Carbon Crediting Standards for Technology-Based Carbon Dioxide Removal in Developing Countries

Final Report

Carbon Counts Company (UK) Ltd

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CARBON COUNTS

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Cover photo: Stratos direct air capture facility in construction, TX, July 2025 (Courtesy of 1PointFive)

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Acronyms and Abbreviations

A6.4ER	Article 6.4 Emission Reductions
BECCS	Bioenergy with carbon capture and geological storage
BiCRS	Biomass carbon removal and storage
BTR	Biennial Transparency Reports
CBDR-RC	Common but differentiated responsibilities and respective capabilities
CCP	Core Carbon Principles (IC-VCM)
CCS	Carbon dioxide capture and geological storage
CDM	Clean Development Mechanism
CDR	Carbon dioxide removal
CER	Certified emission reduction (from the CDM)
COP	Conference of Parties to the UNFCCC
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CRCF	EU Carbon Removals and Carbon Farming Certification
DAC	Direct air capture
DACCS	Direct air capture with geological storage
DIC	Dissolved inorganic carbon
dLUC	Direct land use change
DNA	Designated national authority (Article 6)
EAC	Environmental attribute certificate (e.g. RECs)
eCDR	Engineered carbon dioxide removal
ETF	Enhanced transparency framework (Article 13)
ETS	Emissions trading system
EU	European Union
EW	Enhanced weathering
GCC	Global Carbon Council
GHG	Greenhouse gas
ICP	Independent crediting programme
ICTU	Information to enhance clarity, transparency and understanding
IC-VCM	Integrity Council for Voluntary Carbon Markets
iLUC	Indirect land use change
IPCC	Intergovernmental Panel on Climate Change

ITMO	Internationally transferred mitigation outcome
LC/LP	London Convention and London Protocol thereto
LT-LEDS	Long term low emissions development strategy
LULUCF	Land use, land use change and forestry
MPRSA	Marine Protection, Research and Sanctuaries Act
MRV	Measurement, reporting and verification
NCS	Natural climate solutions / nature-based CDR
NDC	Nationally determined contribution
NGHGI	National GHG inventory [of emissions and removals]
OAE	Ocean alkalinity enhancement
OIMP	Other international mitigation purposes
PACM	Paris Agreement Crediting Mechanism (Article 6.4)
REC	Renewable energy certificate
RMP	Rules, modalities and procedures for the Article 6.4 mechanism
SBM	Article 4, paragraph 4, mechanism (PACM) Supervisory Body
TER	Technical expert review (under the ETF)
UIC	Underground Injection Control
UNFCCC	United Nations Framework Convention on Climate Change
VCM	Voluntary carbon market

Executive Summary

The Paris Agreement commits signatory country Parties to the balancing of emissions by sources and removals by sinks of greenhouse gases (GHGs) by the second half of this century, a goal known as 'net zero'. Therefore, as well as deep emission cuts, carbon dioxide removals (CDR)—including natural climate solutions (NCS) and engineered CDR (eCDR; see box below)—are a crucial part of Paris-aligned climate action. CDR can be used to offset ongoing emissions from hard-to-abate sources such as industrial processes, livestock, and aviation. The total contribution of CDR to reaching net zero is estimated to be in the range 7 to 9 gigatonnes (Gt) CO_2 per year.

NCS methods such as forestation are a long-standing approach to climate mitigation, especially for countries of the global south with significant standing stocks of forest carbon. Experiences with nascent eCDR methods are far more limited. Current levels of CDR globally are estimated at around 2.2-2.6 $GtCO_2$/year, of which 99.9% is the result of NCS (afforestation and reforestation). Novel eCDR accounts for just 1.35 megatonnes (Mt) CO_2/year removed. Yet, eCDR could account for 30-50 percent (2.3 to 4.5 $GtCO_2$) of the total CDR effort to reach net zero by mid-century. Significant scale up of CDR, and especially eCDR, is therefore needed to meet ambitious climate goals.

This report considers the role, methodologies and governance arrangements under which carbon credits and carbon markets could be used to build out deployment of eCDR, with an emphasis on developing countries. The overarching aim is to assess the technical readiness for crediting eCDR in the global south, and potential challenges that need to be addressed. It concludes with recommendations and a strategy for possible ways to foster eCDR in developing regions.

Engineered CDR methods covered in this report:

- **Bioenergy with carbon capture and geological CO_2 storage** ("BECCS") or the permanent chemical binding of captured biogenic CO_2 in products ("BECCU"), including **waste-to-energy with CO_2 capture and geological storage** (WtECCS)
- **Direct air capture with geological CO_2 storage** ("DACCS") or the permanent chemical binding of direct air captured CO_2 in products ("DACCU")
- **Biochar use** (e.g. in construction) but excluding where storage takes place in the soil carbon pool (e.g. agriculture use; landscaping)
- **Enhanced weathering** (EW; spreading of calcium- and magnesium-rich silicate rock dust on, for example, agricultural land, in coastal environments or through river liming)
- **Ocean storage** through direct abiotic enhancement of the ocean bicarbonate carbon pool (e.g. via ocean alkalinity enhancement; OAE)
- **Ocean carbon removal and storage** (e.g. electrochemical ocean carbon removal and storage)

Contexts for eCDR in developing countries

Views on the role of eCDR in developing countries are mixed. On the one hand, various groups have voiced concerns over the moral hazards and climate justice implications. On the other hand, some developing countries are showing interest in carbon capture and storage (CCS) with a growing interest in related eCDR methods such as BECCS and DACCS (albeit in some cases possibly conflated). Project developers are also moving forward with creditable eCDR project activities and proposals in developing countries including Brazil, India and Kenya.

Mentions of eCDR in developing country climate plans submitted by selected Parties to the Paris Agreement—the nationally determined contributions (NDCs) and long-term low emission development strategies (LT-LEDS)—are reviewed. Analyses suggests low levels of knowledge or interest in eCDR at present. Many countries envisage a far bigger role for NCS.

Yet, over the medium term, the need for *all* Parties to contribute to the Paris Agreement lends itself towards more ubiquitous distribution of climate action. The situation infers a dual role for eCDR: for developed countries, a hard push towards net zero by 2050 or before; for developing countries, more opportunistic moves that allow them to gain experience and monetize actions through carbon markets according to national circumstances and priorities.

Crediting methodologies for eCDR

Carbon markets, especially the crediting of eCDR project activities, is currently the main means to support eCDR deployment globally. Around 30 eCDR methodologies plus related modules are available from standard setters including independent crediting programmes (ICPs), governmental bodies and international measurement, reporting and verification (MRV) standards (i.e. from the Intergovernmental Panel on Climate Change; IPCC) (Table ES-1).

Table ES-1 Scope and coverage of eCDR methodologies

Standard setter	eCDR Method Scope									
	CO_2 capture + geological storage				Biomass capture + store		Alkalinity/bicarbonate + hydrosphere store			
Name	DACCS	BECCS	WtECCS	BECCU	Bio-oil	Biochar	Enhanced weathering	River liming	Wastewater liming	Ocean alk. enhance.
ACR	✓	~								
Verra/VCS	✓	✓	✓			✓	~			
GCC	✓	✓	✓							
Gold Standard		✓		✓						
Puro.Earth	✓	✓	✓	✓		✓	✓			
Isometric	✓	✓	⚠	✓	✓	✓	✓	✓	✓	✓
Env & Clim. Change Canada	✓									
Alberta	✓	✓	✓							
European Union (EU)	✓	✓	✓	×		✓				
British Standards Institute	✓	✓	×							
IPCC	●	✓	✓	×	×	● (s)	×	×	×	×
Key / Nomenclature										
	✓	Covered		●	Partially covered		~	Under consideration		
	⚠	Uncertain/Possibly		×	Excluded		(s)	Soil storage only		

A review of these methodologies indicates that, within at least the ICPs, an abundance of methodological choices exist covering a continually expanding suite of eCDR methods. Suggestions are that a suitable methodology for crediting eCDR could be found for many different circumstances and applications.

However, the growing suite of eCDR methodologies also reveals the novelty of some methods and related MRV approaches. The following methodological challenges are identified:

- **Complex methodological designs** with many branches and options, and the exact requirements can often be difficult to discern in terms of, among others, eligibility, monitoring, long-term reservoir monitoring, permitting, liability transfer etc.
- **Scientific and technical limitations** in identifying, measuring and quantifying CO_2 drawdown and observing the fate of captured carbon in enhanced carbon reservoirs.
- **Variations in requirements across different eCDR methods**, for example, in terms of the need to monitor enhanced carbon reservoirs, which in some cases is absent, unclear, or reliant on experimental computer models / 'digital twins'.
- **Variations in requirements across standards for the same eCDR method**, for example, differing requirements for geological CO_2 storage site permits.
- **Variation in approaches to permanence and reversals** with some standards applying differing durability labels to different eCDR methods (60+, 100+, 200+, 1000+ years etc), differing non-permanence risk assessments, variations in the use, size and operation of buffer pools and mixed approaches to long-term monitoring, liability for reversals and the transfer of liability to the host jurisdiction. None apply temporary credits or discounted (tonne year accounting) methods to eCDR.
- **Gaps in the coverage by IPCC assessed methods**, which is important in terms of governance under the Paris Agreement and carbon markets thereunder (see next).

Governance of eCDR

The eCDR methods are reviewed in the context of governance needs, applicable laws, and the Paris Agreement rulebook in respect of accounting for NDC achievement and Article 6 cooperation and trading among country Parties. The review finds that:

- **Geological CO_2 storage**: building from 15+ years of experience with CCS, methods of eCDR such as DACCS and BECCS are ready to move forward under carbon markets. A key element is the existence of IPCC assessed methodologies and metrics for the capture, transport and geological storage of CO_2. Some challenges persist in terms of the readiness of developing country legal and regulatory systems to host such activities, and the relevant Article 6 approvals and authorizations.
- **Other forms of CO_2 storage**: less certainty exists over the readiness of these methods due to gaps in MRV frameworks and environmental safeguards. IPCC assessed methodologies and metrics are largely absent, and some legal impediments also exist (e.g. for marine carbon storage under international law).

Conditions in the current Paris rulebook mean that the absence of IPCC assessed methodologies and metrics other than for geological reservoirs hampers the inclusion of eCDR within NDCs, in accounting towards achievement of NDCs, and casts doubt upon their eligibility to generate tradeable units under Article 6. The pending IPCC Methodologies Report on CDR, due in 2027, will be important step in addressing this gap.

More broadly, the treatment of non-permanence and the approaches to address carbon reversals remains untested in respect of NDC accounting, including under circumstances where mitigation outcomes from eCDR may be traded under Article 6 and counted towards another NDC or other relevant mitigation purposes or credited within the VCM without any authorization.

Recommendations

Based on the findings, we recommend international organisations develop a three-part approach to support and foster eCDR in developing countries:

- **Raise awareness, build capacity, implement training**: to help countries improve their basic understanding of eCDR (e.g. relative to CCS) and the mitigation opportunities it presents; to elevate understanding and resolve complexity in deployment (technical, methodological); to manage risks and environmental integrity in terms of oversight (legal, regulatory), which are essential supporting pillars of market creation.
- **Develop tools and products for eCDR assessment and inclusion into NDCs and LT-LEDS**: establish first-of-a-kind guidance on how countries can assess national eCDR technical potential and create tools and standardized formats for inclusion of eCDR in key Paris Agreement documentation (e.g. NDCs; LT-LEDS; Article 6).
- **Pilot eCDR carbon crediting:** with a dual approach covering NDC use for more mature eCDR methods, and results-based climate finance for more nascent types.

Conclusion

Methodological and governance issues notwithstanding, the trading of ITMOs between countries can clearly drive climate action to locations where it is most cost effective. An example is BECCS, where it may be more efficient to deploy the activity in the country of biomass origin and trade the resulting carbon units (e.g. a countries such as Brazil or in South East Asia), rather than ship biomass over long-distances—with significant GHG emissions—in order to generate carbon removals where they should be in demand (because of mid-century net zero targets in, e.g., Europe or Japan). Similar niches may exist for DACCS in locations with high availability of renewable or low carbon intensity and high geological storage potential.

Carbon markets can be pivotal in supporting technology learning and promoting country readiness, following the learning-by-doing strategy outlined above.

1 Introduction

1.1 Backdrop

In contrast to the 1997 Kyoto Protocol, which focussed on limiting developed country emissions, the 2015 Paris Agreement calls upon *all* signatory Parties to, among others:

> "...achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century" (Article 4.1)

The Paris Agreement therefore enshrines *net zero* as the basis for global climate action in these times. Net zero recognizes that global warming is a function of the cumulative stock of long-lived climate pollutants in the atmosphere, rather than simply the rate at which greenhouse gases (GHG) are emitted to the atmosphere (Allen et al. 2009; Matthews et al. 2009; Zickfeld et al. 2009; Meinshausen et al. 2009).

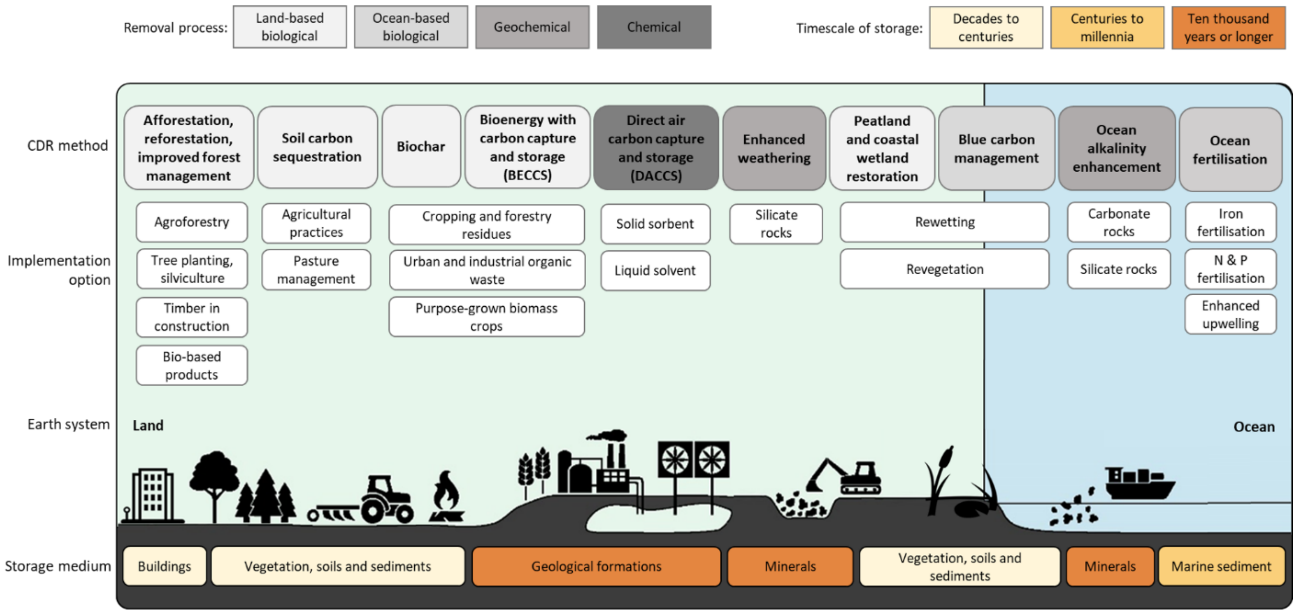
Without completely eliminating all anthropogenic GHG emissions ('absolute zero'), net zero tacitly accepts the need to remove carbon dioxide (CO_2) from the atmosphere and durably store it in enhanced terrestrial and/or aquatic sinks and reservoirs. The drawdown of CO_2 is crucial to counteract the ongoing emissions from hard-to-abate, residual, sources while stabilizing global temperatures. In setting out their nationally determined contributions (NDCs) towards the Paris Agreement's goals, countries are increasingly exploring ways in which they can find a balance between cutting GHG emissions and enhancing GHG removals over the next 25 to 50 years. In the private sector, several corporations are looking at exclusively balancing their emissions with credits originating from CO_2 removal activities, including, Shopify, Stripe and Microsoft (Lütke 2019; Anderson 2019; Smith 2020).

The growing interest in carbon dioxide removal (CDR) in pursuit of net zero prompted Working Group III of the Intergovernmental Panel on Climate Change (IPCC), in its 6th Assessment Report (IPCC 2022; AR6), to dedicate a significant new cross-cutting section to the topic. Therein, the IPCC defined CDR as:

> "Anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical CO_2 sinks and direct air carbon dioxide capture and storage (DACS), but excludes natural CO_2 uptake not directly caused by human activities." (Babiker et al. 2022, p.1261; IPCC 2022, p.1796)

The diagram below is widely used to rapidly convey the scope and diversity of CDR methods that could be used in pursuit of net zero.

Figure 1-1 Taxonomy of CDR



Notes: Main implementation options are included for each CDR method. Specific land-based implementation options can be associated with several CDR methods (e.g. agroforestry can support soil carbon sequestration and provide biomass for biochar or BECCS). Source: Babiker et al. (2022), adapted from Minx et al. (2018).

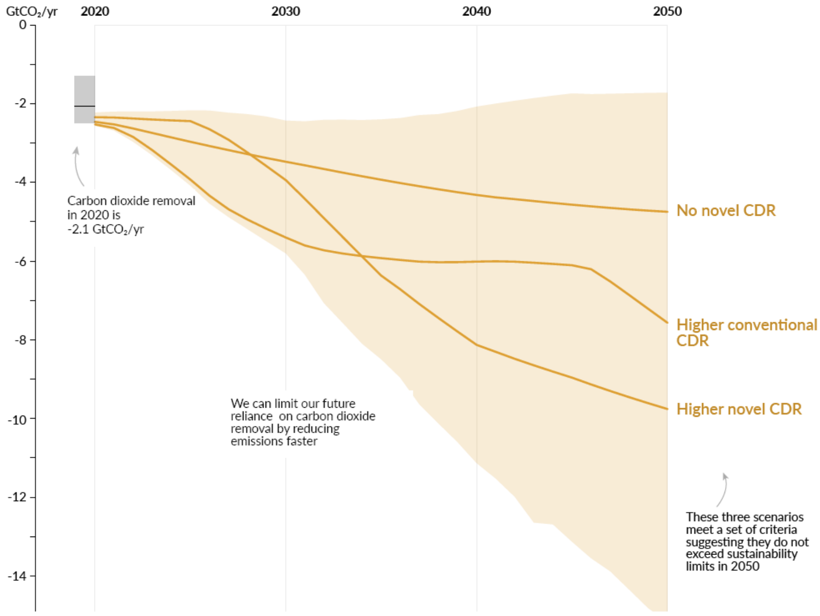
CDR is able to perform three functions in climate action: reducing net emissions in the near term; offsetting unavoidable emissions from hard-to-abate sectors to achieve net zero in the medium term; and, if removals exceed emissions, achieving net-negative emissions in the longer term (including in ‘overshoot' scenarios) (Babiker et al. 2022; Smith et al. 2023).

At the time of achieving net zero atmospheric CO_2, analysis in the IPCC AR6 suggests that global CDR levels could range between **5.5 and 16 gigatonnes (Gt) CO_2/year** under 1.5°C temperature increase limitation pathways (at around mid-century) and between **6.8 and 16 GtCO_2/year** in 2°C pathways (around two decades after mid-century under the 1.5°C pathway) (Smith et al. 2023). According to Smith et al. (2023), almost all scenarios applied in the AR6 envisage a period of net-negative emissions after mid-century.

In an update, Smith et al (2024) landed on a central range of between **7 and 9 GtCO_2/year in 2050** across a range of IPCC-reviewed data aligned with a 1.5°C temperature increase limitation goal (Figure 1-2). Within the range of IPCC scenarios, between **2.3 and 4.5 GtCO_2/year could result from implementation of novel, engineered, CDR**, with the balance being met by conventional, land-based, CDR (Gidden et al., 2024).

Yet, today, human induced drawdown of atmospheric CO_2 is estimated to stand at around 2.2 to 2.6 GtCO_2/year (Smith et al. 2024; Friedlingstein et al. 2025), of which 99.9% is the result of conventional CDR by afforestation and reforestation activities (Smith et al. 2024). Novel engineered CDR methods (see Section 1.3 below) are far less mature, accounting for around only 1.35 *mega*tonnes (Mt) CO_2/year in 2003 (Smith et al. 2024). Significant scale up of engineered CDR is therefore needed to meet ambitious climate targets.

Figure 1-2 Carbon dioxide removal ($GtCO_2$/yr), in 2020 and in three Paris-consistent 1.5°C scenarios



Source: Smith et al. (2024)

1.2 Aim and objectives

This report considers the role that carbon credits and carbon markets could play in building out deployment of ‘novel’ or ‘engineered’ carbon dioxide removal (hereafter, eCDR), with an emphasis on developing countries.

The overarching aim is to assess the technical readiness for crediting eCDR in developing countries, taking account of the supporting elements including methodological, monitoring, measurement, reporting and verification (MRV), and governance and regulatory aspects. The assessment concludes with recommendations and a strategy for possible ways to foster eCDR in developing countries.

The report is structured as follows:

Section 2 Contexts for eCDR in developing countries: why, whether and how developing countries view eCDR at the current time.

Section 3 Stocktake of eCDR methodologies, drawing from historical and current concepts and the implications for deployment in developing countries.

Section 4 Governance for eCDR, including potential gaps, and how these might be addressed by developing countries wishing to host creditable eCDR projects

Section 5 Conclusions and recommendations by which to support eCDR in developing countries.

1.3 Scope

1.3.1 CDR Methods

The following eCDR methods are considered:

- **Bioenergy with carbon capture and geological CO_2 storage** ("BECCS") or the permanent chemical binding of captured biogenic CO_2 in products ("BECCU")
- **Direct air capture with geological CO_2 storage** ("DACCS") or the permanent chemical binding of direct air captured CO_2 in products ("DACCU")
- **Biochar use** (e.g. in construction) but excluding where storage takes place in the soil carbon pool (e.g. agriculture use; landscaping)
- **Enhanced weathering** (EW; spreading of calcium- and magnesium-rich silicate rock dust on, for example, agricultural land, in coastal environments or through river liming)
- **Ocean storage through direct abiotic enhancement of the ocean bicarbonate carbon pool** (e.g. via ocean alkalinity enhancement; OAE)
- **Ocean carbon removal and storage** (e.g. electrochemical ocean carbon removal and storage)

1.3.2 CDR Certification: Methodologies & Protocols

Methodologies, protocols, standards (hereafter referred to as 'methodology' or 'methodologies') from the following standard-setters are considered:

- **Independent crediting programmes** (ICPs; e.g. in the voluntary carbon market, such as ACR, Verra/VCS, Gold Standard, Global Carbon Council (GCC), Puro.earth, Isometric).
- **International programmes** (e.g. United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement Crediting Mechanism; Box 1-1)
- **Domestic programmes** (e.g. the European Union Carbon Removal and Carbon Farming Certification (CRCF; EC 2024) Regulation; Canadian Federal and Provincial schemes etc.)
- **Other activities and analogues**, where relevant (e.g. treatment of carbon dioxide capture and geological storage (CCS) in cap-and-trade emissions trading systems (ETS) such as the EU ETS or California ETS; treatment of CDR under the U.S. 45Q; the MRV, accounting and tracking of progress towards NDCs; emerging guidance on CDR MRV from the IPCC Taskforce on National GHG Inventories (TFI)).

Box 1-1 Paris Agreement, Article 6 and carbon markets

Article 6 of the Paris Agreement establishes the basis for a global carbon market. Under Article 6, Parties may voluntarily cooperate to meet the Agreement's goals by transferring mitigation outcomes—either emission reductions or removals—achieved in one country to another country for counting the towards achievement of its NDC. Mitigation outcomes originated under Article 6 may also be counted towards international mitigation purposes (IMP; such as the Carbon Offsetting and Reduction Scheme for International Aviation; CORSIA), or other purposes (OP; such as use in voluntary climate-related action and claims or results-based finance). IMP and OP are collectively referred to as other international mitigation purposes (OIMP).

The Article 6 market-based mechanisms are established through two similar but separate pathways

- **Article 6.2 cooperative approaches**. A decentralised system of trading of internally transferred mitigation outcomes (ITMOs) between Parties in pursuit of their NDCs, or for OIMP. Cooperative approaches could encompass methodologies and credits from ICPs, subject to authorization by the host country Party.
- **Article 6.4 crediting mechanism (PACM)**. A centralised UN-operated crediting mechanism issuing *Article 6, paragraph 4, emission reductions* (A6.4ERS) to project activities, operating under the rules, procedures and methodologies developed under the CMA-appointed Supervisory Body (SBM).

