p. 61**) (UNDRR Nature for resilience). As such, both frameworks apply an ecosystem, and integrated risk-informed approach to the protection, conservation, restoration, and sustainable management of nature.

[79] Frameworks without any direct regulatory or legal implications at the climate-ocean-biodiversity policy domain, but which can indirectly contribute to the facilitation of new knowledge or activities valuable within the context of ocean-based carbon removals.

UN Environment Programme (UNEP)

Core objective: Global initiative to help reach and safeguard a healthy, resilient environment for all

Geographic scope
Global

Legal status
Non-binding

Focus
Mitigation and adaptation

Carbon mentioned
Yes

Relevance for mCDR
Helps nations to achieve their climate targets. Underscores the importance of nature-based solutions for climate mitigation and adaptation purposes.

mCDR types
Nature-based mCDR

Founded in 1972, the United Nations Environment Programme (UNEP) is the leading global authority on the environment focusing on providing a strong international response to the triple planetary crisis (climate change, nature and biodiversity loss and pollution and waste). UNEP hosts the United Nations Environment Assembly (UNEA), the world's highest-level decision-making body on the environment, with a universal membership including all 193 UN Member States. It sets priorities for global environmental policies and guides international environmental law to preserve and rehabilitate our environment and as such is an instrumental part of the 2030 Agenda for Sustainable Development. (see **6.1 UN 2030 Agenda for Sustainable Development p. 82**) (UNEP Sustainable Development Goals).

UNEP Climate action

In the context of global climate change UNEP's activities strongly support three key international initiatives: the Paris Agreement (see **3.1.1 Global climate frameworks p. 30**), the Convention on Biological Diversity (CBD, see **3.3.1 Global biodiversity framework p. 60**) and the UN Agenda for Sustainable Development 2030 (see **6.1 UN 2030 Agenda for Sustainable Development p. 82**). In supporting the Paris Agreement, UNEP assists its MS in monitoring and implementing their commitments under the Agreement. Although UNEP does not set climate targets, it does provide strategic guidance through for instance dedicated reports on climate scenario's and emission pathways (UNEP repository, UNEP Climate action). In addition, UNEP supports improved climate resilience focused on ecosystem-based adaptation through nature-based solutions like a.o. the restoration of coastal blue carbon ecosystems or the protection of marine biodiversity, thereby supporting progress toward both SDG 13 (Climate Action) and SDG 14 (Life Below Water).

UNEP Oceans

From an ocean perspective, UNEP acknowledges the critical importance of a healthy ocean to protect economic assets, enrich biodiversity and improve the resilience of the planet and society. As a general assumption, maintaining ecosystem integrity is considered crucial for the continuous supply of societally relevant ecosystem services and contributes to all 17 SDGs and the targets set within the Kunming-Montreal Global Biodiversity Framework (see **3.3.1 Global biodiversity frameworks p. 61**). Hence, UNEP works to protect, conserve and restore healthy and productive blue ecosystems and their biodiversity. In its approach, UNEP aims to unify environmental, economic, and social dimensions to support effective decision-making and to implement management solutions that allow for the sustainable use of marine and coastal ecosystems.

Nature-based solutions and integrated ecosystem-based management serve as core guiding principles for safeguarding and restoring marine ecosystems. Within this context, blue carbon ecosystems (here considered as mangroves, seagrass, seaweed and salt marshes) occupy a prominent role as they represent a powerful and direct linkage between climate action, nature protection and societal well-being (Macreadie et al. 2021, Schindler Murray et al. 2023, Simpson & Smart 2024). One way UNEP assists in their protection and restoration is by providing targeted reports on how to sustainably manage and restore these multi-purpose ecosystems (UNEP-Ocean, seas and coasts).

In addition to climate action and marine conservation and restoration, countries are increasingly looking to develop their blue economy, whilst complying with inter-connected targets such as the SDGs and those established in, the Global Biodiversity Framework, and the Paris Agreement. UNEP seeks to support countries and businesses in shifting towards a sustainable, resilient and equitable blue economy where blue economic activities don't harm the marine environment. For instance, in the vein of integrated ecosystem management, its Sustainable Blue Economy Transition Framework adopts a holistic - a so-called 'whole-of-government approach' - to governing human interactions with ocean, coastal and inland water systems. This approach should enable a fair distribution of economic and social benefits, protect ecosystems from further degradation and promotes the restoration of those already affected.

The Regional Seas Programme

UNEP's Regional Seas Programme is designed to foster collaboration across marine regions to strive for region-specific actions that benefit the management and protection of shared marine and coastal environments. The programme covers 18 regions which have adopted regional action plans backed by a legal framework in the form of a regional convention and thematic protocols, collectively known as the Regional Seas Conventions and Action Plans (RSCAPs) (e.g. the OSPAR Convention and the North-East Atlantic Environment Strategy (NEAES) 2030 see **3.2.2 Regional and European ocean frameworks p. 46**). The Programme a.o. intends to strengthen the climate resilience of ocean management strategies, helping vulnerable regions adapt to escalating climate pressures and protect marine biodiversity as a foundation for a sustainable future.