In either case, Parties must fulfil certain governance requirements, including **authorization of ITMOs and A6.4ERs** specifying how they will be used (unauthorized A6.4ERs may be used for other types of 'mitigation contribution', such as domestic crediting systems). Where A6.4ERs are authorized for use towards NDCs or OIMP, they are equivalent to ITMOs. Authorized ITMOs and A6.4ERs are subject to **corresponding adjustments**, meaning that the amount of reduction or removal generated will not be counted towards achievement of the host country Party's NDC but rather only that of the acquiring Party's NDC, or other entity under OIMP.

Of those listed, at time of writing the ICPs have been most active in eCDR methodology development over the past few years, with around 30 eCDR methodologies available or close to launch at time of writing (June 2025; Table 1-1 and Annex A, which also lists over 20 related methodological modules/tools and other relevant documents published by the ICPs).

Of the domestic crediting schemes:

- Canada Federal, and Alberta and British Columbia (provincial) Greenhouse Gas Offset Systems have published protocols for DACCS (e.g. ECCC 2025).
- In Europe, the European Commission has to date published a draft Delegated Regulation under the CRCF setting out a methodology for DACCS, BECCS and for biochar (EC 2025).
- In the UK, the Department for Energy Security and Net Zero (DESNZ) has, via the British Standards Institute (BSI), published BSI Flex standards setting out minimum quality thresholds for BECCS and DACCS, and invite project developers to propose methodologies (DESNZ 2023a; BSI 2025a; BSI 2025b)

Table 1-1 ICP methodologies for novel CDR in the voluntary carbon market

CDR method	Meths#	ICP/Developer	Dates of publication
DACCS + geostorage	5	Puro.earth [1]; ACR[2]; Verra/VCS (CCS+)[1,2]; Global Carbon Council[1,2] *; Isometric	Jan-2021 → Aug-2024 (ACR v1.0 Apr-2015)
DACCS + mineral geostorage (in situ)	1	CarbFix/Climeworks/DNV	Jun-2022
BECCS + geostorage	6	Puro.earth[1]; Global Carbon Council[1,2]; Verra/VCS (CCS+)[1,2]; Isometric; Gold Standard; [Drax/Stockholm Exergi]	Jan-2021 → Sep-2024
BECCU + mineral product storage	2	Gold Standard; Puro.earth	Mar-2023 → May-2023
Mineralisation (open ex situ, using industrial wastes)	1	Isometric	Jan-2025
Biochar (construction)	3	Carbon Standards International[3]; Puro.earth; Verra[3]	Jan-2022 → Oct-2024
Bio-oil geostorage	2	Carbon Direct; Isometric	Aug-22 → Sep-24
Enhanced weathering	4	Carbon Standards International; Isometric; Puro.earth; Verra/VCS[3]	Oct-2022 → Jan-2025
River / Wastewater alkalinity enhancement	2	Isometric (x2)	Feb-2025
Ocean alkalinity enhancement (from coastal outfalls)	1	Isometric	May-2024
Oceanic removal (electrochemical)	1	Isometric	Aug-2024

Source: authors analysis up to June 2025. Notes: [1]DACCS and BECCS combined in single methodology; [2]Includes fossil CCS; [3] Idea note, proposal, concept, under preparation or under consultation. See also Annex A.

At the international level, the negotiations on the methodological treatment of CDR within the **Article 6.4** ran for around 3 years between 2021-2024, with the *Standard: Requirements for activities involving removals under the Article 6.4 mechanism* (PACM Removals Standard v0.01; (UNFCCC 2024a) being proposed by the PACM Supervisory Body (the SBM) and noted by Parties in late 2024.[1] New supporting documents are under preparation at time of writing.

A **Methodology Report on CDR** to supplement **IPCC National Greenhouse Gas Inventory (NGHGI) Guidelines** is also under development since 2024. The plenary of the IPCC 7th Assessment Cycle held in February 2025 did not, however, agree on the proposed structure for the CDM methodology report, and the subject will be considered in the next plenary scheduled for October 2025 (IPCC-63).

[1] Decision 5/CMA.6

2 Contexts for eCDR in Developing Countries

2.1 Background

Widespread scale up of CDR in all world regions is essential to meet the Paris Agreement's goals. Yet experience from over 30 years of international climate policy shows that CDR presents some specific and specialised governance and rulemaking challenges. These issues are often augmented in developing countries, where weak institutions can constrain implementation capacity and adversely affect the safety and durability of storage in enhanced terrestrial or aquatic carbon sinks and reservoirs.

Financing and incentives for climate mitigation can also be more difficult to mobilise in the global south. Investment capital is typically scarce and economic and natural resources face a multiplicity of demands. The situation presents a challenging cycle: incentivising and deploying CDR absent of strong safeguards elevates the risk of carbon reversal, which increases financing challenges, risks wasting precious resources, potentially undermines the primary climate mitigation objective of the activity and compromises the environmental integrity of the Paris Agreement and its carbon market (if the mitigation outcomes are traded across borders). Strong safeguards are therefore a core component of effective eCDR development.

Conversely, some CDR methods may be better suited to developing country circumstances in terms of resource availability and the need for widespread scaling (e.g. spatial requirements for scaling enhanced weathering (EW) on agricultural land).

Mindful of these characteristics, this section considers the contexts and perspectives for eCDR in developing countries, its relevance to national climate mitigation policy, current practice and future outlooks for eCDR in these regions.

The research draws upon scholarly literature and opinions expressed by stakeholders under the Paris Agreement, as well as the stated goals and contributions of developing countries towards the Paris Agreement.

2.2 Experiences, opportunities and challenges for eCDR

CDR through nature-based approaches (hereafter "natural-climate solutions" or NCS)[2] are long-standing methods of climate change mitigation in developed and developing countries.

Under the Kyoto Protocol, the clean development mechanism (CDM) registered approximately 65 afforestation and reforestation project activities in developing countries with potential emission reduction credits totalling around 2.2 $MtCO_2$/yr (UNFCCC 2025a; UNEP 2025).

The voluntary carbon market (VCM), since inception in the late 1990s, has encompassed a wide suite of NCS approaches. In 2022 and 2023 credit issuances by ICPs to NCS project activities in all world regions stood at almost 19 Mt per year (Forest Trends' Ecosystem Marketplace 2024):

- afforestation, reforestation and revegetation – 10.8 to 4.1 $MtCO_2$ respectively
- improved forest management (IFM) – 4.5 to 2.4 $MtCO_2$ respectively, and
- blue carbon – 3.4 to 0.38 $MtCO_2$ respectively

Several domestic crediting schemes are issuing carbon credits to NCS activities including the UK's Woodland Carbon and Peatland Code, the Canada Greenhouse Gas Offset Credit System, the Australia Carbon Credit Unit Scheme and France's Label Bas Carbone.

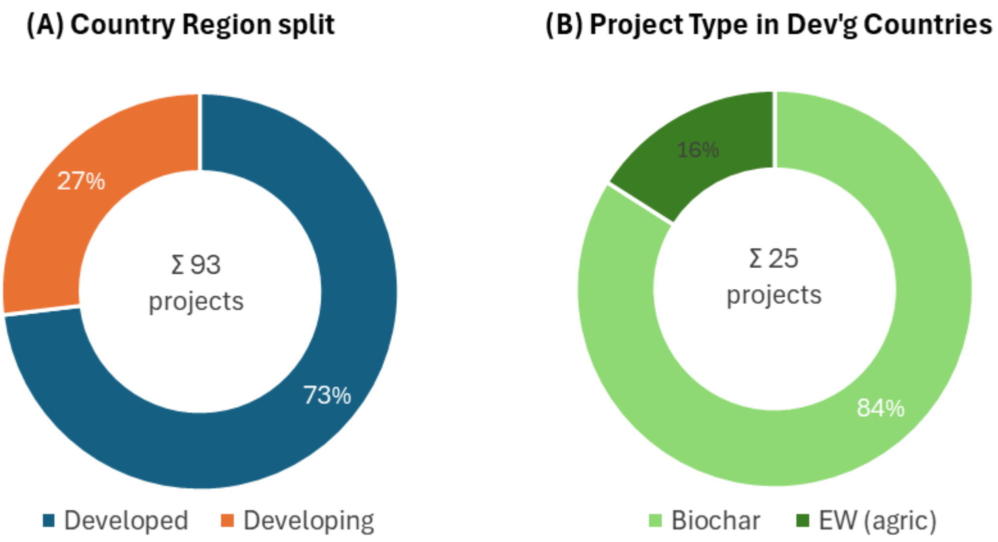
Conversely, novel eCDR has historically received less attention. Most crediting methodologies were established in the last few years (Table 1-1), far fewer projects have been registered and only a handful of credits have been issued.

Analysis suggests that, at time of writing, 93 eCDR projects using the methods covered by the scope of this report are registered with four main ICPs. Just over a quarter of these are located in developing countries, covering mainly biochar production with soil storage and a handful of EW projects (Figure 2-1). Almost 900,000 tCO_2 of carbon removal credits have been issued worldwide to the eCDR project types covered herein. Of these, ~263,000 credits have been issued to eCDR in developing countries, relating almost entirely to biochar projects registered with Puro.earth. Excluding biochar leaves a total of 21 registered eCDR project activities worldwide, of which four are in developing countries, all of which involve EW. A total of 235 credits have been issued by Isometric to one EW project in Brazil.

There are a number of likely reasons for the low rate of uptake of eCDR to date and the particularly low rate in developing countries.

[2] Including afforestation and reforestation, improved forest management, soil organic carbon enhancement and blue carbon (wetland restoration, mangrove planting, salt marsh restoration and sea grass meadow development).

Figure 2-1 Distribution of eCDR projects on selected ICP registries (Sept 2025)



Source: Author analysis of project data from the Puro.earth registry, Isometric registry, Verra registry, Gold Standard registry. Excludes most methodologies outside the scope of this report (e.g. wooden building elements, forestry, biomass burial), but includes all types of biochar.

Firstly, the inclusion of sink enhancements within the scope of climate targets has historically proved complex and contentious (e.g. Höhne et al. 2007). Uncertainty over measurability/accuracy (or monitoring, reporting and verification; MRV), baselines, accounting and the risk of non-permanence and carbon reversal have proved to be pervasive concerns for CDR in international climate policy. These were reflected in restrictions on the accounting of removals by land use, land use change and forestry (LULUCF) towards developed country Kyoto Protocol targets, and the limitation on CDM crediting in developing countries to only afforestation and reforestation sink enhancements. In the case of the latter, concerns over environmental integrity impacts of non-permanence and carbon reversal meant these activities could only be issued temporary or long-term credits.[3]

The range of eCDR methods featuring in today's climate discourse were hardly considered during the Kyoto Protocol era: the current suite of eCDR methodologies in the VCM have nearly all been promulgated in the last 5 years (Annex A). Their recent emergence has reignited many of the historical issues, as well as raised several new ones. A significant volume of recent scholarly and grey literature has questioned various aspects of eCDR including the foundational science, efficacy and risk of failure (e.g. Anderson and Peters 2016; IPCC 2018; Zickfield et al 2021), competition for land, resource use, efficiency and leakage risks (e.g. Quiggin 2024), moral hazard (mitigation obstruction/deterrence; Fuss et al. 2018; McLaren et al. 2019; Temple 2021), lack of co-benefits (e.g. Honegger and Reiner 2017), adverse/deleterious side effects (Keller et al. 2014; Torres Burtka 2023), sustainable development impacts (IPCC 2022), infringement upon human rights (Günther and Eckardt

[3] Temporary or long-term credits (tCERs/lCERs) safeguard against the environmental integrity risk posed by carbon reversal by expiring, obliging the buyer to periodically renew/replace. This buyer side liability approach to carbon reversal severely hampered market demand for tCER/lCERs by Annex I Parties (see Section 3.3.5).

2022) and legality etc (Buylova et al. 2021; Lebling and Savoldelli 2025). As summarised by the IPCC:

> "Limits to our understanding of how the carbon cycle responds to net negative emissions increase the uncertainty about the effectiveness of CDR to decline temperatures after a peak" (IPCC 2018; p. 34) [and that]
>
> "Mitigation strategies that focus on lowering demand for energy and land-based resources exhibit reduced trade-offs and negative consequences for sustainable development relative to pathways involving either high emissions and climate impacts or pathways with high consumption and emissions that are ultimately compensated by large quantities of BECCS." (IPCC 2022, p. 141)

These perspectives notwithstanding, the potential scale of eCDR needed to meet net zero aligned with Paris goals means that there are also a significant number of supportive voices. These groups have been instrumental in fostering a CDR boom (Time 2022; Economist 2023), backed up by several ICPs in the VCM that are pioneering eCDR crediting standards (Section 1.3.2). Yet, despite these developments, criticisms over integrity and quality in the VCM, coupled to a desire to focus on national CDR activity, has prompted developed country governments consider their own domestic eCDR certification standards (e.g. EU, UK and Canada; Section 1.3.2; Section 3).

Second, such concerns will be augmented in developing countries, where levels of awareness and understanding can be lower, and institutional capacity and oversight face additional challenges. Many countries have limited knowledge and or a sense of national technical eCDR mitigation potential, and some may be wary of hosting eCDR activities because of perceived risks and concerns over residual liabilities for stored carbon. These concerns will be exacerbated if the resulting mitigation outcomes are transferred to other countries and subject to corresponding adjustment against their own climate mitigation goals (Box 1-1). Some may struggle to see clear upsides in this constellation. Yet disclosure of the types of mitigation activities that host countries intend to consider under Article 6.4, and how Article 6 activities contribute towards implementation of NDCs, are both key participation requirements (UNFCCC 2021a; UNFCCC 2021b; UNFCCC 2025b). Absence of consideration of eCDR in NDCs may therefore hamper the crediting of such actions (Section 4).

Finally, there are also broader questions about the relevance of eCDR to developing countries in light of fairness, distributive justice and common but differentiated responsibilities and respective capabilities (CBDR-RC), a core tenet of the United Nations Convention on Climate Change (UNFCCC) and the Paris Agreement (Section 2.3).

2.3 Relevance of eCDR to climate action in developing countries

A range of views have been expressed on the deployment of eCDR in the global south, covering topics such as opportunities, co-benefits, costs and risks. Opinions tend to be polarised, with strong views both for and against. This section attempts to contextualise and summarise where the balance of opinion lies in respect of various open questions: whether and/or which eCDR methods may be suited to developing countries? How big a role could or should eCDR play? And how much relative to the global north? Over what timeframe should eCDR be rolled out in developing countries?

First and foremost CBDR-RC frames all elements of climate action under the UNFCCC. Although the Paris Agreement calls on *all* Parties to contribute, it also requests that CBDR-RC be reflected in ambition and progression in NDCs and the design of long-term low emission development strategies (LT-LEDS). It also allows developing countries to take longer to peak emissions before making rapid reductions. The Agreement therefore embraces the basic idea that developed countries will reduce emissions while developing countries can increase emissions in line with economic and social development goals. According to some, maintaining this underlying tenet will likely require developed countries to go net negative in future to ensure headroom in the global carbon budget to offset the ongoing emissions of developing countries as they grow (Mohan et al. 2021).

Many agree with this view. Several observers suggest that the potential burden of CDR must not fall on the low emitters of today, the poor countries, even if they end up representing a high share of global emissions post-2050 (e.g. Tongia 2022). These stakeholders argue that the need for CDR is overwhelmingly due to over-emissions by today's high emitters, and that expectations of future CDR should not become a rationale for not mitigating—a phenomenon termed 'mitigation obstruction' or 'mitigation deterrence' (Fuss et al. 2018; McLaren et al. 2019). Some have expressed similar moral hazards concerns, with the risk that additional carbon budget space made available through net-negativity will rather be used by developed countries as a source of carbon flexibility and to further delay steep cuts in emissions (Mohan et al. 2021). Some view eCDR as an imperative solely for developed countries as a means of 'climate reparations' (Wallace-Wells 2021; Nawaz 2024).

Drawing on a range of similar views, an *Information Note* on CDR inclusion in the PACM issued by the UNFCCC Secretariat in May 2023 asserted that, although eCDR results in permanent net removal CO_2 from the atmosphere, the cons include that the methods:

> "…are technologically and economically unproven, especially at scale, and pose unknown environmental and social risks…" [and they] "…do not contribute to sustainable development, are not suitable for implementation in the developing countries and do not contribute to reducing the global mitigation costs, and therefore do not serve any of the objectives of the Article 6.4 mechanism" (UNFCCC 2023a, Table 3)

The findings expressed in the document precipitated a significant response from the global CDR community. Over 100 stakeholders submitted views to the 5th meeting of the SBM,[4] which were subsequently consolidated through a structured consultation. A new *Information Note* consolidating public inputs (v02.1) was issued in August 2023, which included the views of

[4] https://unfccc.int/process-and-meetings/the-paris-agreement/article-64-mechanism/calls-for-input/sb005-annotated-documents

eight government Parties/groupings[5] and 370 separate inputs from observer organisations (UNFCCC 2023b).

Many of the submissions to the UNFCCC reaffirmed the range of concerns highlighted above. Conversely, a range of more supportive views also emerged through this process, which outlined various benefits of eCDR including:

- **Enhancing climate ambition**. Widespread scale-up of CDR is essential to meet climate goals, and that eCDR offers a broad range of technologies that can adapt to local conditions, have greater potential than NCS, can lower the overall cost of mitigation, and can help countries to meet ambitious NDCs.
- **Unlocking untapped renewable energy potential**. eCDR methods with high renewable energy requirements can provide anchor industrial demand that will enable investment in currently untapped renewable energy in developing regions. This in turn can improve energy access and reduce energy poverty.
- **Supporting sustainable development and enhancing livelihoods**. eCDR methods can promote sustainable development as they scale-up and create new jobs. Purported benefits of specific methods include:
    - Ocean storage can help restore ocean ecosystems and enhance coastal livelihoods in the developing world and, because of its size, has the potential to scale.
    - Bio-oil injection can bring economic benefits, increase wildfire resilience, and improve air quality.
    - EW can bring measurable co-benefits such as improved crop productivity, reduced pestilence and soil enhancement.
- **Conserving ecosystems**. Biological and non-biological marine eCDR pathways can capture and store CO_2 in ways that provide co-benefits, such as reduced anthropogenic ocean acidification, improved fishery yields, and feedstock production for food and durable products.

Support to existing notable eCDR plans and pilots in the global south were cited as other reasons to encourage such methods in the developing regions. A summary of risks and co-benefits associated with different CDR methods is set out below (Table 4-1).

Furthermore, the Executive Secretaries of the five UN Regional Commissions, in a joint statement in the run up to COP26, lent additional weight to furthering CDR in developing countries by calling for:

> "Enhanced regional cooperation to develop nature-based and technological solutions for capturing CO_2 emissions from the atmosphere and ensuring its long-term storage… [and that]…

[5] Russian Federation, United Kingdom, Papua New Guinea (for CRfN), Norway, Republic of Korea, Colombia (on behalf of Chile, Colombia, Guatemala, Panama, Paraguay, and Peru), European Union, Brazil (on behalf of Argentina, Brazil and Uruguay - ABU)

In developing countries, carbon dioxide removal activities, whether nature based or technological, should also feature as part of the effort to provide sustainable livelihoods that can accelerate the attainment of the SDGs." (Algayerova et al. 2021)

On a practical level, developing countries with natural resource endowments well-suited to hosting eCDR—for example, ample biomass resources, significant geological CO_2 storage capacity, significant renewable energy potential, and/or significant tracts of arable land amenable to EW—may be incentivised to take an early lead on deployment. These circumstances may be amplified where such countries are also significant fossil fuel producers and exporters, as they may view eCDR as an important domestic activity to support continued access to energy markets in a climate-constrained world.

A strong case for mobilization also exists in the VCM at time of writing. The voluntary actions of a select group of corporate entities seeking to neutralise their emissions though the acquisition of a range of novel CDR credits (e.g. Microsoft, Frontier and Next Gen buyer consortia, Google, JP Morgan, Airbus) is driving new, dedicated, demand for eCDR with highly significant offtake prices. Forward purchase agreements for CDR credits among these entities at time of writing are estimated to be reaching over US$ 33 million tCO_2,[6] with a combined value likely exceeding US$ 6.5 billion. Demand covers a range of novel CDR methods, with specific prices in the range US$ 200-1700 per tCO_2 (IEAGHG 2024).

The next section reviews the currently pledged climate mitigation ambition of selected developing countries and the role of eCDR therein.

2.4 Status of eCDR in developing country climate action

NDCs are the primary channel through which countries formally communicate their climate commitments under the Paris Agreement, with enhanced pledges being made progressively every five years. NDCs are also closely linked to carbon markets through the Paris Agreement's Article 6 (Box 1-1).

In addition to NDCs, preparation of LT-LEDS under the Paris Agreement provide strategic insights regarding the anticipated pathways to national climate ambition and sustainable development in timeframes spanning decades. LT-LEDS are also often linked to NDCs, forming a basis upon which new, progressive, NDCs can be developed. They can also highlight new technologies and innovations that a country may not be able to pursue now, but is planning to implement over its longer-term pathway for climate mitigation and towards net zero emissions.

Both NDCs and LT-LEDS are strongly linked with eCDR activities, including within the context of carbon finance, taking note of the generally high costs of eCDR implementation. Countries may choose to communicate in their NDC higher cost mitigation strategies that include eCDR

[6] Based on cdr.fyi purchaser leaderboard. Accessed, August 2025

as being conditional on international support and finance including through ITMO or A6.4ER transfers. The scope and ambition of an NDC may also determine which activities a country may consider authorizing under Article 6, and which ones are eligible or ineligible overall.

The inclusion of eCDR into LT-LEDS can offer a glimpse into countries' outlooks on their possible future reliance on carbon removal to achieve long-term climate goals, such as mid-century net-zero targets.

2.4.1 Scope

A status assessment was conducted based on a review of the most recent NDCs and LT-LEDSs of 30 countries, with submission dates mostly in the period 2020 to 2025 (Table 2-1).

An initial list of countries was prepared, drawing from recent literature that highlighted countries' national policy commitments towards eCDR (Amer 2024; primarily NDCs and LT-LEDS) and from selected search strings in an online open reference source database (ClimateWatch 2025). The study by Amer (2024) focussed on selected countries and highlighted the status of eCDR in their NDCs and provided recommendations for countries to enhance emissions reporting on eCDR methods. The second, ClimateWatch (2025), is an authoritative online data and information resource for climate change action by countries, and includes among others, digitalised information sets taken from countries' NDCs and LT-LEDSs. The system supports rapid scanning of all national climate pledges and strategies using different search strings.

Studies from Lamb et al. (2024), McElwee (2022) and Smith, Vaughan and Forster (2022) were also consulted to help identify additional countries in which CDR may be a prominent mitigation approach. In-house expert knowledge was also drawn upon to identify other countries where eCDR was known to be of interest. Based on this second step, additional countries were also added to the initial list to broaden the regional spread and increase the diversity of national circumstances. The majority of countries assessed (27 out of 30) examined are classified as developing countries by the OECD.

Table 2-1 Summary of eCDR coverage in selected NDCs and LT-LEDS (July 2025)

Region	Country	NDC		LT-LEDS	
		Version	eCDR mention	Version	eCDR mention
AFRICA	Lesotho	Feb-25	Yes	-	No document
	Malawi	Jul-21	Yes	-	No document
	Togo	Oct-21	Yes	-	No document
	Ghana	Nov-21	No	-	No document
	Kenya	Nov-21	No	-	No document
	Nigeria	Jul-21	No	Apr-24	Yes
	Rwanda	May-20	No	-	No document
	South Africa	Sep-21	No	-	No
	Zimbabwe	Feb-25	No	Nov-22	No
ASIA	China	Oct-21	Yes	Oct-21	Yes
	Mongolia	Oct-20	Yes	-	No document
	Pakistan	Oct-21	Yes	-	No document
	Thailand	Nov-22	Yes	Nov-22	Yes
	Vietnam	Nov-22	Yes	-	No document
	Indonesia	Sep-22	No	Jul-22	Yes
LAC	Bahamas	Nov-22	Yes	-	No document
	Brazil	Nov-24	Yes	-	No document
	Uruguay	Dec-24	Yes	Dec-21	No
	El Salvador	Jan-22	Yes	-	No document
	Colombia	Dec-20	No	Nov-21	Undecided
	Ecuador	Feb-25	No	-	No document
	Mexico	Nov-22	No	Nov-16	No
MENA	Bahrain	Oct-21	Yes	-	No document
	Iran	Nov-15	Yes	-	No document
	Iraq	Oct-21	Yes	-	No document
	Kuwait	Oct-21	Yes	-	No document
	Oman	Nov-23	Yes	Jul-23	Yes
	Saudi Arabia	Oct-21	Yes	-	No document
	Tunisia	Oct-21	Yes	Nov-22	No
	UAE	Nov-24	Yes	Jan-24	Yes

Notes: LAC = Latin American and Caribbean; MENA = Middle East and North Africa

2.4.2 Methodology

Using ClimateWatch (2025) and direct assessment, NDCs and LT-LEDS were reviewed for mentions of eCDR, including CCS, BECCS, DAC, biochar, enhanced weathering, and ocean alkalinity enhancement.[7]

Furthermore, the types of pledges and targets were also noted, including whether:

- The NDC or LT-LEDS includes a net zero commitment or otherwise (implying the potential need to use CDR)
- Whether any eCDR targets or inclusions were quantitative or qualitative (implying a degree of knowledge and readiness potential), and
- How nature-based CDR (NCS) was considered (LULUCF) (implying whether the country was expecting to exclusively or mainly use natural carbon sinks to meet its goals)

Several national policy documents in addition to NDCs and LT-LEDS were also reviewed for the selected countries where further information could inform specific findings. Documents in English or Spanish were reviewed directly, and others were translated.