To guide RSCAPs in delivering the marine dimensions of UNEP's core objectives (mitigating climate change, halting biodiversity loss and pollution) and promoting sustainable livelihoods, UNEP issues periodic Regional Seas Strategic Direction Reports. These reports additionally support alignment with the ocean-related targets of the SDGs and the Global Biodiversity Framework. The most recent edition, *Regional Seas Strategic Directions 2022-2025* (UNEP 2021), provides a consolidated assessment of progress across the 18 Conventions and Action Plans. It examines how their respective activities are being translated into a coordinated global response to major environmental pressures, with the overarching goal of advancing a pollution-free, resilient and biodiverse ocean.

UNESCO World Heritage Convention

Core objective: The protection of global sites with 'Outstanding Universal Value' - whether natural or cultural

Geographic scope
Global

Legal status
Binding

Focus
Conservation

Carbon mentioned
No

Relevance for mCDR
The protection of coastal blue carbon ecosystems under the Convention is driven by their natural value resulting in societally relevant ecosystem services.

mCDR types
Nature-based mCDR

The Convention Concerning the Protection of the World Cultural and Natural Heritage (UNESCO World Heritage Convention, Paris 1972) is a global treaty for the protection of cultural and natural heritage of Outstanding Universal Value (OUV) (Article 1), thereby contributing indirectly to biodiversity conservation through the protection of these natural sites. By ratifying the Convention, countries pledge to conserve designated World Heritage Sites and national heritage of cultural or natural value situated within its territory[8]. When accepted as a site of OUV, countries are required to develop and implement an adequate management plan to ensure its protection and monitoring. If well planned and sustainably managed, these OUV-sites can generate significant financial opportunities for the direct area and surrounding communities, for instance through sustainable ecotourism. Moreover, inclusion on the Heritage list often acts as a catalyst, fostering enhanced conservation measures and raising public and institutional awareness of the exceptional natural and/or cultural value of these and similar areas.

The World Heritage Convention seeks to strengthen international nature conservation by aligning itself with other leading environmental protection frameworks such as the Convention on Biological Diversity (CBD) (see **3.3.1 Global biodiversity frameworks p. 60**) and the Sustainable Development Goals (SDGs) (see **6.1 UN 2030 Agenda for Sustainable Development p. 82**).

Today, the UNESCO World Heritage List contains 51 marine sites across 37 nations. Together, they comprise at least 21% of the global area of blue carbon ecosystems which contain carbon stores equivalent to 10% of global greenhouse gas emissions in 2018 (Duarte et al. 2021, Heritage List). UNESCO supports research into these sites and applies the findings into conservation practice, including measures to strengthen climate resilience. Explorative research into blue carbon opportunities, such as revenue generation through blue carbon credits associated with restoration activities, is also part of its scope. To provide strategic direction to its marine research component, UNESCO developed an *Ocean Science Roadmap* within the framework of the UN Ocean Decade (see **6.4.1 International frameworks p. 100**), highlighting critical research gaps that challenge the sustainable protection of marine World Heritage sites (UNESCO 2021).

[80] For which they receive funding through the World Heritage Fund.

UN Decade on Ecosystem Restoration 2021-2030

Core objective: Preventing and reversing the degradation of earth's ecosystems

Geographic scope
Global

Legal status
Non-binding

Focus
Restoration

Carbon mentioned
Yes

Relevance for mCDR
Boosting the restoration of marine ecosystems to achieve a healthy and resilient ocean

mCDR types
Nature-based mCDR

Acknowledging that healthy ecosystems are crucial for answering major global challenges like food security, protecting biodiversity or fighting climate change and acknowledging the need to drastically speed up the global restoration of degraded ecosystems, the UN General Assembly declared 2021-2030 the UN Decade on Ecosystem Restoration. The aim is to prevent, halt and reverse the degradation of ecosystems on every continent and in every ocean. To support the implementation of the UN Decade on Ecosystem Restoration, and promote a shared vision for restoration, a set of documents detailing general and ecosystem-specific restoration principles were developed (IUCN 2021, FAO IUCN CEM & SER. 2021, UNEP 2021, UNEP-Oceans and Coasts). Coinciding with the UN Decade of Ocean Science for Sustainable Development (2021-2030) (The Ocean Decade), the international community anticipates that both initiatives will mutually reinforce one another and strengthen the collective ambition of achieving healthy oceans by 2030 (UN SDG 14, Claudet et al. 2020).