2.4.3 Results

The analysis supports the findings outlined in the 2024 *State of CDR* report (edition 2), which concluded that:

> "…countries have not transparently communicated their expectations for scaling novel CDR by 2030". [and that] "few countries pledged to scale novel CDR by 2030 as part of their NDCs" (Smith et al. 2024)

The results of the review show that most current NDCs do not include much in the way of novel eCDR methods, with the main exception being some fairly loose mentions of BECCS and DACCS (five in total).[8]

This finding notwithstanding, the majority of reviewed NDCs do include some mentions of analogous components of eCDR as part of their commitments, namely: carbon capture and storage (CCS), as applied to fossil CO_2 emission sources. Some NDCs also include broader statements about developing 'carbon capture' technology. In several incidences, CCS pledges are somewhat conflated with eCDR activities such as BECCS and DACCS, all of which involve chemical capture of CO_2 in gaseous form and its storage in geological formations. Such confusion suggests that the significance of the mentions of CCS and eCDR across the suite of documents should be treated with caution.

[7] Search terms used on ClimateWatch (2025) included "carbon removal", "carbon capture", "BECCS", "DACCS", "CCS", "biochar", "rock weathering", "ocean alkalinity", "marine CDR" etc.
[8] BECCS: UAE, Brazil, Thailand, Indonesia. DACCS: Bahrain, Saudi Arabia, Thailand, Oman, UAE.

Overall, 20 of the 30 countries covered in the analysis include a mention of CCS in their NDC, with only five out of the 30 explicitly mentioning eCDR methods (Table 2-1). Of the 20, the majority (16 countries) set out their goals only in qualitative terms (e.g. characterised as 'research', 'promotion' or 'support' for carbon capture or CCS).

The few that do include quantitative commitments to CCS in NDCs or LT-LEDS (four in total) only mention it in broad terms (e.g. quantified potential mitigation achieved by carbon capture technologies) and all highlighted the need for international support to be available. Examples include citing the finance needed to deploy CCS in a sub-critical coal power plant (Malawi) or specifying an increase in emissions cuts relative to BAU if carbon capture methods become feasible (27.2% cut vs. 22.7% drop by 2030, Mongolia). No quantitative targets for eCDR deployment were found in any NDC.[9]

Only one quantitative commitment towards BECCS was found: Indonesia’s LT-LEDS states that the country anticipates installed capacity of BECCS power plants to reach 23GW in 2050, equalling 8% of the energy supply mix (Government of Indonesia 2021, p.58).

The majority of reviewed countries also include NCS in their NDC (26), compared to the 20 or so broadly mentioning CCS and only five mentioning eCDR. Several countries’ LT-LEDS also suggest strong reliance on NCS to meet long-term net zero commitments. For example, Indonesia specifically states that increasing removals in forestry and land use is a necessity for achieving net zero by 2060, and Brazil highlights that increasing nature-based removals will allow the goal of net zero emissions by 2050 to be achieved.

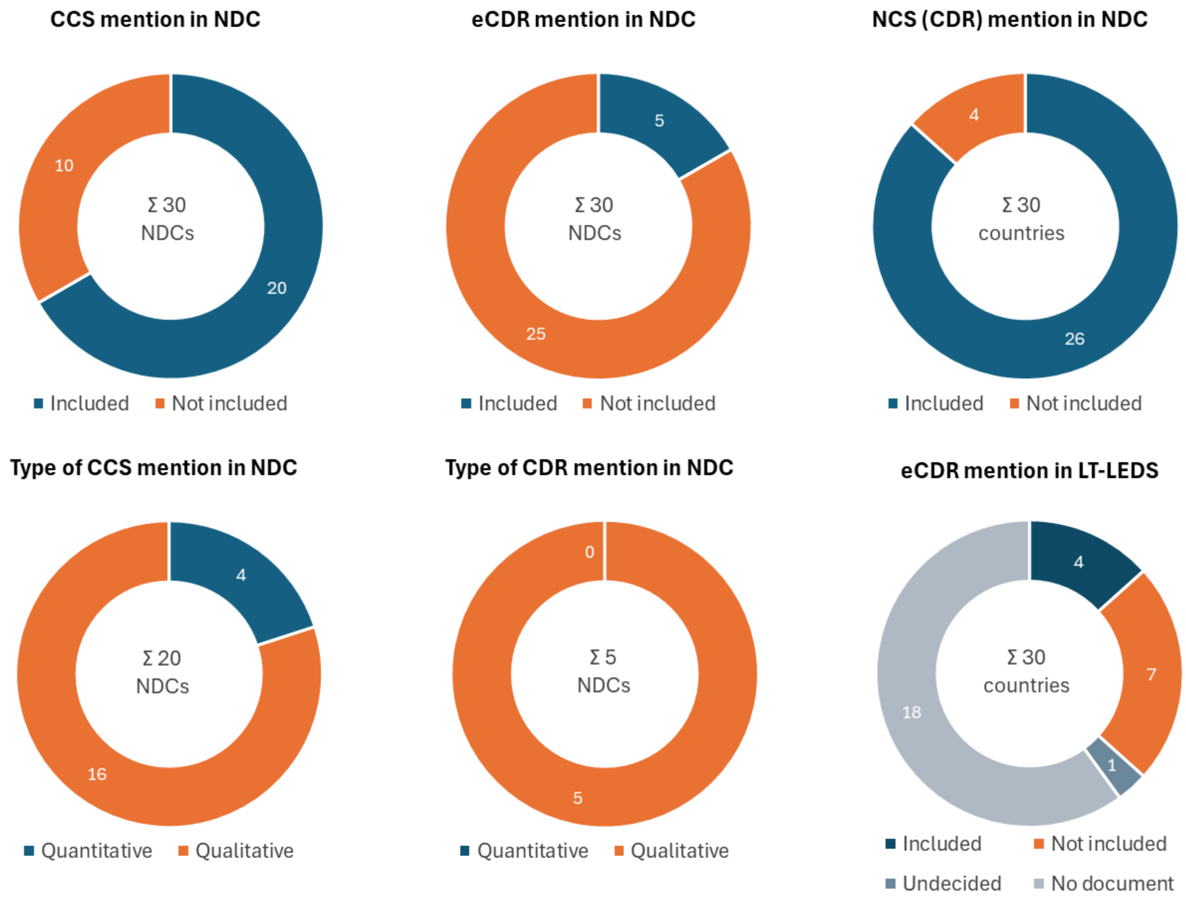
In regional terms, the selected countries in Asia, and most countries in Middle East and North Africa (MENA) show the interest in eCDR. In contrast, few African countries seem to show awareness or support for CCS or eCDR-based mitigation methods. Latin American and Caribbean (LAC) countries are split somewhat evenly in terms of considering and not considering eCDR. No discernible temporal trends could be observed, with a mix of both older and more recent NDCs including and not including eCDR mentions.

Overall, the results highlight that eCDR methods currently play only a limited role in developing country climate pledges, and only then in abstract and qualitative ways that lack clear commitments and/or concrete targets and implementation plans.

Unlike mandatory NDCs, the submission of LT-LEDS under the Paris Agreement is voluntary. The results showed that the majority of the 30 reviewed countries have yet to submit an LT-LEDS (18). Of those that did, only four countries included eCDR in their LT-LEDS compared to seven which did not mention it (Figure 2-2). One country was apparently ‘undecided’ (Colombia). When including eCDR into LT-LEDS, several countries (e.g. Indonesia) highlighted its necessary role in their mid-century net zero mitigation goal.

[9] Few developed countries have established quantified eCDR targets in NDCs.

Figure 2-2 Mentions of eCDR and NCS in selected NDCs and LT-LEDS



Source: Authors analysis

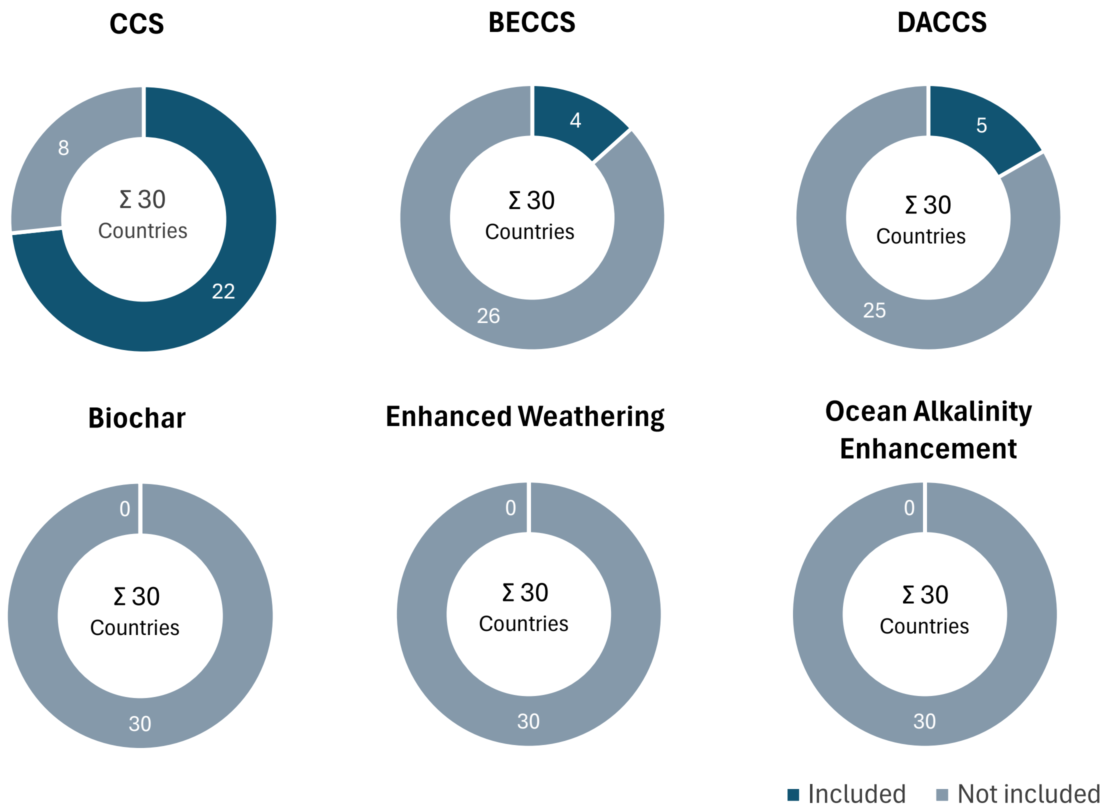
Several NDCs and LT-LEDS' mention CCS, which may or may not include BECCS or DACCS given the use of CCS as an umbrella term. A few of the documents also specifically mention BECCS and DACCS, identifying their role as potential technologies to achieve net zero by mid-century and decarbonize future energy mixes.[10]

In some cases, such commitments may be outside of NDC or LT-LEDS documents and are instead described in other national policy documents. For example, Nigeria, which was not identified as a candidate eCDR country, does include BECCS in its Energy Transition Plan (Government of Nigeria, 2023).[11]

No mention of other eCDR methods, such as biochar, EW or OAE, could be found in any national policy documents.

[10] BECCS: Brazil, Thailand, Indonesia, UAE. DACCS: Bahrain, Saudi Arabia, Thailand, Oman, UAE.
[11] Nigeria did not appear in the ClimateWatch search results.

Figure 2-3 Mentions by technology types in selected NDCs and LT-LEDS



Source: Authors analysis

2.4.4 eCDR in developing country policy

The analysis of Paris Agreement pledges and national climate policy documents suggests that eCDR is seldom considered as a mitigation option by developing countries today. The review did, however, highlight a few more advanced countries that are engaging in discussions about the national role of eCDR over coming years and decades, and especially beyond 2050 (Table 2-1).

Comparatively more countries are including NCS in their NDCs. These pledges tend to be firmer than those for eCDR and include clearer quantitative targets and mitigation actions and plans. This is understandable given that NCS is a long-standing mitigation approach, particularly for countries in the global south with large forest coverage.

Countries that included eCDR into their NDCs did so only qualitatively (e.g. somewhat vague qualitative targets such as 'supporting', 'researching', or 'promoting'), suggesting some limited, exploratory, interest. This perhaps reflects some of the wider challenges posed to eCDR uptake, as highlighted in Section 2.3.

The analysis also revealed that not all eCDR methods are being equally taken up into national climate policy documents and planning. Methods involving 'carbon capture'/CCS' are considered within the context of an umbrella term. However, many instances of 'CCS' do not necessarily correlate to 'engineered' CDR.

The inclusion of BECCS stands out as being the most advanced. This may be because, unlike almost all other eCDR methods, it is clearly recognised and included as a negative emission technology within the *2006 IPCC Guidelines for Greenhouse Gas Inventories* (IPCC 2006; Table 2-2). The current UNFCCC-agreed guidance for compiling of NDCs (the 'ICTU'), as well as rules for carbon markets under Article 6, mean that exclusion of some eCDR methods from current IPCC guidelines may be problematic (Box 2-1).

Table 2-2 Coverage of eCDR methods in current IPCC Guidelines

CDR Method	Coverage	Applicable sections / comments	Publication
DACCS	Partial	Volume 2:5 (CO_2 Transport and Storage), Mineral storage explicitly excluded in Vol 2, Chapter 5	IPCC (2006)
BECCS	Yes	Volume 2:2 (Stationary combustion, Tier 3) Volume 3 (Various industrial sources, Tier 3 only) Volume 2:5 (CO2 Transport and Storage, Tier 3 only)	IPCC (2006)
Bio-oil injection	No	Parties could propose own methodology (probably Tier 3)	n/a
Mineralization	No	Explicitly excluded in Vol 2, Chapter 5. Parties could propose own methodology (probably Tier 3). In-situ mineralization (with DAC) explicitly excluded in Vol 2, Chapter 5	n/a
Biochar	Partial	Volume 1 (new guidance for mineral soils) Volume 4 (Biochar amendments to soil + Appendix 4)	IPCC (2019)
EW	Partial / No	Parties could propose own methodology (probably Tier 3)	IPCC (2006)
Marine CDR	No	Oceanic GHG fluxes not measured and reported in national GHG inventories	n/a

Source: adapted from IEAGHG (2024)

Beyond the challenges in integrating eCDR into national climate policies, the analysis also showed that the frontrunners that have included eCDR are paving the way and have identified clear reasons and opportunities for doing so, such as Indonesia.

Box 2-1 ICTU and Article 6: linking NDCs and units with GHG inventories and IPCC Guidelines

The current absence of activity/sector specific IPCC guidelines for the accounting and reporting of most types of eCDR hampers their inclusion in NDCs (Table 2-2). Under the agreed guidance for the preparation of NDCs—the 'information to enhance clarity, transparency and understanding' (ICTU; UNFCCC 2018a, Decision 4/CMA.1)—an NDC's scope must include:

> "…sectors, gases, categories and pools […] consistent with Intergovernmental Panel on Climate Change (IPCC) guidelines". (UNFCCC 2018a, Annex I.3(b))

And that, in accounting for NDCs:

> "Parties whose NDC cannot be accounted for using methodologies covered by IPCC guidelines provide information on their own methodology used…" (UNFCCC 2018a, Annex II.1(b)) [and also that]
>
> "…once a source, sink or activity is included, continue to include it". (UNFCCC 2018a, Annex II.3(b))

The Guidance on Cooperative Approaches under Article 6.2 (UNFCCC 2021a) and the Rules, Modalities and Procedures for Article 6.4 (RMPs; UNFCCC 2021b) also both require the units (respectively ITMOs or Article 6.4 Emission Reductions; A6.4ERs) to be in carbon dioxide equivalent (t CO_2 eq) measured/calculated:

> "…in accordance with the methodologies and metrics assessed by the Intergovernmental Panel on Climate Change and adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA)" (UNFCCC 2021a, Annex I.1(c); UNFCCC 2021b, Annex I.1(b))

This requirement implies that project-based crediting methodologies applied under Article 6 should also align with IPCC methodologies.

Development of additional IPCC guidelines through a Methodologies Report on CDR is a goal of the 7th IPCC assessment cycle, due for completion by the end of 2027 (IPCC 2024). Before this publication, Parties wishing to count eCDR methods towards their NDC goals will need to design and apply their own approach, which will be subject to *technical expert review* (TER) under the UNFCCC biennial transparency reporting requirements. The same requirement also extends to crediting and trading under Article 6.

The lack of IPCC guidelines can be considered a barrier to country-level accounting of eCDR activities towards NDC commitments (Section 4.2.2). The potential complexity of proposing 'own methodologies' may deter countries from including a wider range of eCDR activities within their NDCs or from authorizing such activities under Article 6.

2.5 Outlooks for eCDR in developing countries

The case and prospects for deployment of eCDR in developing countries appear somewhat mixed. On the one hand, there are strong voices against any, or at least any significant, use of eCDR in the global south. These views draw primarily from moral hazard and climate justice perspectives. At the level of implementation, concerns also stem from environmental integrity risks posed by weak governance and regulatory capacities to provide lasting assurances against non-permanence and compensation/remediation in the event of carbon reversal (see Section 4).

On the other hand, at least some developing countries are taking a more open view: analysis of Paris Agreement pledges shows evidence of interest in CCS generally, and growing interest in related eCDR methods, specifically BECCS and DACCS. Several countries explicitly describe the rationale behind mentioning eCDR in their NDC, namely: aiming to decarbonize existing fossil fuel industries, as well as the necessity of negative emissions through eCDR to achieve their net-zero targets to 2050. Indonesia, for example, states in the foreword of its LT-LEDS that decarbonization and achieving its net-zero target requires:

> "..reducing [a] substantial amount of coal consumption and implementing CCS/CCUS and BECCS." (Government of Indonesia 2021, p. i)

Other developing country regions are also seeking to take advantage of natural resource endowments to lead on advanced eCDR methods, in particular, Kenya (Box 2-2).

Furthermore, there is a strong case that early-stage climate mitigation technologies such as eCDR need action now so that they are ready for wider deployment at the time when net zero comes into sharper focus. For example, Ho (2023) among others suggests that, subject to radical and immediate emissions cuts, for CDR to be relevant in today's climate dialogue:

> "…research is needed to seek CDR methods that minimize land use and energy consumption, and can be scaled up radically and cheaply. Doing that now is essential, so that we have the technology available in the future, when it will be effective, and when it can be used to remove legacy emissions to address intergenerational justice". (Ho 2023)

Box 2-2 Direct air capture and mineral storage in Kenya

Kenya's Great Rift Valley—with its significant renewable energy potential (e.g. primarily geothermal, but also solar and wind) and manifestations of young, shallow, basalts—has, over recent years, become a hotspot for pioneering DAC with mineral storage. Several announced activities suggest multi-million tonne DACCS could be deployed in the Great Rift Valley region in coming years.

→ **Sirona Technologies**, a Belgium-based DAC firm, in partnership with **Cella**, a U.S.-based mineral CO_2 storage firm, are developing a DACCS project near Lake Elementaita in the Great Rift Valley. The plan for **Project Jacaranda** is to commence with 500 tCO_2 captured and stored in 2025—equivalent to one module of Sirona's DAC technology—scaling to 5,000 tCO_2 in 2026, 100,000 tCO_2 in 2028, and 1 $MtCO_2$ in 2030. Électricité de France (EdF) is providing renewable solar power to the project site. The project website hosted by Sirona Technologies[1] indicates that, so far, one DAC module has been deployed and drilling for storage has commenced. The same source also suggests that future power demand could be met from excess geothermal sources, since many such power providers with permits are not being exploited due to insufficient demand for the energy.

→ **Octavia Carbon**, based in Kenya, deployed a DAC pilot plant in 2024 near Naivasha.[2] The firm has also teamed with **Cella** since 2023 to develop mineral storage in the Great Rift Valley. Under Octavia's **Project Hummingbird**, the aim is to capture and store 1000 tCO_2/year in its initial phases.

→ **Climeworks**, a Swiss-based DAC plant developer and builder, has also stated its goal to deploy DACCS with mineral storage in Kenya's Great Rift Valley by 2028.[3] Since late 2023 the firm has been collaborating with **Great Carbon Valley**, a Kenya-based firm aiming to deploy DAC with geostorage anchored to green industrial hubs across Kenya.[4]

→ **Great Carbon Valley (GCV)** plans 15+ DAC sites by 2030 with the aim to reaching 1 $MtCO_2$ storage annually. GCV is backed by **Africa Climate Ventures.**[5] The GCV website also suggests that the firm is partnered with **Cella** and **CarbFix** (an Icelandic mineral CO_2 storage specialist).[6]

→ **RepAir Carbon**, an Israel-based DAC developer, announced in early 2024 that it has also teamed with **Cella's** injection project in the Great Rift Valley. The proposed **Project Acacia** intends to capture and store 1000 tCO_2/year in Phase 1, scaling to 50,000 tCO_2 in 2030.[7]

Source: (1) https://www.sirona.tech/project-jacaranda; (2) https://www.octaviacarbon.com/; (3) https://climeworks.com/press-release/climeworks-and-great-carbon-valley-chart-path-to-large-scale-dac; (4) https://www.greatcarbonvalley.com/; (5) https://africaclimateventures.com/; (6) https://www.greatcarbonvalley.com/projects/direct-air-capture; (7) https://www.repair-carbon.com/projects

Others also suggest that carbon markets can play a crucial role in supporting such innovations. For example, the Task Force on Scaling Voluntary Carbon Markets (TSVCM), a private sector-led initiative to re-energise market activity in the Paris Agreement era, recommended that:

> "Promoting emerging technology through voluntary carbon markets is critical to help bring these solutions to scale and reduce costs" (TSVCM 2021, p.9) [and that]
>
> "Rapid-supply scale-up action across all offset categories is required from today … to overcome mobilization challenges and long lead times to ensure that demand can be met in the run up to 2050 and beyond. This includes early investment in technology-based removals to ensure sufficient scale at accessible costs in 2050…" (TSVCM 2021, p.70)

Moreover, the need for *all* Parties to contribute to the Paris Agreement's net zero goal lends itself to a subtle shift towards a more ubiquitous distribution of climate action. For the Paris-aligned goals to be met, both developed and developing countries will need to deploy CDR, albeit likely to be in varying amounts. As such, eCDR can be expected to play a dual role in the coming decades to 2050: for developed countries, a hard push as they aim to reach net zero by 2050 or before; for developing countries, more opportunistic moves that allow them to gain experience and monetize actions through carbon markets according to national circumstances and priorities. The latter can be further underscored by the power of carbon markets to drive climate mitigation actions in locations where they are most efficient and cost effective.

In support of such progress, precedents for best practice exist. Under the Kyoto Protocol, six years of substantial and complex negotiations for engineered climate solutions involving fossil CO_2 capture with geological storage (i.e. CCS) ensued over the period 2005 and 2011. These culminated in agreement of dedicated rules for CCS in the CDM: the *Modalities and procedures for carbon dioxide capture and storage in geological formations as clean development mechanism project activities* (CCS M&Ps; UNFCCC 2011; see also Dixon et al. 2013). Key to acceptance was the establishment of legal and regulatory safeguards, assurance and insurance mechanisms for host countries and project participants (Box 2-3). Unlike afforestation/reforestation projects, this framework was considered sufficiently robust to allow the issuance of permanent/non-temporary CERs to CCS activities. However, the CDM decline from around 2012 meant that no practical implementation experience was gained.

Over recent years, the ICPs in the VCM have developed methodologies for CCS and eCDR that, for at least those methods involving geological CO_2 storage, have taken design cues and precedents from the approach developed under the CDM (see below).

Yet more work is needed. Over the period 2010-2015, the World Bank CCS Trust Fund explored regulatory programmes for geological CO_2 storage in various developing countries including South Africa, Botswana, Egypt, Jordan, Morocco and Mexico among others. But so far few, if any, have implemented domestic governance arrangements for CO_2 storage.

Box 2-3 Summary of requirements for CCS projects under the CDM

For host countries:

Parties wishing to host geological CO_2 storage activities under the CDM must:

1. Submit an expression of agreement to the UNFCCC secretariat to allow the implementation of CCS project activities in its territory;
2. Indicate whether or not they accept an obligation to address carbon reversal in project approvals/.
3. Establish laws or regulations which:
   a. Set procedures that include provisions for the appropriate selection, characterization and development of geological storage sites.
   b. Define rights and access to store CO_2 in subsurface pore space.
   c. Provide for timely and effective redress for affected entities and ecosystems, including in the post-closure phase.
   d. Provide for timely and effective remedial measures to stop or control any unintended CO_2 leaks, and to restore long-term environmental quality significantly affected by a CCS project activity.
   e. Establish means for addressing liability arrangements for CO_2 geological storage sites.
   f. Establish measures to address an obligation to address carbon reversal.

For project proponents:

1. Five percent of all issued CERs to be withheld in a reserve account, which may be accessed to address a carbon reversal.
2. Conduct a minimum of 20-years post-injection storage site monitoring.
3. Submit monitoring reports at intervals no greater than every five years.

Source: UNFCCC (2011) Decision 10/CMP.7

Furthermore, the extent to which similar assurances are needed, or can even be achieved, for other eCDR methods not utilising geological CO_2 storage remains an open question. As outlined below, some methodologies are seemingly applying different types of requirements and obligations for project activities and eCDR methods, which is producing unevenness across the eCDR sector. Variation in standards can impact upon financing, market functioning and credit fungibility, as considered further in Section 4.

Mindful of these points of departure, the next section considers the current status of such methodological and governance frameworks.

3 Methodological Features

3.1 Background

Over recent years, the business case for eCDR has almost exclusively relied on the forward sales of carbon (removal) credits in lieu of future deliveries from individual project activities. This has largely been a private sector-led, voluntary, enterprise working alongside ICPs, although governments are also now stepping in to the marketplace.

The approach to carbon credit origination draws from project-based accounting methods that evolved in the VCM and the CDM over the last 20 years or so.[12] Design features for project-based accounting methodologies typically encompass the following elements:

1. Eligibility or applicability conditions
2. Boundary setting and leakage identification
3. Baseline scenario, baseline emissions and additionality determination
4. Project emissions, accounting, monitoring and measurement, and
5. Non-permanence and carbon reversal risk.

The registration of projects and issuance of credits typically involves a two-step procedure following the rules of the selected programme and the relevant methodology: (i) submit a project design document (PDD) to the crediting programme, which includes an *ex ante* estimate of credit generation, and which is assessed for registration or rejection; (ii) subject to registration: after project start, measure/monitor the same parameters and/or assumptions as in the PDD to establish and report an *ex post* calculation of emissions and removals. Credits are issued on the basis of the ex post monitored, reported and verified emission reductions or net removals.

Drawing from these basic requirements, this section considers the building blocks for project-based accounting for eCDR methods in terms of the methodological design elements listed in items 1 to 5 above. Specific 'fiches' for various eCDR methods are presented summarising how methodologies address various design aspects (per Table 1-1 and Annex A). Gaps and uncertainties are summarised at the end.

[12] Project-based accounting seeks to estimate the net GHG effect of implementing a specific, discrete, definable, mitigation activity (reduction or removal intervention) relative to how GHG emissions and/or removals would have occurred in its absence. The latter component relies on developing a counterfactual baseline scenario using location-specific policy, legal, regulatory, technological and financial circumstances to discern *baseline emissions* and demonstrate the *additionality* of the action.

3.2 Calculating net removals

The methodological framework to estimate credits or certificates to be awarded to a CDR activity under project-based accounting approaches is illustrated schematically below (Figure 3-1). Based on Figure 3-1, net removals may be calculated as:

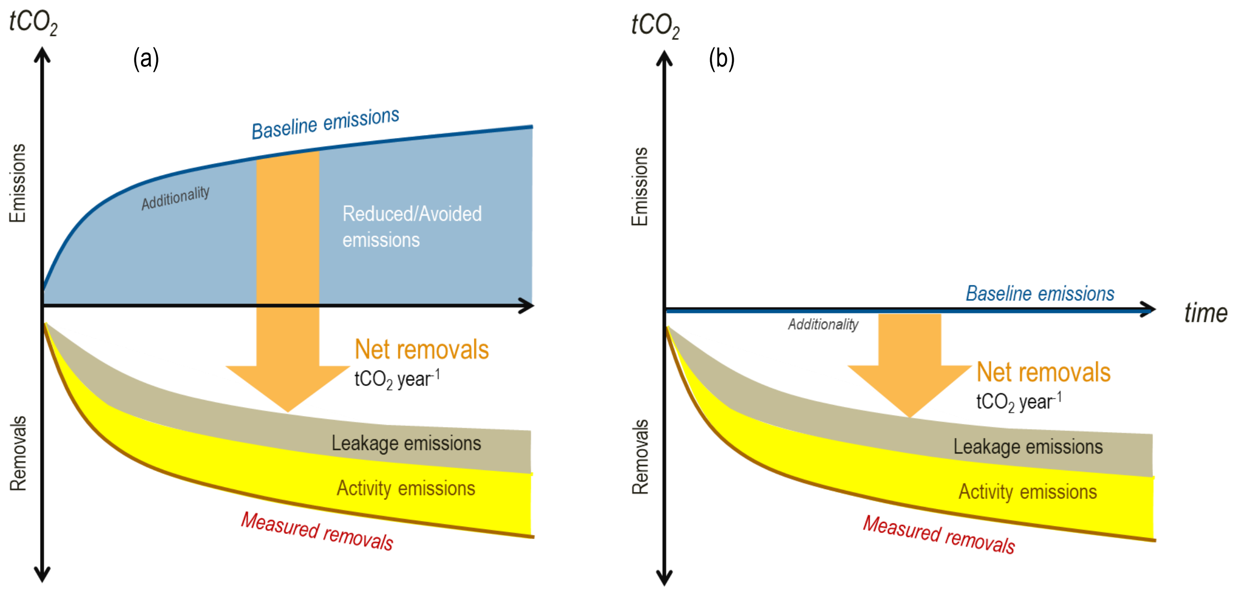
$$NR_p = BE_p - (MR_p + AE_p + LE_p)\,^{13} \qquad \textit{[Equation 1]}$$

Where;

NR = Net removals (tCO_2 or tC)
BE = Baseline emissions/fluxes (tCO_2 or tC)
MR = Measured removal/C stock change (tCO_2 or tC)
AE = Activity emissions/fluxes (tCO_2 or tC)
LE = Leakage emissions/fluxes (tCO_2 or tC)
p = relevant measurement period (e.g. 1 year)

Methodologies and related documents for eCDR crediting (Annex A) seek to prescribe approaches to data collection and processing for use as inputs to this general method.

Figure 3-1 Project-based accounting (schematic)



Source: adapted from IEAGHG (2024). Note: project-based accounting allows for estimated net removals to include a quotient of emission reductions/avoidance, per the blue wedge in (a) (e.g. where emissive activities occur in the baseline scenario but not in the project scenario). An example would be waste-to-energy with CCS, which co-captures biogenic and fossil CO_2 originating from mixed waste streams. In many eCDR situations the activity is undertaken solely for climate mitigation purposes and therefore has a baseline without any emissions or removals, per (b) above (i.e. zero baseline). The project scenario needs to be *additional* to the baseline scenario.

[13] Adjustments may be applied to switch between negative emissions (-) and net removals (+), and to account for circumstances where the baseline includes carbon removal.

3.3 Features of eCDR methodologies

3.3.1 Applicability and Eligibility

Crediting or quantification methodologies are designed for specific CDR activities (see Annex A) and often include certain conditions for when they can and cannot be used. These are usually defined in 'applicability' or 'eligibility' requirements.

Applicability or eligibility conditions can be a way for programme operators to establish assurances over the legality, environmental integrity and quality of the underlying activity, and to ensure that technical parts align with the methodological approach.

For eCDR activities, applicability and eligibility conditions can be broadly divided along the following lines (see examples in Table 3-1):

- **Technical**. Establishing conditions or restrictions on, for example, CO_2 sources, carbon capture technology types, modes of CO_2 transport, carbon storage media; biomass sources; types of products for storage; other feedstock requirements etc.
- **Geographical/Jurisdictional**. Defining any jurisdictional conditions under which the methodology may or may not be used. These can feature constraints on CO_2 capture, transport and storage, and the legal and regulatory requirements (e.g. prescribing the types of local permit needed, or the conditions to be covered by a permit).

Table 3-1 Examples of eligibility conditions in eCDR methodologies

	Technical	Jurisdictional
Geological reservoirs	**Enhanced oil recovery** (EOR): ACR limited to only EOR. Others explicitly exclude EOR (e.g. Gold Standard; Puro.earth; Isometric; ECCC; EU). **Saline aquifers**: all except ACR **Depleted oil & gas fields**: all except Isometric **Sub-seabed**: explicitly excluded by Gold Standard **In situ mineralisation**:[1] explicitly covered in Puro.earth and Isometric. May be implicitly eligible (e.g. Gold Standard, Verra/VCS, EU, BSI).	ACR: U.S. and Canada only Alberta: Alberta ECCC: Canada EC: European Union and EEA BSI: UK (but with global relevance) Other ICPs: some ambiguity over permits: several refer to EU, U.S. or "equivalent".
Products	**Biochar use**: construction products (e.g. cement, concrete or asphalt in EU and Isometric); various uses (Puro.earth covers digestate, construction etc; Verra subject to proof of permanence). **Captured CO_2**: $CaCO_3$ product where not thermally decomposed (Gold Standard Puro.earth); various uses involving carbonation (e.g. concrete curing; Isometric)	None.
Feedstocks	**Biomass**: all emplace restrictions (see below). **Alkali materials**: Puro.earth and Isometric emplace conditions on the application sites and the source rocks (e.g. silicate rock)	Only land and not aquatic environment (Puro.earth EW) Agricultural land as defined by FAO (Isometric EW)

Notes: [1] Injection of CO_2 dissolved in water into basalts for the purposes of geological storage by rapid shallow mineralization.

Other quality aspects indirectly addressed though eligibility conditions include:

- **Biomass feedstocks**. Constraints and requirements for biomass used in the project, which can provide assurances that the carbon stock at the source is in equilibrium and therefore leads to a net removal of CO_2 when captured and stored (see Box 3-1).
- **Non-permanence and carbon reversal**. Requirements for alignment with, or reliance upon, existing national/regional rules and regulations relating to storage (especially the permitting of geological storage sites) or conditions for the product (see below).

3.3.2 Boundaries and Leakage

The activity boundary determines the components and data to be included when calculating net removal by an eCDR activity, typically encompassing lifecycle or value chain emissions that may need to be included in the estimate, or otherwise mitigated through measures.

An activity boundary is typically defined according to the GHG sources, sinks and reservoirs that are altered by an activity (IC-VCM 2024), within a defined spatial/geographical area (IC-VCM 2024) and/or under control of the project participant (UNFCCC 2005). Sources, sinks and reservoirs of GHGs inside the boundary are counted as project emissions.

Box 3-1 Accounting of carbon transfers from short (bio) to long (geo) carbon cycles

Using biomass for eCDR (e.g. BECCS) only produces a net removal effect if appropriate management is applied to maintain the source biological carbon stocks (i.e. growth and harvesting remaining broadly in balance or as a net removal). Information on biological carbon stocks is recorded in the land use, land use change and forestry (LULUCF) section of a country's national GHG inventory (NGHGI), with the assumption that carbon in harvested biomass is mostly instantly emitted to the atmosphere.

If national biological carbon stocks reduce across a reporting year, this is recorded as an emission to the atmosphere in the LULUCF reporting category. Conversely, if national biological carbon stocks increase, this is reported as a net removal. Biogenic waste material is also accounted for in the same way, assuming that it is either recorded as an emission upon harvesting or there is short-term equilibrium between growth and decay (e.g. as is the case with non-woody crops or with wastewater sludge). Biogenic waste residues may also be assumed to be either left to decay in situ (which can be recorded as methane emissions) or combusted by another user.

Reporting emissions generated by the combustion of biomass in the *Energy* reporting category of NGHGIs would result in double counting. Hence, biomass combustion emissions are recorded but zero-rated in the *Energy* category of a NGHGI. When these same emissions are captured and geologically stored, they are recorded in the *Energy* category as a negative emission (IPCC 2006). The accounting is correct since BECCS produces a carbon stock transfer from the fast biological carbon cycle into the slower geological carbon cycle (see e.g. Zakkour et al. 2014).

Yet, for some land management practices and/or forest management approaches, biological carbon stocks may be depleting due to overharvesting and/or through other longer-term unsustainable land management practices (e.g. soil erosion). Increasing demand for biomass for energy may also drive land use change through displacement of existing users onto previously unmanaged land or conversion of forest land to cropland (leakage through indirect land use change; iLUC).

The extent to which these impacts are effectively recorded, reported and managed depends on the quality of the NGHGI of countries supplying biomass, which in many cases is patchy (see Zakkour et al. 2014).

Methods for eCDR involve long value chains including the upstream supply of energy and materials to an activity site and the downstream transport and storage of carbon or CO_2. The choice of boundary and consideration of leakage effects are therefore crucial to determining an activity's overall net negativity: removing CO_2 in one location while simultaneously creating significant new sources of GHG emissions elsewhere undermines the environmental integrity of an activity and the resulting credits. Although project-based methods are inherently 'consequential' (see IEAGHG 2024), concern over leakage risks is leading stakeholders to increasingly call for lifecycle accounting to ensure only net effects are measured (Box 3-2).

Methodologies from Puro.earth and Isometric typically require a wide range of lifecycle sources to be counted as project emissions drawing on the concepts of cradle-to-grave lifecycle assessment (construction, decommissioning, materials consumption, land use change from site development and so on). Verra/VCS (in the VM0049 methodology), ECCC (2025), EC (EC 2025) and BSI (BSI 2025a; BSI 2025b) also take account of similar types of lifecycle emission sources for BECCS and DACCS. Usually, one-off project emissions from construction and decommissioning may be amortized across an activity's operational lifetime to soften the impacts upon credit flows early on in a project lifecycle.

Box 3-2 Lifecycle accounting to determine overall net negativity of CDR

Mindful of the potential adverse side effects of emissions intensive supply chains, both standard-setters and the buyers of eCDR credits are calling for lifecycle approaches and value chain accounting to ensure high quality and integrity.

On the buyer side, Carbon Direct and Microsoft (2024), for example, require that projects seeking funding under the Microsoft CDR Program deliver net negativity[14] by, inter alia, accounting for and reporting:

> "…all GHG emissions associated with a CDR project using repeatable and verifiable GHG quantification methods"…[generally requiring]…"the use of cradle-to-grave life cycle assessments (LCAs) and/or models that accurately estimate CDR, calibrated by periodic direct measurement." (Carbon Direct and Microsoft, 2024. p. 11)

Other buyer groups engaged in CDR credit purchases echo similar sentiments.[15]

On the supplier side, ICPs and other standard setters are implementing wide accounting boundaries and sometimes requiring LCA-style GHG assessment in support of CDR activity certification. For example, the European Union carbon removal and carbon farming certification regulation (CRCF)[16] requires that quantification of carbon removal takes account of, inter alia, the associated GHGs covering:

> "…the increase in direct and indirect GHG emissions over the entire lifecycle of the activity which are attributable to its implementation, including indirect land use change" (Article 4)

Puro.earth and Isometric require cradle-to-grave GHG assessments prior to registration, and ongoing ex post monitoring of identified lifecycle components.[17] BSI has similarly applied wide boundaries in its Flex standards for BECCS and DACCS.

However, these calls notwithstanding, variations persist in the way eCDR methodologies treat different sources, especially *potential* downstream emissions from the storage reservoirs enhanced by different eCDR methods.

[14] Demonstrating evidence of removing atmospheric carbon dioxide on a lifecycle basis (https://www.microsoft.com/en-us/corporate-responsibility/sustainability/carbon-removal-program).
[15] Frontier includes a purchase criteria of net negativity (https://frontierclimate.com/apply),
[16] Regulation (EU) 2024/3012 of the European Parliament and of the Council of 27 November 2024 establishing a Union certification framework for permanent carbon removals, carbon farming and carbon storage in products.
[17] Isometric protocols typically refer to a "cradle-to-grave GHG Statement…encompassing the GHG emissions relating to the activities outlined within the system boundary", which is similar to a LCA.

A temporal boundary may be applied to delineate monitoring and accounting responsibilities for longer-term non-permanence and carbon reversal risks (see Section 3.3.5). Isometric defines leakage to include emissions “outside the …temporal boundary of a project...”

The long value chains of eCDR methods and the broad prescription of lifecycle GHG accounting with wide boundaries (Box 3-2) introduces significant complexity for data collection and uncertainty management and poses challenges for ex post monitoring.

Any sources of GHG emissions that are reasonably attributable to a project activity but occurring outside of the project boundary are typically treated as leakage emissions (UNFCCC 2005; UNFCCC 2024b). Leakage emissions can arise from the following (based on IC-VCM 2024): [18]

1. **Activity-shifting**, where the mitigation activity causes emissions, and/or agents thereof, to shift to locations outside of the project boundary
2. **Market leakage**, where the mitigation activity has an impact on the supply or demand of an emissions-intensive product or service, thereby increasing or decreasing emissions elsewhere.
3. **Ecological leakage**, where a mitigation activity affects emissions indirectly (e.g. places more pressure) on nearby ecosystems (e.g. that are hydrologically connected).

In the case of eCDR, the following three sources of leakage are considered within methodologies:

- **Biomass consumption**. Activity shifting (direct and indirect land use change; dLUC/iLUC) and market leakage (previous users forced to source other, less sustainable, biomass materials)
- **Energy/electricity consumption**. Market leakage (e.g. low carbon intensity/renewable energy users having to move to other, more carbon intensive, supply sources)
- **Materials production and consumption**. Market leakage (e.g. previous users of alkaline/weathering rock materials switching other, more carbon intensive, supply sources)

The approach taken towards leakage emissions tends to be either mitigation/prevention, leakage quantification, or a combination of both.

Biomass and leakage

Biomass is a significant source of leakage risk for several eCDR methods (Box 3-1). Therefore, eCDR methodologies involving biomass implement various conditions on its source, and require project proponents to either track its origins and/or to use third-party certification standards to demonstrate its sustainability and traceability (Box 3-3).

[18] Note. Verra VM0049 also considers everything up- and downstream of the activity site to be leakage.

Box 3-3 Biomass sourcing, zero-rating and mitigating leakage

Methods of eCDR using biomass (BECCS, bio-oil, biochar etc) only create a carbon removal if appropriate management is applied to the biomass source (Box 3-1). At the activity level there are challenges to discern whether the upstream supply source jurisdiction is effectively accounting for the full GHG effects of biomass use and appropriately quantifying and reporting a full NGHGI encompassing possible dLUC/iLUC leakage effects inside the source country.

To fill this gap, eCDR methodologies using biomass tend to set requirements for biomass 'sustainability' as a proxy indicator of leakage risk management and mitigation. Sustainability assessment approaches generally consist of, firstly, a biomass classification system (e.g. waste; forest products; agricultural products; other) and, second, sustainability and traceability criteria/conditions for each type. For example, requirements from Verra (VMD0059, Appx. 1) include (in sum):

- **Traceability**. Provide relevant data on e.g. biomass type and category, volumes, origin, modes of transportation employed, certification, chain of custody information etc.
- **Sustainability.** Subject to demonstrated traceability, the following applies:
  - *Waste*. Considered to be 'sustainable' by default = no leakage (subject to demonstrating that it is waste).
  - *Forest and agricultural products*.

    Compliance with regulatory/certification programmes:

    - A recognised regulatory programme (e.g. EU Renewable Energy Directive; UK Renewable Obligation Order) *or* an alternative regulatory programme meeting listed requirements (below)
    - An eligible certification programme (e.g. Forest Stewardship Council; Sustainable Biomass Program; International Sustainability and Carbon Certification etc) *or* an alternative certification programme meeting listed requirements (below), or,

    Compliance with listed requirements: biodiversity; sustainable forest management; soil heath; water; food security; social sustainability; LULUCF (country of origin must have current NDC covering LULUCF); cascading use.
  - *Other*. Not sustainable.

Where the above conditions are not met, VMD0059 variable ways of accounting are applied (e.g. market leakage effects are to be quantified following methods in *CDM TOOL16 Project and Leakage Emissions from Biomass*; UNFCCC 2022).

Puro.earth follows a similar approach to Verra, with mitigation of biomass leakage risks through conditions set in the *Puro Biomass Sourcing Criteria*, and the assessment and quantification of unmitigated leakage emissions (circumstances where the criteria are not met during operations). Isometric, in its *Biomass Feedstock Accounting* module, also follows a similar approach, with an assessment of direct and indirect market leakage effects of biomass sourcing using multi-criteria and allowing 'zero leakage' emissions to be applied to materials meeting the criteria. This can include third party certification programmes for forestry biomass. Where the *Counterfactual Storage* scenario results in CO_2 remaining stored, the biomass is deemed ineligible. The GCC methodology requires project participants to use *CDM TOOL 16* (UNFCCC 2022). The CRCF (EC 2024) requires that certification methodologies, among others:

- Promote the sustainability of biomass in accordance with the sustainability and GHG emissions saving criteria for biofuels, bioliquids and biomass fuels laid down in Article 29 of the Renewable Energy Directive (EU 2018/2001);
- Ensure the consistency of the application of the principle of the cascading use of biomass as per national authorities in accordance with Article 3 of the Renewable Energy Directive (EU 2018/2001);
- Ensure the avoidance of unsustainable demand for biomass raw material.

These requirements are mirrored in the EU's draft BECCS methodology (EC 2025).

In circumstances where the biomass used in activities cannot be demonstrated to be sustainable, usually no carbon removal credits are awarded. Verra allows for some *sustainable* but *non-traceable* biomass to be counted as an emission reduction (*VT0013 Differentiating Reductions and Removals in CCS Projects*).

Low carbon energy supply and leakage

Energy requirements for liquid- and solid-DAC (L-DAC/S-DAC) are, respectively in the order of 5.5-8.8 GJ (1,500-2,400 kWh) to 7.2-9.5 GJ (2,000-2,600 kWh) per tCO_2 captured (IEA 2022). The source of energy used therefore has significant impacts upon the net negativity of DACCS activities.[19]

Most eCDR methodologies applicable to DACCS therefore place conditions on the way in which emissions from electricity and heat supplied to the process can be counted when quantifying net negativity. Cues for accounting design come from the EU rules on renewable fuels of non-biological origin (EC 2023), the UK Low Carbon Hydrogen Standard (DESNZ 2023b) and the U.S. Clean Hydrogen Production Tax Credit (IRS 2025), as hydrogen production by electrolysers faces similar energy and GHG efficiency concerns. The key methodological requirements are outlined below (Box 3-4).

Box 3-4 Energy accounting in energy intensive eCDR systems

Significant effort has been devoted to the assurance and MRV of low carbon intensity (CI) or renewable energy use in DACCS (hereafter 'low CI' energy), including the avoidance of potential leakage effects (e.g. market leakage due to previous low CI energy users switching to other, more emissive, energy sources). The various methodological approaches include many nuances, but in general, assurances over low CI energy include requirements to:

1. Use low CI energy self-generated onsite ("behind-the-meter").
2. Use low CI energy generated offsite from sources owned or otherwise purpose-built for the DAC facility operator and acquired via a wheeling agreement (see e.g. Verra VT0010), and/or
3. Procure low CI/renewable energy through 'green' power purchase agreements (PPA)

   - Wheeled power or PPAs subject to:

     a. The DAC facility and low CI power plant(s) being on the same electricity transmission system, eGRID subregions (U.S./Canada), bidding zone (EU) or equivalent;
     b. Environmental attribute certificates (such as renewable energy certificates) issued to the power plant(s) being acquired and retired by the DAC facility operator;
     c. Matching of expected demand and contracted supply.
4. Procure or otherwise acquire waste heat, subject to among others:
   a. Evidence that the waste heat was previously non-recoverable by the third party
   b. The underlying process is not expanded because of the heat demand of the DAC facility

Where these conditions are met, the energy used at the DAC facility may be zero-rated. To date eCDR methodologies are not allowing the application of 'virtual' green PPAs.[20]

Temporal correlation, the time matching of dispatched power and its use by the eCDR project, is also an active methodological topic. Some stakeholders argue that the granularity of temporal correlation needs to be very high because of diurnal and seasonal imbalances in renewable energy supply (i.e. intermittency) and DAC energy demand, meaning that DAC facilities are likely to use electricity supplied from high emission sources at some points across a daily and yearly

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[19] Notably, S-DAC systems can exhibit higher carbon removal efficiency under certain conditions, particularly when cleaner electricity is available or when process co-benefits (e.g., water recovery) are factored in. Therefore, while L-DAC may require less energy per tonne of CO_2 captured, this does not always translate to superior environmental performance. (IEAGHG 2025)

[20] The counting of low CI energy solely on the basis of the purchase and retirement of environmental attribute certificates (EACs) without any contractual linkage (PPA or wheeling agreement) or geographical linkage/correlation (supply and offtake in different electricity transmission systems).

cycle. Others argue that temporal correlation higher than annual matching is not technically feasible or is financially prohibitive. Variations currently exist in expectations around temporal matching, including:

- **EU CRCF** (EU 2025); **BSI** (2025b): annual matching, with review of hourly matching aligned with EC (2023) by 2028
- **Isometric** (Energy Accounting module): hourly matching (>200 GWh/yr) or annual matching under certain conditions.
- **Puro.earth** (Geologically Stored Carbon methodology): annual matching, with the expectation of a transition to hourly matching in future.
- **Verra** (VT0010): annual matching, with view to increasing the reconciliation frequency.