UN Decade of Ocean Science for Sustainable Development 2021-2030

Core objective: Boosting the development of "the science we need for the ocean we want" in support of the achievement of SDG 14

Geographic scope
Global

Legal status
Non-binding

Focus
Knowledge building and valorisation

Carbon mentioned
Yes

Relevance for mCDR
Stimulates multidisciplinary research into a.o. ocean-based climate action

mCDR types
Nature-based mCDR, engineered mCDR, CO_2-storage

In December 2017, the United Nations General Assembly (UNGA) adopted Resolution A/RES/72/73, proclaiming 2021-2030 the global "United Nations Decade of Ocean Science for Sustainable Development". This 'Ocean Decade' serves as a common framework to ensure that ocean research can effectively support nations in achieving SDG 14 (see **6.1 UN 2030 Agenda for Sustainable Development p. 82**) and is to trigger a revolution in ocean science. The Ocean Decade's research is structured around ten overarching "Challenges[81]" reflecting the most pressing priorities. Among those, challenge 5 is dedicated to ocean-based climate action as it promotes scientific advancements to 'Unlock ocean-based solutions to climate change'. However, the climate issue can be regarded as one of the transversal themes running through the different Decade Challenges. The challenges are to be addressed through a suite of endorsed Actions, Programmes, Contributions, and Projects (Decade Actions).

At the request of the UNGA, the Ocean Decade is managed by the Intergovernmental Oceanographic Commission (IOC)[82] of UNESCO, which for its implementation developed an Ocean Decade Implementation Plan through close consultation with Member States, UN bodies, and relevant stakeholders. The plan provides a collaborative framework to stimulate transformative initiatives that contribute to science-based solutions in support of achieving the 2030 Agenda and the realisation of a resilient, productive, sustainable and inspiring ocean. In support of the Ocean Decade, also ten white papers dedicated to each challenge were developed to provide strategic guidance to ensure the challenges are met in time (Vision 2030). On a European level, the European Commission (DG RTD) developed a roadmap that outlines how the EU will structure and improve its cooperation with the IOC to produce the 'science we need for the ocean we want' (DG RTD, IOC UNESCO 2024).

[81] The ten challenges are: 1. Understand and beat marine pollution; 2. Protect and restore ecosystems and biodiversity. 3. Sustainably nourish the global population; 4. Develop a sustainable, resilient and equitable ocean economy; 5. Unlock ocean-based climate solutions; 6. Increase community resilience to ocean and coastal risks; 7. Sustainably expand the Global Ocean Observing System; 8. Create a digital representation of the Ocean; 9. Skills, knowledge, technology and participation for all; 10. Restore humanity's relationship with the ocean.

[82] IOC-UNESCO is the leading international body tasked with promoting international cooperation in marine sciences anchored in the principle of sustainability and fair progress. A key instrument to fulfill its mandate is its annual *State of the Ocean Report* which has the ambition to inform policymakers about the state of the ocean and stimulate research and policy actions towards 'the ocean we need for the future we want', contributing to the 2030 Agenda as well as other global processes such as the UNFCCC (see **3.1.1 Global climate framework p. 29**), the Convention on Biological Diversity (see **3.3.1 Global biodiversity frameworks p. 60**) and the Sendai Framework for Disaster Risk Reduction (see **6.4.1 International frameworks p. 95**) (IOC UNESCO State of the Ocean Report 2024).

Mission Restore our Ocean and Waters by 2030

Core objective: Protect and restore the health of EU's Ocean and waters, while supporting a sustainable blue economy

Geographic scope
EU

Legal status
Non-binding

Focus
Protection and restoration

Carbon mentioned
Yes

Relevance for mCDR
Climate targets have to be realised without jeopardising the quest for sustainability and healthy oceans.

mCDR types
Nature-based mCDR

To enhance the effectiveness of the Horizon Europe Programme[83], thematic EU Missions were established. These thematic missions, of which there are five, are major initiatives setting concrete, time-bound targets leading to focused efforts on five global challenges: climate-neutral and smart cities, adaptation to climate change, cancer, soil health and ocean restoration. The mission approach aims to stimulate collaboration among researchers, policy makers, citizens and other stakeholders and strengthen the diffusion and impact of EU's research and innovation.

Acknowledging the major economic, ecological and societal importance of aquatic ecosystems and the different and severe threats these systems are facing, the EU launched the EU Mission Restore our Ocean and Waters by 2030. Its goal is threefold[84]:

1. Protect and restore marine and freshwater ecosystems and biodiversity in line with the EU Biodiversity Strategy for 2030 (see **3.3.2 European biodiversity frameworks p. 63**).
2. Prevent and eliminate pollution of our ocean, seas and waters in line with the EU Action Plan Towards Zero Pollution for Air, Water and Soil (COM (2021) 400).
3. Make the sustainable blue economy carbon-neutral and circular, in line with the European Climate Law and the vision outlined in the Sustainable Blue Economy Strategy (COM (2021) 240).

The mission operates through area-based 'lighthouses' that cover a particular river or sea basin. Focusing on implementation, these lighthouses act as living labs for demonstrating, deploying and scaling up of promising, innovative technologies.

Alongside 'Mission Ocean', and in support of the EU Green Deal, the European Commission launched the EU Mission on Adaptation to Climate Change aiming to accelerate adaptation efforts and improve climate resilience by assisting regions, cities, and local authorities in preparing for heatwaves, floods, and droughts.

[83] Europe's main research and innovation programme designed to help achieve major international goals like the UN Sustainable Development Goals or climate goals while boosting the EU's competitiveness and growth.

[84] All targets are now taken up into the EU Ocean Pact (Nice 2025).