To mitigate market leakage risks, the vintage of the low CI power plant is also considered. Limiting procurement of low CI electricity to recently built (or repowered) plants provides indications that the risk of diverting it from other users is minimised, a topic referred to as the 'additionality' of power (after EC 2023). Most eCDR methodologies set a maximum period of 36 months between the operation of the power plants under procurement and the eCDR project (Isometric; Puro.earth; EC; BSI).

Puro.earth (Geologically Stored Carbon methodology) and previous versions of the Isometric Energy Accounting module (v1.1) allow for low CI energy leakage to be managed by relying on existing regional and local policies and measures, such as sourcing electricity from plants covered by ETSs and power sector decarbonization plans, if present.

Materials use and leakage

Leakage emissions relating to the acquisition of other non-energy system inputs is also covered in some eCDR methodologies. For example, Isometric methodologies variously include market, activity-shifting and ecological leakage arising from "feedstock replacement", "replacement of consumables" and/or "replacement emissions" as generic requirements. Exemptions apply for waste material. Similarly, Puro.earth (EW methodology) mentions the possibility that leakage could occur where the EW feedstock material:

> "…was already used to deliver another product or service, and thereby possibly entail the extraction of additional primary material, if demand persists".

In such circumstances, Puro.earth requires that the project LCA include emissions from primary material extraction, ex ante, which shall be counted as *economic* leakage during project quantification, ex post.

3.3.3 Baseline and Additionality

The net removals achieved by an activity are calculated relative to baseline emissions, which may, depending on the scope of the methodology, include emission reductions/avoided emissions (Figure 3-1). The reviewed eCDR methodologies establish the baseline scenario in various ways including being:

- The most plausible baseline scenario among all realistic and credible alternatives, following the *CDM TOOL 02 Combined tool to identify the baseline and demonstrate additionality* (UNFCCC 2017; for example, GCC and Gold Standard);
- A conservative scenario of what likely would have happened without the activity, and revenues from carbon finance (Puro.earth, various)
- The scenario where the activity does not take place in the absence of carbon finance and any project infrastructure is not built (Isometric);

- In the case of biomass use, the assumption that the waste biomass is either left to decay or combusted for purposes other than energy production (Puro.earth; Verra VM0044 and VM0049). Usually, any emissions of methane from biomass decay are not counted for reasons of conservativeness. Isometric is alone in requiring a *Counterfactual Storage* scenario to be considered (see below).
- In the case of BECCS, dependent on whether the activity is a new-build or a retrofit of CO_2 capture to an existing biomass energy plant. In the cases of retrofit, the construction emissions already occurred and the supply chain and associated emissions already exist and may therefore be omitted from the project emissions calculation (Verra; Puro.earth; Isometric; EC; BSI).

Many eCDR methodologies build around a baseline scenario of 'no removals', and therefore baseline emissions (or removals) of zero (0). However, certain baseline scenarios may also produce baseline emissions above or below zero:

- >0, if there is fossil CO_2 or other types of GHG emissions in the baseline scenario that are mitigated by the activity (e.g. the fossil CO_2 fraction emitted by a waste-to-energy plant prior to implementation of CO_2 capture/BECCS; Figure 3-1(a)). Puro.earth, for example, allows for "…non-zero baseline emission claims if sufficient scientific demonstration is provided and accepted".[21]
- <0, where CO_2 drawdown may passively take place without the activity (e.g. weathering by minerals absent of their use in a project activity). For example, Isometric methodologies and modules include a *Counterfactual Storage* test to determine whether or how much of the CO_2 drawdown achieved by a removal activity is eligible for crediting: where captured CO_2 would otherwise remain stored in biomass, the activity is ineligible; where captured CO_2 is used in mineral storage, the natural CO_2 drawdown by the minerals absent of the activity should be counted within the baseline.

Additionality is an essential property of high-integrity carbon credits (e.g. IC-VCM 2024).[22] In general, eCDR activities are undertaken solely for the purpose of climate mitigation and are therefore typically viewed as fully additional. However, in some eCDR methods—such as those involving biogenic wastes or adding alkalinity to fields and watersheds—co-benefits could also feature in the business case (e.g. waste disposal; soil treatment; water treatment). In some cases, the activity may have already been carried out for other purposes (e.g. buffering wastewater; de-acidification of river catchments).

While some eCDR methodologies assume blanket additionality (similar to a positive list), most of the reviewed eCDR methodologies still require the typical project-level assessment and demonstration covering:

1. **Regulatory additionality/surplus** (e.g. exceeds legal requirements)

[21] This could include methane from biomass decay; Puro.Earth *Biochar Methodology*.
[22] That the activity/intervention would not have occurred absent of the incentive of carbon credit revenues.

2. **Financial additionality** (e.g. significant economic barriers to activity to implementation absent of credits) and
3. **Common practice** (e.g. not widely applied in the sector or region).
4. **Performance standards/benchmarks,** where the activity must produce more removals than the baseline, also apply in several methodologies (e.g. ACR, GCC, Isometric).

3.3.4 Project emissions, accounting, monitoring and measurement

Robust MRV is widely accepted as crucial to carbon crediting (e.g. World Bank 2022; IC-VCM 2024) and 'high quality' CDR is no different (e.g. Mercer and Burke 2023; UNFCCC 2024a). Indeed, the absence of robust MRV has been cited as a barrier to CDR deployment (EC 2021).

Thus, sound approaches to the monitoring, measurement and reporting of various energy, material and carbon flows across eCDR value chains is needed to determine, within acceptable levels of accuracy and conservativeness,[23] the gross CO_2 drawdown, the emissions involved in delivering such an effect, and any subsequent re-release of captured carbon during transport or storage (e.g. due to reverse reactions or reservoir fluxes leading to carbon reversal; Figure 3-1).

These calls notwithstanding, the reviewed eCDR methodologies show variations in the way monitoring is applied to different eCDR methods. Approaches include:

- **Continuous or intermittent direct monitoring (activity data)**. This is required for many system components, such as for energy consumption and supply, materials supply, and, in many cases, carbon and CO_2 flows at various stages of capture, transport and storage. For methods involving passive drawdown (e.g. alkalinity methods such as EW), direct observation of the carbon sink/CO_2 drawdown is not applied. Monitoring/observation of the carbon reservoirs is also not always prescribed and depends on the nature of the store.
- **Modelling**. The complex, unobservable, nature of the CO_2 removal effect for some methods (e.g. alkalinity methods) and/or the fate and behaviour of CO_2 in the storage reservoir or carbon products in the environment usually call for predictive models (e.g. carbonates and bicarbonate, collectively, dissolved inorganic carbon; DIC). The extent to which ex post observations can be used to verify and calibrate models varies significantly across environmental pathways and reservoir types, as well as standard setters (more details for specific methods are set out below).
- **Assumptions and published sources (emission factors)**. Many input parameters, especially emissions associated with material inputs/consumption, construction, and decommissioning emissions, rely on published (e.g. Ecoinvent) or self-generated emissions factors, which can introduce uncertainty and unevenness.

[23] Acceptable can mean striking a balance between scientific and political confidence and technical and economic feasibility.

- **Assumptions using 'cut-offs'[24] (with zero-rated emission factors)**. Some up- and downstream system components are handled through proxy indicators of system input performance/quality. The approach truncates the project/lifecycle boundary, implicitly limiting the need for direct monitoring. Examples include using biomass sustainability certification as a proxy indicator for mitigation of dLUC/iLUC leakage effects (Box 3-3) and low CI energy certificates as a proxy for mitigation of project and leakage emissions from energy use (Box 3-4). In the examples, the cut-off approach supports the assumption of low or zero emissions, zero-rating, or other fixed factors for system inputs.

Cut-offs simplify monitoring requirements and reduce methodological complexity but should involve monitoring of the proxy indicators (e.g. biomass certificates; EACs for procured electricity). Some methodologies also use a form of cut-off to account for potential emissions from the storage reservoir by either:

- Assuming permanence with zero reversal risk (predicated on stated conditions for the production process or for the stability of the carbon storage reservoir; see below).
- Application of a fixed factor to account for possible future reversals, or
- Using modelled estimates of carbon reversal risk/potential, which acts like a cut-off.

In some cases, ongoing monitoring of the carbon reservoir is required. Requirements vary according to the storage and reservoir type (see Table 3-2; Section 3.3.5). Several eCDR methodologies also extend accounting and/or monitoring components to temporal aspects at either end of the operational lifetime of the project (see Section 3.3.5).

3.3.5 Non-permanence and carbon reversal

Following removal of carbon from the atmosphere, eCDR methods emplace it into enhanced carbon reservoirs for long-term storage. Repositories include the lithosphere (geological reservoirs), the hydrosphere (rivers, lakes and the ocean) and the technosphere (the built environment). Features of each are summarised below (Table 3-2).

Storing carbon in enhanced reservoirs presents some unique methodological issues relative to other mitigation activities and methodologies: principally, most mitigation technologies permanently *reduce* or *avoid* the formation of CO_2 by replacing emissive activities with similar, less-emissive, substitutes. Conversely, activities involving eCDR *remove* CO_2 that is already in atmosphere and *store* it for potentially variable periods of time as carbon or CO_2 in either closed, engineered, or open environmental systems (Table 3-2).

Therefore, unlike emission reduction activities, carbon removals (and CCS) remain prone to re-emergence of the CO_2 back to the atmosphere at some future point in time, which can vary according to the durability of the final storage reservoir. The *permanence* of storage has been

[24] In lifecycle assessment, "cut-off" means to exclude system components as immaterial. The term here is used to indicate that these system inputs are not directly measured but assumed to be of a given quantum or status based on other measures, such as proxy estimates or third-party certification.

debated in recent years, with previously fixed ideas of 1000+ years being somewhat modified over time (Box 3-5).

Table 3-2 Types of eCDR storage systems

Reservoir type	Storage type	Features	Implications for methodology design
Geological (engineered)	Closed system	Reservoir isolation/stability is a key feature driving storage site selection (closed system) Low risk of CO_2 fluxes across system boundary (mainly wells or unidentified connecting faults). Boundary can be delineated by predictive models with fairly high levels of confidence.	Modelled fate and behaviour of CO_2 to assess migration and reversal risks from the reservoir. Model can be calibrated through ex post observation (monitoring) of the storage system. Isolated system avoids need to consider counterfactual CO_2 fluxes/drawdown. Likelihood of reversal decreases over time through conversion of free-phase CO_2 to immobilised forms.
Construction (engineered)	Product	Stability of chemical bonds (i.e. mineral carbonate) provides basis for assuming long-term, stable, storage away from the atmosphere for extended durations (multi-century).	Limited scope to monitor carbon reservoir. Counterfactual/baseline product may be relevant (e.g. whether CO_2 drawdown would occur in situ over time, or whether other products would also durably store carbon). Likelihood of reversal predicated on assumptions on normal use and fate of product at end-of-life (e.g. no thermal or chemical decomposition of the carbon bonds)
Soil, Rivers, Ocean (natural)	Open system	Reservoirs are connected to wider environmental components (e.g. groundwater, rivers, atmosphere), therefore, challenging to delineate (open system). Potential exists for CO_2 fluxes to occur across storage media (system) boundary. Boundary can be delineated by predictive models with medium to low levels of confidence.	Modelled fate and behaviour of carbon species in the enhanced reservoir can be challenging to calibrate ex post through observation (monitoring; see Section 3.3.4). Counterfactual/baseline CO_2 drawdown must be accounted for and netted out. Storage subject to ongoing risk of perturbation through biological action and geochemical changes in the reservoir. Storage may lead to increased CO_2 fluxes elsewhere in the reservoir. Likelihood of reversal remains static or increases over time (see Section 3.3.5).

Note: biochar storage in agricultural soils is excluded from the scope of this study. Geological storage encompasses bio-oil injection and mineralisation.

Carbon reversal is the re-emission or flux of stored carbon from the reservoir back to the atmosphere as CO_2. Non-permanence and carbon reversal can encompass both natural/unplanned (e.g. seismicity in geological reservoirs; bicarbonate synthesis in oceans) and anthropogenically induced events (e.g. reservoir over-pressuring and caprock fracture; venting). For either, the likelihood, scale, attribution and timing of any future carbon reversal will be difficult to predict ex ante.

Box 3-5 How long is permanent?

The concept of permanence is proving to be a dynamic feature of climate policy discourses. Previous notions of permanence considered the benchmark to be a nominal 1,000 years, based on geological CO_2 storage. This view drew from the conclusion of the IPCC (2005), which stated that:

> "Observations from engineered and natural analogues as well as models suggest that the fraction retained in appropriately selected and managed geological reservoirs is very likely [probability between 90 and 99%] to exceed 99% over 100 years and is likely [probability between 66 and 90%] to exceed 99% over 1,000 years" (IPCC 2005, SPM, p. 14). [and that] "The fraction of CO_2 stored through mineral carbonation that is retained after 1000 years is virtually certain to be 100%."

In response to these findings, governments set about introducing regulatory frameworks to ensure appropriate selection, design and management of geological CO_2 storage reservoirs commensurate with achieving 1000-year storage durability.

More recently, alternative formulations have appeared. For example, a minimum storage threshold of a '500-year horizon' has been suggested by some (Ramirez Ramirez et al. 2022), albeit more in the context of LCA. The EU CRCF defines 'permanent carbon removal' as:

> "…any practice or process that, under normal circumstances and using appropriate management practices, captures and stores atmospheric or biogenic carbon for **several centuries**, including permanently chemically bound carbon in products, and which is not combined with enhanced hydrocarbon recovery." (EC 2024)

Operators in the VCM are generally adopting 100 to 1000-years or more permanence as a threshold (e.g. Puro.earth now labels methodologies as 100+ years or 1000+ years durability; Isometric is applying project durability labels of 1000+, 200+ or 60+ years). The IC-VCM (2024) in CCP principle #6 state that:

> "The GHG emission reductions or removals from the mitigation activity shall be permanent or, where there is a risk of reversal, there shall be measures in place to address those risks and compensate reversals"

The IC-VCM CCP assessment framework criteria also state that:

> "For Categories where there is material risk [of carbon reversal]… a 40-year minimum commitment to monitor, report, and compensate for avoidable reversals, from the start date of the mitigation activity, is required."

This suggests a de facto 40-year threshold for permanence, subject to reversals being 'avoidable'. The general sentiment is that a 40-year threshold primarily applies to activities involving biogenic reservoirs (forestry, agriculture, wetlands etc).

Brunner, Hausfather and Knutti (2024), drawing on climatic modelling of different storage periods, suggest that CDR storage periods of less than 1,000 years is insufficient to neutralize remaining fossil CO_2 emissions under net zero emissions.

Source: adapted from IEAGHG 2024

For climate policy and carbon markets, the temporal mismatch between credit issuance and potential reversal make non-permanence a vexing subject for policymakers, regulators, crediting programmes and stakeholders at large: a carbon reversal could occur a long time after credits were issued to an activity and applied by a buyer to balance contemporaneous emissions. The subsequent carbon reversal compromises the environmental integrity of those credits and the targets and/or policies against which they were applied and counted. Several approaches have been implemented or contemplated to address such concerns including temporary credits (where the buyer acquires the reversal risk), discounted credits (tonne year accounting) or assurance-based approaches with permanent credits (with the host retaining, de facto, the reversal risk). Burke and Schenuit (2023) present a taxonomy of approaches.

None of the reviewed standards apply temporary or discounted credits to eCDR. Rather, they rely on four broad building blocks to manage non-permanence and carbon reversal risks:

1. Quality assurance over storage reservoir suitability/durability (ex ante);
2. Monitoring and observation of storage reservoir for continued assurance (ex post);

3. Compensation/remediation in the event of identified carbon reversal; and
4. Arrangements for long-term stewardship of the carbon reservoir.

These are reviewed in turn below.

Quality assurance over reservoir suitability (ex ante)

Storage quality assurance is established in various ways across eCDR methodologies. The primary route is via applicability and eligibility requirements, based on the following:

Permitting with performance modelling, site assessment, risk assessment, monitoring, closure and post-closure arrangements

Methodologies covering geological (closed system) storage generally require project proponents to obtain government-backed permits for wells and geological storage sites (CO_2 or bio-oil).

In the approvals phase, permitting regimes typically implement requirements such as modelling of the injectate plume within the proposed reservoir (CO_2, bio-oil), providing the basis for durability performance assessment, risk assessment and site selection.

In the operational phase and beyond, permits are also subject to regulatory oversight linked to reservoir monitoring and reporting (e.g. of well data and CO_2 plume dispersion), site closure and post-closure arrangements.

The permit usually also sets out liability arrangements for remediating damages due to loss of CO_2 containment and carbon reversals (see: Box 2-3; IETA 2024; IEAGHG 2024), and in some cases includes conditions for transfer of reservoir stewardship. The regulatory permit assurance approach is taken by ACR, Verra (VM0049), GCC, Puro.earth (Geologically Stored Carbon Methodology) and Isometric (saline aquifers; in situ mineralisation; bio-oil injection).

Isometric methodologies involving alkalinity enhancement[25] also generally require various permits to be obtained (mainly with reference to U.S. effluent discharge permits), and a site pre-assessment incorporating, among others, conceptual models of plume dispersion (e.g. an ocean mixing model), planned dosing rate and calculation method, ecological baseline surveys, restoration plans in the event of negative impact detection, assessed interactions with similar overlapping projects etc.

Modelling and/or estimation of carbon reversal

Various methodologies use models to predict reservoir suitability, usually tied to permitting (per above). However, a permit for EW is not typically required, with relevant methodologies instead prescribing predictive modelling of carbon reversal as follows:

- **Puro.earth**. Losses from various pathways including from surface waters and ocean be accounted for by either measurement or "conservative estimation" (see below).

[25] Ocean alkalinity enhancement at outfalls, wastewater alkalinity enhancement and river alkalinity enhancement.

- **Isometric EW**. Model must be applied to estimate losses from (i) rivers/watersheds and (ii) ocean (covering e.g. outgassing, $CaCO_3$ precipitation; re-speciation of dissolved inorganic carbon; DIC)

Conditions on product use

Methodologies covering product storage systems (biochar or concrete curing) do not involve any permitting or modelling, but instead establish conditions on the product type and use with a requirement for 'proof' of no reversal risk:

- **Verra** (VM0044): requires scientific evidence of biochar durability for the given use, allowing for a zero-decay assumption (i.e. permanent storage). Where no such evidence is available, proponents shall apply the soil storage default "permanence adjustment factor due to decay of biomass".[26]
- **Puro.earth** (Biochar Methodology, v3): states that "Biochar used first in non-soil applications may have slower degradation ratio [but] no methodology exists for estimating long-term carbon sink in such products". It also states that "proof that the end-use of the product does not cause CO_2 returning to the atmosphere (it is not used as fuel or reductant) must be kept in records" and that "Any amounts expected to be incinerated rather than in a mineral matrix at end of life should be taken account of".[27]
- **Puro.earth** (Mineral Product Methodology): states that "material must not be exposed to conditions resulting in the reversal, nor utilized for purposes where exposure to such conditions can occur (e.g. high temperatures; exposure to strong acids)".
- **Gold Standard** (Accelerated Carbonation of Concrete Aggregate): requires that the calcium carbonate ($CaCO_3$) product "…be used in applications and products where [it] is neither thermally nor chemically decomposed". The use as "filler material for the construction sector is considered as permanent whereas all other uses are non-permanent unless proven that $CaCO_3$ is permanently stored and will not be released at end-of-life (e.g. through waste incineration)".

Monitoring, observation and calibration (ex post)

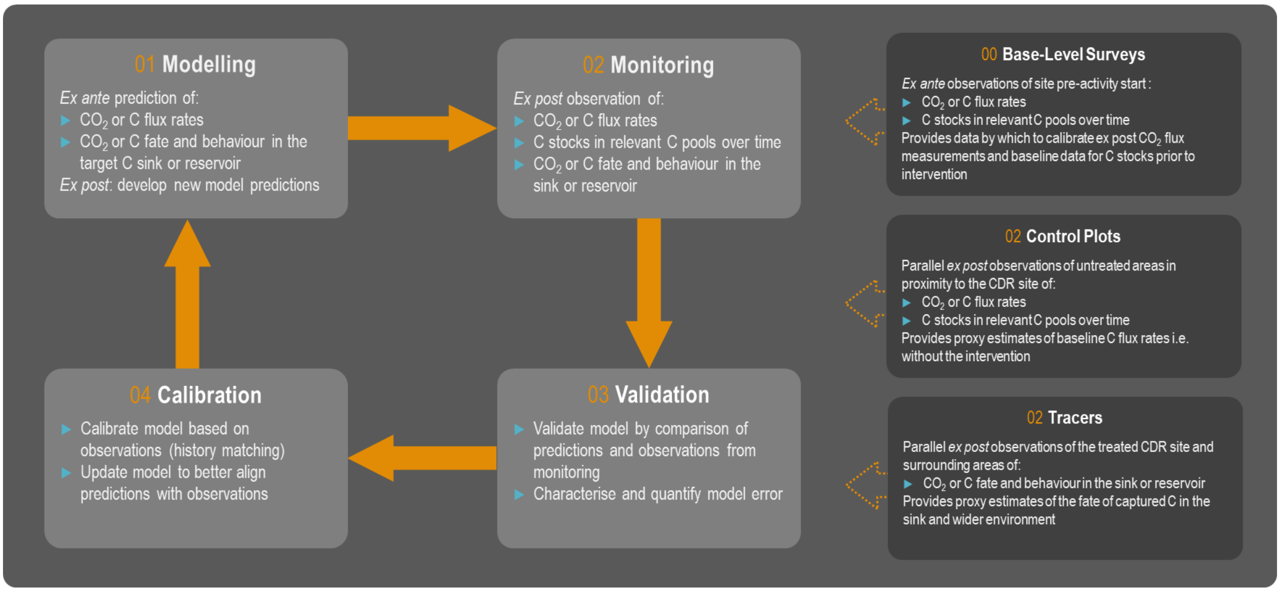
Observing the flow of CO_2 into reservoirs and its fate and behaviour once there (e.g. plume dispersion) is a challenge for MRV. For some closed systems reservoirs, the CO_2 flow/flux into the carbon reservoir can be directly observed and measured. For open system reservoirs (e.g. DIC storage), MRV would need to detect and measure small stock changes in a very large carbon reservoir (e.g. the ocean DIC pool), which is hampered by measurement uncertainty. These approaches therefore rely on modelling rather than observation to estimate CO_2 flux/drawdown and the subsequent fate and behaviour of the carbon in the environment.

[26] Currently set at 0.56, based on IPCC (2019) meaning that 44% of carbon stored in any biochar is assumed to remain stored in year 100 from the date of production. VM0044 states that this is conservative

[27] The Puro.earth Biochar Methodology (v2025) published just before finalizing this report, concludes that "no reversal risks are considered for biochar used in long-lived construction materials" subject to conditions on use.

The IEAGHG (2024) presented an idealised monitoring workflow for the MRV of enhanced carbon reservoirs covering modelling→monitoring→validation→calibration and noted various ways of obtaining baseline observations to support calibrations (base-level surveys, control plots and/or tracers) (Figure 3-2). All of these approaches are variously incorporated with the reviewed eCDR methodologies.

Figure 3-2 Idealised CDR reservoir monitoring and measurement process flow



Source: IEAGHG (2024)

Geological storage (closed system)

The mass of CO_2 injected into the reservoir can be directly measured using flow meters near the CO_2 injection wellhead. Losses in transport can be estimated through mass balance.

Methodologies for BECCS and DACCS all broadly follow the observational and calibration approaches described in steps 1 to 4 above (Figure 3-2). They usually also incorporate base-level surveys, either directly, or through reference to the regulatory frameworks. The approach is also consistent with national GHG inventory (NGHGI) compilation guidelines for CO_2 transport and storage (IPCC 2006).

Enhanced rock weathering (open system; soil, rivers, ocean)

The mass of CO_2 drawdown cannot be directly observed. Various field measurements are instead used to compile a carbonate field mode (e.g. in-field soil and water; drainage water), and observations are calibrated by controls plots to estimate CO_2 drawdown (Isometric; Puro.earth). Losses in transport through so-called reverse reactions are modelled or made by 'conservative estimation' as follows (from Puro.earth):

- losses from surface water systems: 5% of the estimated gross mass of CO_2 stored.
- losses from marine systems: 10% of the estimated gross mass of CO_2 stored.

Isometric also variously applies ‘uncertainty discounts’ that, depending on quality of measurement and assessed uncertainty, deduct of a portion of credits from the monitored and reported removals at the time of issuance. This can be as high as 15% or more depending on project-specific estimates (Isometric 2025). The immaturity of EW monitoring methods suggests that this discount may be significant. The final storage reservoir for DIC is the ocean, which is also subject to an uncertainty discount (see Alkalinity enhancement next).

Alkalinity enhancement (open system; ocean/wastewater/river)

The mass of CO_2 drawdown cannot be directly observed. Per Isometric methodologies and modules, rates are inferred from air-sea gas exchange models (OAE at outfalls), from assumed/modelled rates of CO_2 conversion to carbonate/bicarbonate ions, with support by in-plant measurements (wastewater treatment plants) or the net change in exported DIC from river system to the ocean[28] (river alkalinity enhancement). Where relevant, losses from transport are modelled.

Monitoring requirements outlined in the Isometric Standard suggest comprehensive observations of carbon reservoirs is crucial (Box 3-6). However, the application of these requirements at the methodology level are somewhat mixed.

Box 3-6 Monitoring requirements – Isometric Standard

S.2.5.8.2 Monitoring

A full risk assessment must be undertaken to identify all possible mechanisms that will lead to Reversals and subsequent decreases in Durability. There must be a monitoring plan in place to quantify the amount of potential Reversal that may occur via each identified Reversal mechanism.

The duration of storage monitoring required is process and location specific and requirements will be specified in the relevant Protocol. Monitoring requirements must include:

- adherence to the monitoring program of the Protocol that the individual Project is following;
- the frequency of measurement and reporting, as specified in the relevant Protocol;
- consideration of Baselines and incorporating provisions for reevaluation at the end of a Project's Crediting Period or at set timescales as defined within the Protocol;
- the methodology for detecting all potential Reversal mechanisms;
- provisions for reporting Reversals to the VVB [validation and verification body] and Isometric, as adequate deductions to net Removals may be required;
- identification of (and actionable plan for remediation of) emissions of CO_2e during a Project's operational and post-cessation lifespan;
- monitoring reports that are made publicly available to the Registry; and
- reassessment of reversal risk using the risk reversal questionnaire at a minimum every 5 years, in addition to when any of the following milestones are met:
  - the renewal of each crediting period;
  - when monitoring identifies a reversal-related risk;
  - when monitoring identifies an actual reversal event has taken place.

Source: Isometric (2025)

[28] Based on calibration of observed DIC outflow to the ocean relative to base-level data collected prior to project start.

In terms of fate and behaviour of DIC in the oceanic reservoir, the Isometric alkalinity cluster of methodologies require, among others, observations around the dosing location, the outfall location, the river discharge to ocean, and the mixing zone, and include parameters related to permits. However, these requirements notwithstanding, the Isometric (*Air-Sea CO_2 Uptake* module) currently states that:

> "…reversals in the global ocean DIC reservoir will not be directly observable with measurements and attributable to a particular project" [and that based on decades of research] "…the durability of CDR projects whose final storage reservoir is DIC in the ocean is expected to be between 10,000 and 100,000 years."

A conservative discount may be applicable to ocean storage (*Air-Sea CO_2 Uptake* module), but ostensibly only limited storage reservoir monitoring is required. The reversal risk is considered *Very Low*, which means projects contribute 2% of issued credits to the Isometric project buffer pool (see below).

Isometric (*Air-Sea CO_2 Uptake* module) also note that the dynamics of DIC storage could change if large scale CDR is deployed because of (i) significant elevated ocean alkalinity and (ii) net outgassing of oceanic CO_2 as atmospheric CO_2 concentrations decrease.

Product storage

The mass of CO_2 encapsulated in products can be generally observed and measured. In some cases, methodologies apply a mass balance to the reactor to determine the mass of CO_2 uptake through contact with the storage medium (e.g. Gold Standard concrete curing). As described in the 'Quality assurance' section above, no storage reservoir monitoring is applied to either CO_2 or biochar used in construction materials.

Compensation/remediation for carbon reversals

Ordinarily, during the active phase of removal, emissions from a carbon reversal event can be measured and recorded as project emissions and deducted from the measured removals occurring over a monitoring period (Figure 3-1). However, the scale of a reversal event may exceed the quantum of measured removal within any given monitoring period[29] or occur after the phase of active removal or crediting. In these circumstances, additional liability mechanisms should be applied that oblige an entity to apply adequate remediation/compensation. The concept also assumes that the carbon reservoir can be monitored, and fluxes observed and attributed, which is not necessarily the case for all reviewed eCDR methodologies.

Liability for carbon reversal

Two types of liability and compensation mechanisms are applied in the reviewed eCDR methodologies:

[29] For example, 100 tCO_2 could be injected into a reservoir within a monitoring period, but 120 tCO_2 could leak out over the same period, where the additional 20 tCO_2 relates to measured removals that were credited in a previous monitoring period.

- **No liability,** because either the reservoir fluxes cannot be observed and attributed to an activity, there is an explicit assumption of limited/zero reversal risk, or an ex ante discount is applied based on an assumed likelihood and scale of an anticipated carbon reversal. Notably, such approaches pose some moral hazard risks.[30]
- **Seller liability**, because the project proponent retains liability to surrender or cancel credits in the event of carbon reversal, at least during the operational phase of the project.

The ‘no liability’ approach is applied in eCDR methodologies involving product storage, where zero reversal risk is assumed (i.e. Gold Standard, Puro.earth; exception: Verra VM044, which may use a default discount for some biochar use cases), partially, in Isometric’s cluster of alkalinity-based methodologies (since they assume permanent storage in the DIC reservoir), and to EW if a “conservative estimation” of reversals is applied (under Puro.earth; see above).

The ‘seller liability’ approach is applied elsewhere in ACR, Verra (VM0049), GCC, Gold Standard (geostorage), Isometric (bio-oil and geostorage) and in the PACM.

‘Buyer liability’, an approach where the credit acquirer faces the obligation to replace credits in future (e.g. temporary crediting), is sometimes applied to NCS activities (e.g. as applied to ‘non-permanent’ removals under the EU CRCF). However, neither buyer liability nor tonne-year accounting—a method by which temporary storage may be valued—is applied in any of the reviewed eCDR methodologies.

Buffer accounts

All seller liability approaches require credit withholding via a buffer account (either pooled for all of the same project types, or proponent-specific in the case of Isometric). Isometric also requires that all projects contribute to a buffer pool, even where the methodology implies an assumption of permanent storage (e.g. for EW and alkalinity; Isometric 2025). Credits withheld in the buffer pool can be drawn upon and cancelled in amounts equal to reported carbon reversals.

Risk assessment

The contribution to the buffer is typically linked to the assessed project reversal risk. Thereunder, a minimum threshold is often applied and maximums beyond which the project is rejected. Some examples of the reversal risk assessment and scoring systems of Verra (geological storage) and Isometric (all CDR) are set out below (Box 3-7).

Gold Standard’s draft risk assessment has no maximum risk threshold. Puro.earth’s *Puro Standard* also includes a meta-requirement for a reversal risk estimation (Puro.earth 2025), although it is still being implemented at the methodology level.

[30] Project storage durability is not measured but de facto assumed as in perpetuity, insulating the project proponent or credit buyers from any risks or consequences of carbon reversal.

Box 3-7 Example of reversal risk assessments from ICPs

Approaches to risk assessment are so far proving to be rather different. For example:

The **Isometric Standard** (Isometric 2025) includes a risk questionnaire and risk scoring as follows:

1. Is a reversal directly observable with a physical or chemical measurement as opposed to a modeled result?
   [proceed to q. 8-9]
2. Is the carbon being stored in an impermeable geologic system? (e.g., salt cavern)
   [Add 1 to Risk Score and proceed to q. 3-9]
3. Is the carbon being stored organic?
   [Add 1 to Risk Score]
4. Are conditions for methane production present (anaerobic conditions, lignin content)?
   [Add 1 to Risk Score]
5. Does this approach have a material risk of reversal due to natural disasters including, but not limited to, floods, storms, earthquakes, fires, etc.?
   [Add 1 to Risk Score]
6. Does this approach have a material risk of reversal due to human-induced events from outside actors, such as change in farming practices, change in ownership and management of project sites, or similar?
   [Add up to 2 to Risk Score]
7. Applicable only for subsurface storage: Is the carbon being stored with trapping mechanisms preventing reversals? (e.g., multiple confining layers, CO_2 dissolves or solidifies).
   [Minus 1 to Risk Score (unless 0)]
8. Is there 10+ years of monitoring and/or lab data demonstrating low project risk?
   [Minus up to 2 to Risk Score]
9. Does this pathway have a documented history of reversals?
   [Add 2 to Risk Score]
10. Is there one or more project-specific factors that merit a high risk level?
    [Add up to 2 to Risk Score]

Risk Score Categories (Isometric)

0: Very Low Risk Level (2% buffer)

1-2: Low Risk Level (5% buffer)

3-4: Medium Risk Level (7% buffer)

5+: High Risk Level (10-20% buffer)

Verra's *Geologic Carbon Storage Non-Permanence Risk Tool* (v4.1) covers the following risk categories and scores:

- ↳ Regulatory framework risk (RFR) [Possible score: 0-1.875]
- ↳ Political risk (PR) [Possible score: 0-4]
- ↳ Land and resource tenure risk (LRTR) [Possible score: 0-1.5]
- ↳ Closure financial risk (CFR) [Possible score: depends on %age post injection care costs covered by various funding]
- ↳ Design risk (DR) [Possible score: 0-3]

Any score >7 is rejected. The risk score is used to determine the buffer contribution.

Buffer replenishment

In some cases standard setters are also categorising carbon reversal events as avoidable and unavoidable, with a view to differentiating compensation actions (e.g. UNFCCC 2024a; IC-VCM 2025; Isometric 2025).

Under the PACM, the *Standard: Requirements for activities involving removals under the Article 6.4 mechanism* (the PACM Removals Standard; UNFCCC 2024a), for example, defines 'avoidable reversals' and 'unavoidable reversals'. Although it proposes that the PACM buffer pool can be called upon to compensate for either avoidable or unavoidable reversals, activity participants are only liable to replenish the buffer account in the case of avoidable reversals. The PACM also calls for activity participants to obtain and maintain sufficient coverage for avoidable reversals (e.g. insurance policy or comparable).

Isometric (2025) takes a similar approach to the PACM in its buffer use and replenishment.[31] Verra's *Geologic Carbon Storage (GCS) Requirements* does not distinguish between types of reversal events and always requires the buffer account to be replenished.

Long-term stewardship arrangements

In general, longer-term stewardship of enhanced carbon reservoirs are variably covered in the reviewed eCDR methodologies. The coverage is implicitly linked to the liability arrangements for reversals as follows:

No liability

Mostly applicable to product storage, where the carbon reservoir does not need to be monitored by the project proponent and no short- or long-term stewardship is applied because the risk of reversal is assumed to be very low (essentially zero). On this basis and noting ICTU requirements (Box 2-1), any carbon reversal that does occur (e.g. destruction via waste incineration) should be recorded in the NGHGI of the host country and counted against its emissions targets applicable at that time (e.g. its NDC pledge).

Seller liability

Methodologies for BECCS and DACCS usually require monitoring of the geological storage site by the project proponent in a post-crediting/post-injection phase. In some methodologies, the conditions for termination of monitoring also provide a basis for the structured handover of site stewardship and monitoring responsibility (e.g. ACR and GCC). Similar requirements are presented in Isometric's storage modules, Verra storage modules, and Puro.earth (Geologically Stored Carbon Methodology). All of these approaches draw from typical monitoring requirements established in regulatory permits (for saline aquifers; in situ mineralization). Examples of post-crediting/post-injection monitoring requirements are summarised below (Box 3-8).

Less clarity is provided for open system storage. While the Isometric Standard (Isometric 2025) indicates, for example, that monitoring must include the "post-cessation lifespan" (see Box 3-6), its methodologies for EW and alkalinity enhancement (x3) do not offer clear guidance as to what sort of post-cessation monitoring must be carried out, or when it may be terminated.

[31] The classification of a Reversal as either Avoidable or Unavoidable will be made by Isometric, in consultation with the Project VVB,

Box 3-8 Post-injection geostorage monitoring and the cessation of monitoring

Current guidance for NGHGI compilers proposes the following good practice for geological CO_2 storage sites, especially where no appointed regulatory agency exists:

> "Post-injection Monitoring: The plan should provide for monitoring of the site after the injection phase. The post-injection phase of monitoring should take account of the results of the forward modelling of CO_2 distribution to ensure that monitoring equipment is deployed at appropriate places and appropriate times. Once the CO_2 approaches its predicted long-term distribution within the reservoir and there is agreement between the models of CO_2 distribution and measurements made in accordance with the monitoring plan, it may be appropriate to decrease the frequency of (or discontinue) monitoring. Monitoring may need to be resumed if the storage site is affected by unexpected events, for example seismic events." (IPCC 2006, Vol.2, Ch. 5, p 5.15-5.16)

Existing regulatory requirements include:

- EU CCS Directive (EC 2009): operator remains responsible for monitoring and compensation etc until, among others: (i) all available evidence indicates that the stored CO_2 will be completely and permanently contained; (b) a minimum period no shorter than 20 years has elapsed, unless the competent authority is sooner convinced of complete and permanent storage etc. Thereafter the responsibility for the site is transferred to the competent authority of the host government (i.e. the EU member state country in which the geological CO_2 storage site is located).
- U.S. EPA Underground Injection Control (UIC) Class VI (CO_2) well rule (EPA 2010): specifies a 50-year timeframe for 'post-injection site care', but flexibility is allowed for applying other, shorter, durations based on operational monitoring etc and subject to UIC Program Director approval.

Examples in existing ICP standards include:

- ACR: 5 years minimum and, if necessary, rolling 2-year extensions until "no leakage" is assured.
- GCC: 5 years minimum and, if necessary, rolling 2-year extensions until assurance that the "risk of seepage is sufficiently low and that permanent storage is highly likely to be achieved"
- Gold Standard: absence of "Regulatory or legislative rules providing for the transfer of liability" increases the assessed project risk, and therefore the buffer contribution, by 1%. Other requirements aligned to UIC Class VI well rule.
- Verra (GCS Requirements; Non-Permanence Risk Tool): no less than 10 years, even where closure is authorised sooner. Absence of "legislative or regulatory rule providing for the transfer of liability" increases the assessed project risk, and therefore the buffer contribution, by 1.25%. Other requirements also apply according to regulations.
- Isometric (CO_2 Storage in Saline Aquifers module): according to regulatory requirements/permit, or otherwise a minimum of 50 years.
- Puro.earth (Geological Storage Methodology): as long as required in the applicable legal framework until the transfer of responsibility, or as long as required by the local requirements for storage site closure and post-closure site management.

Source: author analysis and compilation

Isometric intends for its buffer pool to remain in place "as long as there is a risk of Reversal from a Project" (Isometric 2025).

Puro.earth (EW Methodology), while mentioning "Carbon fate in the environment" as a process for which the full scope of emissions must be accounted, does not indicate clear requirements for long-term monitoring.

In all cases, the **host country**[32] in essence acts as the de facto guarantor of last resort for environmental integrity in the event of carbon reversal. This is because, per requirements under ICTU (Box 2-1), if the negative emissions created by an eCDR project are counted towards NDC goals it follows that any subsequent CO_2 fluxes from those enhanced carbon

[32] Or third countries in the event that captured carbon moves across borders.

reservoirs must be monitored and reported in the host country NGHGI. This is the case irrespective of whether the eCDR activity was credited under either of the following pathways:

- the VCM or PACM (as 'mitigation contribution' A6.4ERs), and therefore intended to be counted towards the host country NDC target; or
- cooperative approach under Article 6.2 or PACM (as ITMOs/authorized A6.4ERs) and transferred internationally and counted towards the NDC target of an acquiring country Party, to CORSIA,[33] or other purposes (see Box 1-1)

In other words, regardless of whether the removals and credits from a CDR or eCDR activity were retained domestically or transferred internationally, the requirement in ICTU to continue including NDC-covered sinks and reservoirs within the scope of future NDCs means that—in line with the Paris Agreement's enhanced transparency framework (ETF)—any fluxes (i.e. reversals) therefrom will need to be monitored and reported as emissions in the country's NGHGI (UNFCCC 2018b; Section 4.2.2).

Notably, absent of a clear linkage to ICTU and NDCs, carbon removal credits may be created that do not offer any upside for host countries (i.e. the removal may not be reported in its NGHGI due to 'inventory visibility' issues; see Schneider et al. 2022 and IEAGHG 2024)[34] but still create residual liabilities in the form of enhanced carbon reservoirs that may reverse in future (i.e. the emissions resulting from the reversal may be reported in future NGHGIs, if the reporting guidance changes).

The situation described notwithstanding, the reviewed eCDR methodologies make little or no explicit mention of host country involvement in project approval (other than for some local permitting and regulatory requirements for geological CO_2 storage).

Conversely, where ICPs wish to supply credits into CORSIA as ITMOs under Article 6.2, the ICP needs to flag that specific credits have been authorised by the host country. Implementation of such requirements is so far being established in Article 6- or CORSIA-specific documents prepared by the ICPs rather than in the methodologies themselves (e.g. Puro.earth 2024; Isometric 2025). But little or no information or assessment is provided of the extent to which a particular eCDR methodology may support NGHGI compilation or align with and fulfil ICTU reporting and Article 6 methodologies and metrics requirements (see Box 2-1). This seems like a significant omission and gap in the frameworks for eCDR methods that are not currently covered by IPCC guidance (see Table 2-2).

[33] The Carbon Offsetting and Reduction Scheme for International Aviation.

[34] For example, biochar or EW, due to granularity or exclusion of the reservoir from the scope of the NGHGI, may not show a measured removal in a NGHGI unless the activity-specific data is included therein.

3.4 Methodological summaries by eCDR method

Drawing on the methodological building blocks outlined above, Annex B provides summary fiches on methodological approaches for the following eCDR methods:

1. DACCS
2. BECCS
3. Bio-oil geological storage
4. Mineral carbonation (in products)
5. EW
6. Biochar (use)
7. River / Wastewater alkalinity enhancement
8. OAE (coastal outfalls)
9. Oceanic removal (electrochemical)

The fiches provide a technical overview and status check on eCDR methods including governance aspects, an overview of methodologies and projects, and summary descriptions of the main methodological features.

A comparative summary table of eCDR methodologies including current project and credit issuance status is presented below, using data from the fiches in Annex B (Table 3-3).

Table 3-3 Scope and coverage of reviewed eCDR methodologies (summary)

Standard setter			Approach		eCDR Method Scope										Storage Reservoir Scope					Geographical Scope				
					CO_2 capture + geological storage				Biomass capture + store		Alkalinity/bicarbonate + hydrosphere store				Geological storage			Other storage		Geological storage			Other storage	
Name	Type	Purpose	Lifecycle based	Modular	DACCS	BECCS	WtECCS	DACCU / BECCU	Bio-oil	Biochar	Enhanced weathering	River liming	Wastewater liming	Ocean alk. enhance.	Geological reservoirs[1]	Salt caverns	In situ mineraliz'n	Hydrosphere / Ocean	Construction	Geological reservoirs	Salt Caverns	In situ mineraliz'n	Hydrosphere / Ocean	Construction
ACR	ICP	C	~		✓	~									✓					U.S. & Canada				
Verra/VCS	ICP	C	✓	✓	✓	✓	✓			✓	~				✓			~	● (bc)	🌍				🌍
GCC	ICP	C	●		✓	✓	✓								✓					🌍				
Gold Standard	ICP	C	●			✓		✓							✓		⚠		● (ccu)	🌍				🌍
Puro.Earth	ICP	C	✓		✓	✓	✓	✓		✓	✓				✓		✓	✓	✓ (bc) (ccu)	🌍			🌍	🌍
Isometric	ICP	C	✓	✓	✓	✓	⚠	✓	✓	✓	✓	✓	✓	✓	✓	● (bo)	✓	✓	✓ (bc) (ccu)	🌍	U.S.		🌍	🌍
Env & Climate Change Canada (ECCC)	Govt. (Dom.)	C	●		✓										✓		⚠			Canada				
Alberta	Govt. (Dom.)	C	●		✓	✓	✓								✓					Alberta				
European Union (EU)	Govt. (Dom.)	Q	✓		✓	✓	✓	×		✓					✓	×	⚠		● (bc)	EU				EU
British Standards Institute (BSI)	Govt. (Dom.)	Q	✓		✓	✓	×	×							✓	×	⚠		×	UK (🌍)				
IPCC	Govt. (Intl.)	Q (NGHGI)	×	Sectoral	●	✓	✓	×	×	● (s)	×	×	×	×	✓	×	×	×	×	🌍	×	×	×	×

Project and Crediting Status	DACCS	BECCS	WtECCS	BECCU	Bio-oil	Biochar	Enhanced weathering	River liming	Wastewater liming	Ocean alk. enhance.
Developing countries										
Registered Projects	0	0	0	0	0	n/a	4	0	0	0
Issued Credits	0	0	0	0	0	n/a	236	0	0	0
Developed countries										
Registered Projects	4	2	0	4	2	n/a	2	0	1	1
Issued Credits	1,058	378,856	0	66,394	1,950	n/a	0	0	104	626

Key / Nomenclature

✓	Covered
●	Partially covered
~	Under consideration
⚠	Uncertain/Possibly
×	Excluded
🌍	Global
ICP	Independent crediting programme
1	ACR (v1.1) is restricted to only enhanced oil recovery (EOR), whereas nearly all others prohibit EOR. Except for ACR, all include saline aquifers, and all except ACR and Isometric allow for use of depleted hydrocarbon fields.
C	Crediting (estimating net removal for purposes of issuing carbon credits)
Q	Quantification (estimating net carbon removal, which could form the basis for issuance of carbon credits)
s	Soil storage only
bo	Bio-oil and biomass storage
bc	Biochar use in cementitious construction materials and, in some cases, land reclamation.
ccu	CO_2 capture and use for production of cementitious construction materials.
n/a	Not available (biochar use and biochar soil application are aggregated under the same methodologies)

3.5 Opportunities, gaps and uncertainties

The review of eCDR methodologies indicates that, within at least the ICPs, an abundance of methodological choices exists covering a continually expanding suite of eCDR methods. The situation suggests that a suitable methodology for crediting eCDR could be found for many different circumstances and applications (e.g. potential niches for eCDR in developing countries, such as DACCS that is emerging in Kenya; Box 2-2).

The growing suite of eCDR methodologies also reveals the novelty of some methods and the related methodological and MRV approaches. Effectively identifying, measuring and quantifying CO_2 drawdown and observing the fate and behaviour of captured carbon in an enhanced carbon reservoir appears challenging for some methods. The eCDR methodology ecosystem also exhibits complex structures with many branches and options, and the exact requirements can often be difficult to discern (in terms of e.g. eligibility, monitoring, permitting). Other methodological features are more straightforward, with simple baseline assumptions (e.g. zero removals) and fixed ex ante assessments of the permanence of storage. Some areas exhibit strong alignment across the standards (e.g. in all cases geological CO_2 storage must be permitted under government regulations). Yet deeper analysis reveals some unevenness in requirements across different standards, especially in terms of:

- **Monitoring requirements**. Some require continuous and intermittent intensive monitoring of the reservoir, injectate plumes and its boundary zone (e.g. geological storage), some require chemical sampling and analysis (e.g. EW, alkalinity methods), while some requirement no monitoring at all (storage in construction products; ocean).
- **Non-permanence and carbon reversal**. Especially treatment after the end of crediting, with some requiring lengthy monitoring in a post-crediting phase (e.g. geological CO_2 storage), whereas as others are unclear on whether or when monitoring can or should terminate (e.g. EW and alkalinity methods). In some cases, conservative default factors may be used to assume, a priori, a fixed level of anticipated carbon reversal (e.g. biochar in products and EW). This last arrangement can be problematic in creating moral hazard issues.
- **Risk assessment, discounting and buffer accounts**. Some ICPs apply discounting, which can vary by eCDR method and/or assessed risk. Buffer requirements also vary widely in terms of the levels of contributions (which range from zero to 20%) and functioning (whether it is pooled for all projects or rather project or reservoir-type specific or the conditions under which it may be called upon or require replenishment).

The variation and differing methodological standards and requirements can impact market integrity in circumstances where all eCDR credits are considered equal and fungible. Such variability can financially penalise and deter investments into certain eCDR methods (e.g. because of the cost and timeframes for permitting, monitoring requirements and liability impacts) and push investments towards other eCDR methods with less intensive requirements. However, the situation may simply be a reflection of the technical immaturity and largely unregulated nature of the activity (e.g. EW, biochar in products, alkalinity methods), rather than being an innate characteristic.

Many countries will likely consider there to be challenges to host eCDR activities when faced with the full consequences of doing so. At least in principle, any country hosting CDR—or at least the enhanced carbon reservoirs that result from such activities—must act as the underwriter of last resort in at least two respects:

- If the MRV applied to eCDR methods is later judged or proved to be ineffective, false or misaligned with Paris Agreement requirements. This could occur at various times including during Article 6 technical expert review and/or when countries report removals by eCDR methods in their NGHGI and biennial transparency reports (BTRs), but the approach is questioned during the BTR technical expert review (TER; see Section 4.2.2). The latter could preclude host countries from counting such actions towards their NDC target, even though the former allowed credits to be issued and counted by other entities towards their own targets; or
- In the event of carbon reversal. Emissions from carbon reversal (i.e. fluxes from enhanced carbon reservoirs) should be reported in the host country's NGHGI and BTR and counted against achievement of its NDC target. Even though mechanisms such as buffers are being applied at the level of the project activity or standard, limited consideration has been made for how host countries may access buffers to compensate for carbon reversals against their national GHG accounts.

Notably, these conditions may apply irrespective of whether an eCDR activity is counted domestically towards the NDC, credited under Article 6 and counted towards another NDC or OIMP, or credited on a voluntary basis without any authorization (e.g. VCM; results-based finance; see below). Such challenges will be further exacerbated if there are low levels of awareness and understanding of eCDR, which can be the situation in many countries, both developed and developing.

Moreover, despite facing longer-term liabilities for eCDR, the current eCDR methodology ecosystem seemingly offers little, if any, host country inclusivity or participation in project oversight and registration (primarily in ICP methodologies and protocols). The exact nature of these needs and requirements are somewhat nuanced and vary by credit type and end use, as discussed in context of eCDR governance in the next section.

4 Governance Features

4.1 Background

The methodological features described in the previous section and in Annex B illustrate the nature of the issues posed for the rapid scale-up of eCDR deployment. On the one hand, the burgeoning range of methodologies suggests an expanding toolbox of diversified methods by which to mitigate climate change. On the other, the immaturity of methods, the small number of projects and credits, the complexity and variability in methodological designs, and the vulnerability to carbon reversal pose uncertainties and risks for the effective contribution of eCDR to achievement of the Paris Agreement's goals. These aspects manifest as governance issues and needs in relation to:

1. Reducing and managing uncertainty over the efficacy, effectiveness and efficiency of several eCDR methods because of the lack of field trials and a limited empirical evidence base upon which to cast definitive judgements. Basic questions also remain over the safety and potentially adverse environmental effects of some methods, even if effective and efficient deployment is achievable.
2. Establishing means to identify and measure CO_2 drawdown and to monitor resulting enhanced carbon reservoirs to acceptable levels of confidence and trust. Effective monitoring is crucial to determine if and how much removal occurs and, if so, the stability and durability of the carbon in the reservoirs and whether any reversals occur.
3. Characterising and measuring the long and complex value chains in a transparent, accurate, complete and consistent way so as to determine *net* CO_2 removal, and to identify, manage, measure and mitigate potential leakage effects.

Methodologies addressing these topics are pushing ahead under the umbrella of privately sponsored ICPs in the VCM, typically involving a small group of developers exploring complex experimental design and novel computer simulation models. Their actions are being bolstered by a select group of firms, primarily in the technology sector, that have adopted CDR-based corporate climate 'neutralization' commitments (e.g. Microsoft). In several cases, both performance prediction and subsequent monitoring and measurement of key parameters is heavily reliant upon experimental digital simulation models or 'digital twins' (e.g. alkalinity approaches).

Yet, for the most part the proposed methodological approaches, assumptions and safeguards have not been ground-truthed or endorsed through conventional climate-related peer review bodies. Groups such as the IPCC, the UNFCCC Subsidiary Body for Scientific and Technical Advice (SBSTA), the SBM, the Technical Advisory Body (TAB) of CORSIA[35] and others have

[35] With the exception of DACCS under ACR's methodology (ICAO 2024)

yet to fully endorse methodologies and metrics suitable for the full range of emerging novel eCDR methods. The IC-VCM—the VCM's de facto governance body—has only recently approved a handful of eCDR methodologies under its Core Carbon Principles.[36] But there has so far been only limited stakeholder or public sector involvement in methodology design, and the methodologies themselves offer only limited scope for host country regulators to participate in decision-making and approvals at the level of individual project activities.[37]

In this context, key governance questions yet to be fully addressed include:

- Whether the uncertainty and environmental and social risks of eCDR methods can be effectively identified and managed by countries, especially developing countries, as the entities expected to host these activities and ultimately retain stewardship of the enhanced carbon reservoirs over potentially millennial timescales?
- Whether countries can appropriately connect hosted eCDR activities to NDC achievement—including under Article 6 trading if the units are sold towards the NDC achievement of another country or CORSIA—such that eCDR can be counted as contributions towards the Paris Agreement's goals. And, equally, that the resulting carbon reservoirs are effectively monitored so that reversals can be accounted for?

Drawing on these basic framing questions, the following sections analyse governance arrangements for eCDR in more detail.

The first part considers governance *needs* in respect of both environmental and social safeguards and climate policy and carbon markets. Notably, both parts are connected: eCDR projects that emit more than they remove or that are prone to reversal pose environmental and social risks (e.g. resource depletion; exposure to elevated CO_2 concentrations), which equally impact upon the environmental integrity of climate targets and carbon markets. As such, the governance of the methods and the policies and markets within which they function should be developed hand-in-hand.

The second part considers existing governance *approaches* and *precedents* under both national and international frameworks. The analysis is structured around the different types of storage reservoirs utilised by different eCDR methods, which is a key factor driving variability.

4.2 Governance issues and needs

4.2.1 Governance of eCDR methods

The UNFCCC (2023c) note that eCDR methods pose some additional impacts, hazards and risks relative to conventional emission reduction activities.[38] These include impacts of capture (e.g. energy and materials use; release of matter into the environment for capture purposes)

[36] At 01/10/2025. Six in total. https://icvcm.org/assessment-status/#category-assessment
[37] Notably, all ICP developers open their draft methodologies for public comment and scrutiny.
[38] CCS as an emission reduction technology poses similar issues.

and storage (e.g. upon the media used for carbon storage; effects on in situ materials and potential mobilization of materials or other biproducts into the environment). Drawing on recent authoritative literature, a summary of the possible risks and the potential co-benefits of novel eCDR methods is presented below (Table 4-1).

Table 4-1 Summary of risks, impacts, co-benefits, trade-offs and spillovers for novel CDR

CDR method	Risks and impacts	Co-benefits	Trade-offs & spillover effects
DACCS	Increased energy and water use (with some options). Can lead to GHG emissions or competition for renewable energy.	Water produced (solid sorbent DAC designs only)	Potentially increased emissions from water supply and energy generation
Enhanced weathering	Mining impacts; air quality impacts of rock dust when spreading on soil. Heavy metal contamination, especially nickel and chromium, from some rock types.	Enhanced plant growth, reduced erosion, enhanced soil carbon, reduced soil acidity, enhanced soil water retention	Potentially increased emissions from water supply and energy generation.
Ocean alkalinity enhancement	Increased seawater pH and saturation states may have local adverse impacts on marine biota. Possible release of nutritive or toxic elements and compounds may perturb marine ecosystems. Mining impacts.	Limiting ocean acidification	Potentially increased emissions of CO_2 and dust from mining, transport and deployment operations
Ocean fertilisation	Nutrient redistribution, restructuring of the ecosystem, enhanced oxygen consumption and acidification in deeper waters could perturb marine ecosystems. Could encourage toxic algae. The fraction of removed CO_2 reaching durable storage is uncertain, due to re-metabolisation. Potential for decadal-to-millennial-scale return to the atmosphere of nearly all the extra carbon removed, risks of unintended side effects	Increased productivity and fisheries, reduced upper ocean acidification	Subsurface ocean acidification, deoxygenation; altered meridional supply of macro-nutrients as they are utilized in the iron-fertilised region and become unavailable for transport to, and utilization in, other regions, fundamental alteration of food webs, biodiversity
BECCS	Competition for land and water resources, to grow biomass feedstock if based on purpose-grown biomass feedstock. Loss of biodiversity, carbon stock and soil fertility if from unsustainable biomass harvest. Use of potentially contaminated biomass residues (such as post-consumer wood waste) can pose air pollution risks.	Reduction of air pollutants; fuel security, optimal use of residues, additional income, health benefits and if implemented well can enhance biodiversity, soil health and land carbon	Competition for land with biodiversity conservation and food production
Biochar	Particulate and GHG emissions from production; biodiversity and carbon stock loss from unsustainable biomass harvest. Use of potentially contaminated biomass residues (such as post-consumer wood waste) can pose air pollution risks.	Increased crop yields and reduced non-CO_2 emissions from soil; resilience to drought	Environmental impacts associated with particulate matter; competition for biomass resource

Source: Babiker et al. (2022), Table 12.6; Smith et al. (2023), Table 1.1. UNFCCC (2023c)

Given the risks highlighted, deployment of the various eCDR methods needs to be grounded within robust guardrails that can build confidence and trust in their efficacy and safety.

Drawing upon existing approaches, a basic governance configuration includes the engagement of regulatory agencies in various action across the lifecycle of the activity, as summarised below (Table 4-2). Yet, because of variations in technical maturity, such requirements are currently being unevenly applied to the range of eCDR methods reviewed in this report. This view is reaffirmed by the IPCC, which noted in AR6 that in coming years:

> "CDR governance and policymaking are expected to focus on responsibly incentivising RD&D and targeted deployment, building on both technical and governance experience with already widely practised CDR methods like afforestation/reforestation…learning from two decades of slow-moving CCS deployment… [and] …for some less well-understood methods and implementation options, such as ocean alkalinisation or enhanced weathering, investment in RD&D can help in understanding the risks, rewards, and uncertainties of deployment." (Babiker et al 2022; p.1277).

The IPCC confirms the need to better align governance approaches and to draw from analogous activities such as CCS and forestry. Governance of these activities was developed with a wide group of stakeholders spanning several years, with a primary focus on establishing safeguards that build confidence and trust in their effectiveness as climate mitigation methods (Section 2.5). As things stand, some eCDR methods are closer to launch because of these developments, while others have fewer precedents to draw from, and in some cases face legal impediments to their wider deployment (see below).

Notwithstanding the experimental nature and uncertainty over governance, some ICPs are pushing ahead with credit issuance to some of the most nascent eCDR methods (Table 3-3).[39]

Table 4-2 Governance needs for eCDR

Activity phase	Environmental & social safeguards	Policy & carbon market safeguards
Development (ex ante)	*Project assessment/approvals* Ensuring responsible selection of storage reservoirs and their planned modes of enhancement that minimise environmental and social risks and impacts	*Project assurances* Ensuring the selection of storage reservoirs and modes of operation that are indicative of long-term, durable, carbon storage and mitigate the risk reversal.
Operation (ex post)	*Project oversight* Ensuring operational safety requirements are being fulfilled and risks and impacts are being identified and managed appropriately.	*Project monitoring* Ensuring responsible operation of storage reservoirs and to identify, measure and allocate emissions in case of carbon reversal.
Closure and long-term storage stewardship	Establishing appropriate arrangements that ensure ongoing durable storage of carbon in enhanced carbon reservoirs. Assigning responsibility for the monitoring and measurement and liabilities for any environmental and social damages arising from any carbon reversal.	Establishing appropriate arrangements that ensure ongoing durable storage of carbon in enhanced carbon reservoirs. Assigning responsibility for the monitoring and measurement and liability for remediation in the event of any carbon reversal.

[39] At time of writing (August 2025), almost 1000 credits have been issued to EW, wastewater alkalinity enhancement and ocean alkalinity enhancement at costal outfalls.

4.2.2 Governance of eCDR in climate policy and carbon markets

The inclusion of eCDR in climate policy and carbon markets pose similar governance requirements as applied for environmental and social safeguards: effective regulation for environmental protection purposes also provides solid underpinnings for ensuring the environmental integrity of climate action (e.g. assurances over the quality of selected carbon reservoirs to minimise the impacts and risks to the surrounding environment and to reduce non-permanence and address carbon reversals; Table 4-2).

The following sections consider the governance needs for recognising eCDR under the Paris Agreement from two interconnected perspectives: (i) as actions towards achieving NDCs under Article 13; and (ii) as cooperation and trading under Article 6 (Box 1-1).

Counting eCDR towards achieving NDCs

For eCDR to be counted by Parties towards achieving their NDCs, countries will need to report in accordance with the Paris Agreement's ETF (UNFCCC 2018b). The ETF requires Parties to submit BTRs, which must include, among others, an NGHGI and information to track progress made in implementing and achieving the NDC. The NGHGI in the BTR shall follow 2006 IPCC Guidelines (IPCC 2006), or updated versions thereof, and include descriptions of the methodologies applied (UNFCCC 2018b).

As noted above, eCDR methods are not fully covered by current IPCC guidance (Table 2-2). Yet, the situation is not necessarily a direct barrier to recognising mitigation achieved by eCDR. For example, BTRs may potentially include Parties' own methodologies where actions cannot be accounted for using IPCC guidelines (Box 2-1). Given the current gaps, this will need to be the case for several eCDR methods. Notably, Norway reported the avoided emissions achieved through its Sleipner CCS project in its NGHGI reports from 1999 onwards, which counted towards its Kyoto Protocol targets, despite IPCC guidance on CCS only being available from 2006 (see IEAGHG 2022). The reporting by Norway provided vital lessons from which IPCC methodologies were subsequently developed (IPCC 2006).

BTRs are subject to TER. The *Guiding Principles* of the ETF require reviewers to consider how BTRs promote transparency, accuracy, completeness, consistency and comparability ('TACCC') and ensure environmental integrity. Both imply the need for consistency, parity and equivalence of MRV across climate action and tradeable units.

Trading eCDR under Article 6

The counting of eCDR towards achieving climate targets in NDCs and the trading of units relies on equivalence in MRV and safeguards (Section 3.5). Equivalence means that similar levels of quality and durability may be assumed for similar mitigation actions being implemented by different Parties. These underpinnings support fungibility in the units that may be originated from eCDR activities and traded among entities, especially in respect of the methodological treatment of non-permanence and carbon reversal (e.g. assurances over project safeguards, site selection and the monitoring of enhanced carbon sinks and reservoirs). Without such equivalence, the environmental integrity of the Paris Agreement would be open to doubt and exposed to arbitrage risks.

Requirements

The Guidance on Cooperative Approaches (UNFCCC 2021a) and the PACM RMPs (UNFCCC 2021b; Box 1-1) establish various requirements for Parties and ITMOs (Table 4-3).

In addition to the requirements, the ETF also includes provisions for reporting cooperative approaches and the transfer of units between Parties under Article 6. Thereunder, Parties should also report the methodologies associated with any cooperative approaches (UNFCCC 2018b), which are also required to follow IPCC methods and methodologies (Box 2-1).

Non-permanence risks and carbon reversals

The following host and participating country level assessments and approvals apply:

- **Cooperative approaches**. *Initial Reports* by both Parties must describe how the cooperative approach is ensuring environmental integrity including:

  "…minimizing the risk of non-permanence of mitigation across several NDC periods and how, when reversals of emission reductions or removals occur, the cooperative approach will ensure that these are addressed in full". (UNFCCC 2021a, Annex IV, 18(h)(iii))

  Similar information must also be submitted in *Regular Information* annexed to BTRs.

- **PACM**. The SBM has developed the PACM Removals Standard (UNFCCC 2024a), which establishes various methodological requirements for eCDR activities (Box 4-1).

Table 4-3 Key requirements under Article 6

Requirements	Article 6.2 / Cooperative approaches	Article 6.4 / PACM
Methodologies and metrics	ITMOs must be measured using methods assessed by the IPCC and approved by the CMA (Box 2-1).	A6.4ERs must be measured using methods assessed by the IPCC and approved by the CMA (Box 2-1).
Participation requirements	No later than authorization of ITMOs, cooperating Parties must submit an *Initial Report*—as well as *Regular Information* thereafter—that specifies how a cooperative approach, among others: ➡ Contributes to implementation of its NDC or LT-LEDS, and ➡ Ensures environmental integrity (see below)	Host countries must indicate publicly: ➡ The type of activities that they would consider approving for A6.4ERs; and, ➡ How such activities and associated emission reductions would contribute to the achievement of its NDC, its LT-LEDS if it has submitted one, and the long-term goals of the Paris Agreement
Authorization	Participating must authorize any resulting ITMOs, specifying how they can be used.	Host countries must provide a statement to the SBM specifying whether and how the country authorizes A6.4ERs.

Source: UNFCCC 2021a; UNFCCC 2021b

Box 4-1 Topics covered in the PACM Removals Standard

Monitoring and reporting, specifying the scope and frequency of monitoring to be applied, and the items to be reported

Post-crediting period monitoring and reporting, requiring monitoring to continue after the end of the last crediting period so as to:

- assess whether any reversals have occurred,
- quantify the amount of reversals, and
- confirm the continued storage of GHGs

Addressing reversals, requiring project participants to prevent and minimize reversals, to remediate any reversals in full, and to implement the following:

- *Reversal risk assessment*, considering risks such as financial, regulatory, political/governance, natural disturbance, climate impacts, and to establish a risk mitigation plan. The methodology is to be set out in a *Reversal Risk Assessment Tool* (forthcoming).
- A *Reversal Risk Buffer Pool Account*, with contributions based on quantitative results of the reversal risk assessment. Also includes the option to tag A6.4ERs as being at negligible risk of reversal.

Remediation of reversals, specifying the conditions under which the *Reversal Risk Buffer Pool Account* may be accessed to remediate reversals.

The PACM Removals Standard requires project participants to self-assess the risk of reversal, albeit subject to validation, verification and SBM oversight.

Under the PACM, the SBM and its Methodologies Expert Panel is also working on various additional tools and standards under the PACM Removals Standard including:

- A standard for *Addressing non-permanence and reversals* and
- A tool for *Reversal risk assessment*.

The intent of the PACM standards and tools is to establish how post-crediting period monitoring and compensation for carbon reversals shall operate. Due in 2025, these documents should provide guiding precedents as to how host countries may be better integrated into the structured stewardship of enhanced carbon reservoirs.

Environmental and social safeguards & sustainable development

Initial Reports shall describe how **cooperative approaches** will:

> "…avoid negative environmental, economic and social impacts" [and]
>
> "Be consistent with the sustainable development objectives of the Party, noting national prerogatives"

Similar information must also be submitted in *Regular Information* annexed to BTRs.

For the **PACM**, all projects must be assessed using the *A6.4 Sustainable Development Tool* (SD Tool; UNFCCC 2024c). In late 2023 a draft recommendation on removals under the PACM called upon the SBM to, among others, update the SD Tool in terms of developing:

> "…further requirements in respect of specific removal activity categories or types taking into account national and international best practices in environmental and social safeguards." (UNFCCC 2023d)

Thereafter, the 10th meeting of the SBM in early 2024 committed to:

> "Reinforce proposed safeguards criteria and guiding questions in the draft [sustainable development] tool to be applied for carbon dioxide removal (CDR) activities, including through continued monitoring and analysis of relevant external safeguard systems and frameworks. The Supervisory Body will request the secretariat to develop new specific annex(es) to the draft Article 6.4 sustainable development tool to include safeguards criteria and guiding questions specific to respective CDR activities at an appropriate stage in its development of regulations for activities involving removals." (UNFCCC 2024d)

Work on the matter remains ongoing, and new specific annexes have yet to be published. As such, expectations around the sustainable development contributions or other environmental and social safeguards to be met by eCDR methods under the PACM are pending. Contexts can be guided by the governance needs for eCDR set out above, which highlight the parallels between climate policy and markets and the environmental and social safeguards (Table 4 2; see also Section 3.3.5).

As outlined below, the MRV and safeguards applied to geological CO_2 storage exemplify how consistency and equivalence can be established across rules, standards and jurisdictions.

4.3 Governance approaches

4.3.1 Geological CO_2 storage

National laws and regulations

The European Union, the U.S., Canada and Australia—including their respective states, provinces and territories—have established laws, regulations and standards for undertaking geological CO_2 storage. Examples of dedicated geological CO_2 storage laws include the 2008 Victoria State Greenhouse Gas Geological Sequestration Act, the 2009 EU Directive on the geological storage of CO_2 ('the CCS Directive'; EC 2009) and the 2011 U.S. SDWA UIC Class VI well rule (EPA 2010).[40]

Indonesia and Malaysia are among the few developing countries to have also developed dedicated laws on geological CO_2 storage in recent years, although both remain at early stages of development. Brazil and Mexico are also embarking on the development of national laws and regulations for geological CO_2 storage.

[40] Further details of these laws and regulations can be accessed on the IEA database at: https://www.iea.org/data-and-statistics/data-tools/ccus-legal-and-regulatory-database

These dedicated laws all seek to remove legal ambiguities[41] and establish permitting regimes for CO_2 storage sites that, among other aspects, include procedures for the selection of sites that are indicative of long-term (permanent) storage and to implement monitoring, reporting, site stewardship and liability arrangements for the store over the longer term.

The purpose and safeguards provided by these frameworks are twofold:

1. Building confidence and trust in the efficacy and safety of geological CO_2 storage as a climate mitigation method;
2. Underpinning carbon pricing and market-based policies through effective management of non-permanence and carbon reversal, allowing for permanent, fungible, tradable units to be originated (e.g. as is the case with the connection between the EU ETS and the underpinnings of the EU CCS Directive).[42]

These elements are reflected in the four main building blocks used to assess methodological approaches to managing non-permanence above (Section 3.3.5). As noted above, current methodologies from ICPs tend to rely on these permitting frameworks to provide assurances and safeguards for DACCS and BECCS project activities (Section 3.3.1).

International laws and regulations

At the international level, assurance over the safety of geological CO_2 storage has also been established under international conventions such as the London Convention and London Protocol thereto (LC/LP) and the Oslo-Paris Convention for the Protection of the Marine Environment of the North-East Atlantic ('OSPAR'). Both frameworks address CO_2 storage in the marine environment by: (i) prohibiting injection and storage of CO_2 directly in the water column ('oceanic CO_2 storage'; see also below for their role in marine eCDR) and (ii) allowing geological CO_2 storage under the seabed, subject to application of the following:

- LC/LP: 2012 Specific Guidelines for the Assessment of Carbon Dioxide for Disposal into Sub-Seabed Geological Formations (LC 34/15, annex 8)
- OSPAR: 2007 Guidelines for Risk Assessment and Management of Storage of CO_2 Streams in Geological Formations.

Counting eCDR towards NDCs

The 2006 IPCC Guidelines (IPCC 2006) outline detailed MRV approaches for countries hosting CO_2 capture (Volumes 1, 2 and 3) and CO_2 transport and geological storage operations (Volume 2, Chapter 5). Therein, captured CO_2 should be allocated in the sector generating the CO_2 (i.e. reported as emitted):

> "…*unless* it can be shown that the CO_2 is stored in properly monitored geological storage sites as set out in Chapter 5 of Volume 2" (IPCC 2006, Vol. 1, Chapter 1).

[41] For example, clarifying access and tenure rights to geological pore space.
[42] Installations inside the EU ETS capturing CO_2 may only deduct the amounts captured from the installation's GHG inventory when it is transferred for storage in geological CO_2 storage sites permitted under the CCS Directive.

Notably, the guidance for CO_2 transport and storage requires inventory compilers to apply Tier 3 (i.e. project specific) methodologies and also implies several de facto regulatory and verification elements that need to be conducted by inventory compilers (Box 4-2).

Trading eCDR under Article 6

In terms of underpinning carbon markets, safeguards for geological CO_2 storage were agreed by Parties to the Kyoto Protocol in the CDM modalities and procedures for CCS (UNFCCC 2011; Box 2-3). The requirements under CDM sought to align safeguards for geological CO_2 storage in developing countries with the rules and regulations established in Annex I (developed) countries (see also IETA 2024). Regulatory alignment supports the fungibility of emission reduction units originated from CCS (geological CO_2 storage) activities irrespective of their country of origin.

The following sections consider the requirements for Guidance on Cooperative approaches under Article 6.2 (UNFCCC 2018a) and the RMPs (UNFCCC 2018b) in respect of eCDR involving geological CO_2 storage (Box 2-1; Table 4-3).

Box 4-2 Requirements for geological CO_2 storage under IPCC guidance

The following Site QA/QC requirements are set out in IPCC (2006):

> 'On-site QA/QC will be achieved by regular inspection of monitoring equipment and site infrastructure by the operator. Monitoring equipment and programmes will be subject to independent scrutiny by the inventory compiler and/or regulatory agency.' (p. 5.19)
>
> 'All data including the site characterization reports, geological models, simulations of CO_2 injection, predictive modelling of the site, risk assessments, injection plans, licence applications, monitoring strategies and results and verification should be retained by the operator and forwarded to the inventory compiler for QA/QC.
>
> Where applicable, the relevant regulatory body can provide verification of emissions estimates and/or the monitoring plan described above. If no such body exists, the site operator should at the outset provide the inventory compiler with the results of peer review by a competent third party confirming that the geological and numerical models are representative, the reservoir simulator is suitable, the modelling realistic and the monitoring plan suitable. As they become available, the site operator should compare the results of the monitoring programme with the predictive models and adjust models, monitoring programme and/or injection strategy appropriately. The site operator should inform the inventory compiler of changes made.' (p. 5.20)

Supporting documentation is also listed under '5.10 Reporting and Documentation', including, prior to injection:

- Report on the methods and results of the site characterization
- Report on the methods and results of modelling
- A description of the proposed monitoring programme including appropriate background measurements

And annually from each site:

- The mass of CO_2 injected and stored in the reporting year, and the cumulative mass of CO_2 stored at the site
- A report detailing the rationale, methodology, monitoring frequency and results of the monitoring programme.
- A report on any adjustment of the modelling and forward modelling necessary in the light of monitoring results.

Source: IPCC (2006), Volume 2, Chapter 5.

Methodologies and metrics

Capture of CO_2 from point sources, and the CO_2 transport and geological storage covered by IPCC (2006). Therefore, the requirements for ITMOs and A6.4ERs to be measured in accordance with IPCC assessed methodologies and metrics is fulfilled.

Participation, authorisations and non-permanence

Precedents exist from the CDM that can be drawn upon for participation and methodological design for both cooperative approaches and under the PACM (Box 2-3). However, there is little experience with providing project approvals under these frameworks to date, especially in developing countries.

There is likely to be QA/QC applied at the methodological level (see Section 3.3.5), which should also be cognizant of the QA/QC requirements in IPCC 2006 Guidelines (Box 4-2). These approaches can be used to inform *Initial Reports* and *Regular Information* for the treatment of non-permanence and carbon reversals under cooperative approaches. The standards and tools being developed for removals under the PACM (as described above) will also apply to geological CO_2 storage.

In the case of both cooperative approaches and the PACM, the requirement to indicate how activities contribute to implementation of its NDC and/or LT-LEDS poses challenges given the low level of mentions of DACCS and BECCS in NDCs and LT-LEDS (Section 2).

Environmental and social safeguards

For cooperative approaches, requirements for environmental and social safeguards are less prescriptive and could draw upon existing approaches applied by ICPs or other standard setters, and/or any specific requirements set out in bilateral agreements between Parties.

For the PACM, requirements for environment and social safeguards are to be guided by a specific annex for geological CO_2 storage in the SD Tool, which is pending (see above).

4.3.2 Other types of carbon storage

For eCDR methods using storage reservoirs other than geological formations, the governance frameworks and approaches are less clear.

National laws and regulations

No specific laws exist regarding biochar use in construction, use of CO_2 to make mineral products, or for the development EW or other types of eCDR involving alkalinity enhancement.

Some existing national laws may have relevance. For example, in the U.S., the Marine Protection, Research and Sanctuaries Act (MPRSA) requires permits for marine eCDR activities, including field research trials, where materials are deposited into the oceanic water column. The U.S. Clean Water Act can also apply under certain circumstances. The MPRSA requirements implement the U.S.'s obligations under the LC/LP, as outlined below. Similar national laws will likely apply in other LC/LP signatory Party countries or other for signatories to other regional marine pollution prevention laws.

EW and biochar (construction) activities will also need to comply with prevailing policies, laws and regulations relating to the conservation and preservation of soil and for construction. Such laws can be wide ranging, including construction codes, planning laws and environmental impact assessment (EIA) requirements, or agricultural guidelines relating to the treatment of soil used for growing crops and livestock. In all cases, requirements will be jurisdiction specific.

International laws and regulations

Much of the world's oceans are protected under various international legal conventions and frameworks including:

- The 1982 UN Convention on the Law of the Sea (UNCLOS)
- The 1972 and 1996 LC/LP (see above)
- Regional seas policies and pollution prevention frameworks (for example, the OSPAR Convention, Kuwait Protocol, South-East Pacific Protocol, Mediterranean Protocol etc.)

Any marine CDR activities, and especially those involving the addition of materials directly to the ocean—such as fertilization by adding iron filings or alkalinization by adding crushed rock—are generally covered by these marine protection treaties.[43] In these respects, the following already applies under the LC/LP (albeit focussed on *biotic* methods involving algae rather than *abiotic* methods such as OAE):

- 2008 resolution (LC-LP.1; adopted), which states that ocean fertilization activities fall within the purview of the LC/LP and that such activities other than legitimate scientific research should not be allowed.
- 2010 resolution (LC-LP.2; adopted) setting out an *Assessment Framework for Scientific Research involving Ocean Fertilization*, which requires that proposed research projects should be assessed to determine if they qualify as legitimate scientific research (see Box 4-3).
- 2013 amendments to the London Convention which will, when in force, create a legally-binding regime controlling marine geoengineering techniques (by establishing a formal assessment framework for any materials to be placed into the ocean for the purposes of geoengineering).

In addition, a meeting of Parties to the LC/LP in October 2023 considered, among others, (i) ocean alkalinity enhancement, and (ii) biomass cultivation for CDR (including seaweed cultivation and sinking) as emerging forms of marine CDR.[44]

[43] Under the LC/LP, the deliberate disposal of waste or *other matter* into the sea is prohibited with the exception of activities subject to the reverse list, and the relevant frameworks thereunder.
[44] 45th Consultative Meeting of Contracting Parties to the London Convention and the 18th Meeting of Contracting Parties to the London Protocol (LC 45/LP 18)

Box 4-3 Summary of the LC/LP Assessment Framework for Ocean Fertilization

The 2010 resolution LC-LP.2 defines ocean fertilization as any activity undertaken by humans with the principal intention of stimulating primary productivity in the oceans. The Assessment Framework established thereunder provides a tool for assessing proposed activities to determine if they constitute legitimate scientific research that is not contrary to the aims of the LC/LP.

The resolution requires the following assessment to be carried out:

1. **Initial assessment** (to determine whether a proposed activity falls within the definition of ocean fertilization and has proper scientific attributes)
2. **Environmental assessment**
   a. Problem formulation
   b. Site selection and description
   c. Exposure assessment
   d. Effects assessment
   e. Risk characterization risk management
2. **Decision-making** (in respect of the assessment)
3. **Results of monitoring** (of the approved activity)

Notably, the Initial Assessment states that "there should not be any financial and/or economic gain arising directly from the experiment or its outcomes", which may preclude the issuance of credits for such activities.

Source: Annex 6 to the Report of the 2010 Meeting of the Contracting Parties to the London Convention and Protocol

The ensuing *Statement on Marine Geoengineering* issued by Parties states that the techniques have:

> "...the potential for deleterious effects that are widespread, long-lasting or severe" [and that] "there is considerable uncertainty regarding their effects on the marine environment, human health, and on other uses of the ocean."[45]

The statement also reaffirms that marine eCDR activities should be deferred other than in connection with "legitimate scientific research".

Other marine protection laws in some cases also apply to land-based sources of marine pollution. For example:

- UNCLOS Article 194, 207 and 213 requires parties to take measures to reduce and control any source of marine pollution, including land-based sources;
- OSPAR Article 3 requires contracting parties to take, individually and jointly, all possible steps to prevent and eliminate pollution from land-based sources.

These clauses may bring other eCDR methods within the purview of the marine protection laws in situations where the ultimate fate of eCDR products and bi-products is the ocean, as is the case for all types of alkalinity enhancement methods reviewed in this report, including EW.

[45] https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/LC-45-LP-18.aspx

Counting eCDR towards NDCs

Reporting of GHG emissions and removals in NGHGIs does not extend to inland waterways or the ocean. Thus, IPCC guidelines do not exist for marine eCDR methods, creating challenges for the counting of marine CDR methods towards the achievement of NDCs. Any carbon reversals from the marine DIC pool would go undetected and unreported in NGHGIs.

No specific IPCC guidance exists for the treatment of EW in NGHGIs. However, elements of Tier 3 national soil carbon models applied in accordance with IPCC could be expanded to better account for changes in inorganic carbon within cropland and grassland soils associated with EW activities (Vol. 4, Chapters 2, 5 and 6, IPCC 2006; IPCC 2019). EW could also be considered through updates to the agricultural liming methods (IPCC 2006; Vol. 4, Chapter 11). Nevertheless, since the ultimate fate of DIC produced by EW is the ocean, the same proviso as for marine CDR methods would apply. Any reverse reactions taking place in inland waterways en route to the ocean, with a resultant release of CO_2, would equally go undetected and unreported in NGHGIs.

The IPCC has proposed draft guidelines for the integration of biochar additions to soil within NGHGI compilation methods for cropland, grassland and forestland (IPCC 2019; Vol. 4, Appendix 4), but not for biochar use in construction materials. Notably, the current approach is based on subtractions and additions to the LULUCF soil carbon stock, rather than accounting for negative emissions at the point of biochar creation or use (as is the case with BECCS) and applies a stock decay model to account for biochar degradation over time. These arrangements may present some alignment challenges for NDC accounting.

Trading eCDR under Article 6

Other than the methodologies developed by ICPs reviewed in this report, few precedents exist to guide approaches. Notably OAE was previously considered for crediting under the CDM, where it was concluded that the approach presents 'considerable difficulty' and may require significant effort to address methodological issues (Box 4-4). Unlike CCS (geological CO_2 storage), the potential for OAE was not considered further by Parties to the Kyoto Protocol.

Emission reductions from biomass pyrolysis were covered under the CDM, based on a counterfactual (baseline) of avoiding methane release through biomass decay rather than carbon removal by biochar storage.[46] No projects using the methodology were ever registered by CDM, or Verra or Gold Standard.

The following sections consider the requirements for Guidance on Cooperative approaches under Article 6.2 (UNFCCC 2018a) and the RMPs (UNFCCC 2018b) for eCDR methods utilising storage reservoirs other than geological CO_2 storage.

[46] *AMS-III.L. Avoidance of methane production from biomass decay through controlled Pyrolysis*. Only carbon removal through afforestation and reforestation was eligible under the CDM, and subject to tCER/lCER issuance.

Box 4-4 Consideration of OAE by the CDM Small Scale working group

In 2006 the Small-Scale Working Group (SSC WG) of the CDM Executive Board was mandated to make a qualitative assessment of ocean alkalinity enhancement by the pumping of power station flue gas through ocean water containing limestone in porous baskets. The methodology proposed that the approach would convert CO_2 in the flue gas to dissolved bicarbonate in the released sea water (small-scale methodology proposal: *Carbon Capture and Ocean Storage (CCOS) through Alkalinity Shift* (SSC-038 and SSC_049)). Following its review, the SSC WG concluded that:

> "The technology for carbon capture and ocean storage is in its early stages of development and is yet to be tested and proven under lab or field conditions for application in conjunction with coastal power plants. In addition to proving the technical viability, there may be the possibility for environmental impacts which need to be assessed and possible effects addressed by an environmental management plan before large scale project activities should be considered.
>
> Significant methodological concerns and challenges exist in permanence, leakage and boundary issues relating to these types of project activities. The working group feels that project activities to be considered under CDM should use technology which is proven under field conditions and that CDM should not be used for demonstrating laboratory scale technologies.
>
> It may be noted that considerable amount of efforts by panels and working groups may be required to address the methodological issues of these unproven technologies without significant immediate potential." (CDM: Recommendation from the Working Group for Small Scale Methodologies, SSC WG Meeting 13-14 June 2006)

The CDM Executive Board, at its 26th Meeting (September 2006) recommended that approving the methodology in its current from would pose "considerable difficulties".

Source: https://cdm.unfccc.int/Panels/ssc_wg/SSCWG6_repan2_Revision_AMS_III_G.pdf; https://cdm.unfccc.int/methodologies/SSCmethodologies/clarifications/53202; https://cdm.unfccc.int/methodologies/SSCmethodologies/clarifications/58739; https://cdm.unfccc.int/EB/archives/meetings_06.html#026

Methodologies and metrics

Presently there are no IPCC assessed or CMA approved methodologies or metrics for eCDR methods not utilising geological CO_2 storage. Developments in these respects are subject to:

- IPCC Methodologies Report on CDR (see Box 2-1)
- SBM PACM standards and tools (see above).

Both items are pending. The absence of IPCC methodologies notwithstanding, a draft of the PACM standard: *Addressing non-permanence and reversals* released in September 2025 (UNFCCC 2025c) suggested that a wide range of eCDR methods fall within the scope of PACM including:

- Biochar and carbon storage in construction materials.
- Carbonate storage through EW, and
- Storage of CO_2 in the oceanic water column or through ocean alkalinity enhancement.

Participation, authorisations and non-permanence

There are no precedents from CDM to consider, since no eCDR project types received methodological approvals in the past (as outlined above).

In the case of both cooperative approaches and PACM, the requirement to indicate how selected activities contribute to implementation of a host country's NDC and/or LT-LEDS poses challenges given the absence of mentions and the barriers to inclusion of several eCDR methods in NDCs and LT-LEDS (Figure 2-2; Figure 2-3).

For cooperative approaches, Parties are unlikely to consider eCDR methods in *Initial Reports* until such time that cooperative eCDR activities are being contemplated. As and when they do, both Parties will need to describe how non-permanence risks will be minimized and reversals will be addressed. Cooperative approaches are usually also backed by bilateral agreements between the participating country Parties, which can provide an additional opportunity to include safeguards for how environmental integrity risks of eCDR activities may be managed between Parties.

For the PACM, the standards and tools being developed for CDR will naturally apply to eligible eCDR methods covered by the mechanism. However, additional uncertainty exists over whether Parties, and especially developing country Parties, are ready to include any eCDR methods within their public indications of the types of PACM activities they expect to host, as required under the RMPs (Table 4-3).

In terms of project authorisations, at time of writing the more novel eCDR methods are subject to complex methodological approaches implemented by ICPs, which have so far largely excluded host country participation in terms of approvals, permits or other forms of decision-making (see Section 3.5). If similar requirements are implemented under PACM, it seems likely that host countries will need to have made a clear assessment of individual eCDR methodologies and form an opinion on alignment with their NDC, methodologies and metrics and tracking under the ETF prior to authorizing ITMOs or A6.4ERs from novel eCDR activities. As such, it seems that few if any developing countries may be ready to offer such authorisations in the near-term.

Environmental and social safeguards
Requirements for environmental and social safeguards will be guided by conditions specified in *Initial Reports*, and, for the PACM, the pending specific annexes of the PACM SD Tool (see above).

Examples can be drawn from the LC-LP Assessment Framework for Ocean Fertilization (Box 4-3) and also from experiences of ICPs in the VCM, such as those established for EW by Puro.earth and Isometric (Box 4-5).

4.4 Gaps and means to close gaps

The governance landscape for eCDR methods is similar to that of eCDR methodologies in being somewhat uneven across the suite of approaches.

On the one hand, **eCDR methods involving geological CO_2 storage** can draw upon more than 15 years' experience in establishing well-aligned laws, regulations and standards for project development across multiple jurisdictions, which are reinforced by robust top-down MRV requirements within IPCC guidance (e.g. IPCC 2006).

Box 4-5 Example of environmental and social safeguards for EW under ICPs

Puro.earth Enhanced Rock Weathering methodology (v2, 2022) provides extensive guidance on environmental and social safeguards. The methodology notes that “depending on the weathering material used, PTEs [potentially toxic elements] may include heavy metals, radionuclides, or asbestiform minerals”. These may have negative effects on ecosystems human health (directly or indirectly through the food chain). Project developers are required to undertake five-step risk assessment covering problem formulation, characterisation studies and mitigation measures etc., which is subject to independent third-party review. Guidance is also provided on the following:

1. **Heavy metals**. Options for risk management include: setting maximums on applied materials; maximums on application rates; maximums on soil concentrations; combinations thereof; or, use of ‘bioavailability’ measures. EU regulatory limits on heavy metal concentrations in fertilizers are cited as an analogue for limits on applied materials (EC 2019), and Finnish national legislative limits on soil concentrations are also cited.
2. **Asbestos**. Asbestiform substances, that is fibrous silicate materials, pose inhalation risks to human health. They are present in some EW material such as serpentines. These materials react with CO_2 to form carbonates. Exposure can occur during mining, handling or spreading, and post application through wind erosion. Examples of exposure limits are cited from construction standards.
3. **Radionuclides**. The methodology cites a lack of studies as a constraint on setting limits.

Environmental safeguards require that project proponents demonstrate, among others,

- **Safe material sourcing,** including excavation permits, environmental permits etc.
- **Safe material application,** covering rights to spread materials on the sites, and do no significant harm to surrounding environment and local communities.
- **Monitoring (crops; soils)**, including the absorption of major cations by crops, soil organic carbon stocks. Unclear if catchment monitoring is required.

Social safeguards include:

- **Local community protection,** evidence of informed consent, including acceptable contaminant levels and environmental risks, plus ongoing engagement.
- **Occupational health and safety,** including performing activities of crushing, grinding and spreading in compliance with local regulations.

Isometric Enhanced Weathering in Agriculture protocol is less prescriptive than Puro.earth’s, referring to ‘regulatory limits’ for heavy metal contamination risks and requiring an environmental monitoring plan where there is significant risk of limits being exceeded. Isometric’s EW methodology also mentions ‘Proof of approval for necessary permits’, while literature sources indicate that EW activities may involve several types of permitted activity (see Webb 2020).

Source: Puro.earth Enhanced Rock Weathering Methodology (v2, 2022). Isometric Enhanced Weathering in Agriculture protocol (v1.1).

These substantive developments have built confidence and trust in the efficacy, durability and safety of climate mitigation methods involving geological CO_2 storage. In turn, these underpin their reporting in NGHGIs, their counting towards the achievement of NDCs and the issuance of permanent, fungible, tradeable units or credits to such activities. However, only a handful of DACCS and BECCS projects have been developed under these frameworks, and only in developed countries, while only a few developing countries have implemented the policy and legal infrastructure needed to support safe deployment and the crediting of such actions.

As concluded by Schenuit et al, (2024) in their assessment of three case studies of CDR readiness in developing countries:

> "…the current level of regulation and innovation suggests that the rapid and substantial ramp-up of CDR identified in the IAM [integrated assessment model] pathways is *not* plausible in any of China, India or Brazil – especially with regard to CCS-based CDR"

Nevertheless, while the creation of bespoke legislation inevitably takes time and political capital, efforts are being made to bridge this gap. The CCS, DACCS and BECCS methodology from the GCC provides comprehensive guidance on the permitting processes for geological CO_2 storage with the intent of using existing regulatory frameworks to permit such actions (e.g. environmental impact assessment regulations). Such approaches can fast-track deployment by avoiding the need to wait for specific legislation to be established.

Other **eCDR methods not utilising geological CO_2 storage** lack such a cohesive and comprehensive approach to MRV and safeguards. Legal and regulatory developments are being established in a piecemeal and ad hoc fashion drawing on approximations and broad analogues. When coupled with the absence of clear IPCC guidance on the necessary MRV for inclusion in NGHGIs and their counting towards achievement of NDCs, their current standing may not be deemed sufficiently robust to build confidence and trust in safety and durability across a broad base of stakeholders. Indeed, some marine CDR methods are explicitly prohibited under international law such as the LC/LP and possibly other regional marine protection treaties. Adding in uncertainty over their efficacy, the complexity of the quantification methodologies and their embryonic and mainly digitised methods by which to observe and measure CO_2 drawdown or reversals, the governance challenges seem manifold.

Yet, these more novel, lower cost, eCDR methods are being vigorously pursued in the VCM. In past year or so, ICPs have issued almost 1,000 credits to EW and other alkalinity enhancement activities in Brazil, Canada and the U.S., and issuances are in the pipeline for two EW projects in India (Table 3-3). Seemingly ambiguities over governance and Paris-aligned MRV is having negligible impacts on deployment and VCM crediting. Notably, a recent thought-leadership report focussed on the treatment of non-permanence and carbon reversal in the VCM makes no mention of national accounting or the host country role (IC-VCM 2025).

The situation notwithstanding, counting the removals achieved by these activities towards NDCs and gaining authorisations under Article 6 can be expected to face challenges due to gaps in the NGHGI MRV framework and a lack of knowledge and understanding of the intricacies of eCDR methodologies among DNAs and other national authorities.

Better alignment of governance is needed. Applying differential safeguards and limited assurances over carbon reversal could create market distortions that drive investments towards eCDR methods and activities with lowest compliance requirements and higher risks of carbon reversal and unintended negative side effects.

The aim of regulators and standard-setters today should therefore be on replicating equivalent levels of assurance that can build confidence and trust in the efficacy and safety of novel eCDR methods. Policymakers and the scientific community also need to find ways in which action on the ground can be connected to the Paris Agreement MRV and accounting systems, especially ICTU, the ETF, NGHGIs and Article 6 transfers, and the IPCC methodologies and metrics that join these together. Presently gaps exist which may not be readily filled by VCM methodologies.

Notably, while the governance issues highlighted may be viewed through the prism of eCDR specific characteristics, many reflect broader challenges posed for Article 6 participation impacting upon a wider suite of mitigation types, as discussed in World Bank, A6IP, GGI, GIZ, ICVCM, UNDP, UNFCCC and VCMI (2025).

5 Conclusions and Recommendations

5.1 State of play for eCDR in developing countries

5.1.1 The case for deployment

The near-term case for widespread deployment of eCDR in developing countries is mixed. On the one hand, various groups including green NGOs and academia have voiced concerns over the moral hazards and climate justice implications of deploying eCDR in developing countries today. On the other hand, some developing countries are showing interest in CCS generally, and a growing interest in related eCDR methods such as BECCS and DACCS. Project developers are also moving forward with creditable eCDR project activities and proposals in developing countries including Brazil, India and Kenya.

Over the medium term, the need for *all* Parties to contribute to the Paris Agreement's net zero goal lends itself to a subtle shift towards a more ubiquitous distribution of climate action. The situation infers a dual role for eCDR in climate action over the coming decades to 2050: for developed countries, a hard push as they aim to reach net zero by 2050 or before; for developing countries, more opportunistic moves that allow them to gain experience and monetize actions through carbon markets according to national circumstances and priorities.

This outlook is supported by the need for technology learning around eCDR. Several observers are making the case for urgent eCDR deployment today in order that the most effective technologies be identified and readied for wider deployment at the time when net zero comes into sharper focus.

Carbon markets can support efficient eCDR deployment. The trading of ITMOs between countries can drive climate action to locations where it is most cost effective. An example is BECCS, where it may be more efficient to deploy the activity in the country of biomass origin and trade the resulting carbon units (e.g. a developing country such as Brazil or South East Asia), rather than ship biomass over long-distances—with significant GHG emissions—in order to generate carbon removals where they should be in demand (because of mid-century net zero targets in, e.g., Europe or Japan). Similarly, DACCS may be well-suited to the Middle East region, powered by renewable energy and utilising abundant geologic storage resources, subject to the speed at which sufficient low CI energy can be deployed (IEAGHG 2025).

5.1.2 Current status of action

The analysis of Paris Agreement pledges and national climate policy documents suggests that, with a few exceptions (e.g. Indonesia), eCDR is hardly considered as a mitigation option by developing countries today. Comparatively more countries are including natural climate solutions (NCS) in their NDCs, and on a firmer basis (e.g. quantified targets and plans). This is understandable given the long-standing status of NCS as a key mitigation approach, particularly for countries in the global south with large forest coverage.

The current UNFCCC-agreed guidance for compiling of NDCs—the 'ICTU'—as well as rules for carbon markets under Article 6, pose a hinderance to eCDR inclusion within Paris Agreement contribution goals. For example, the need to follow methodologies and metrics and reporting categories in IPCC guidance may be a barrier for including many eCDR methods into NDCs and Article 6 carbon markets. Most eCDR methods are not currently covered by IPCC assessed and CMA approved guidance (Table 2-2; Box 2-1). An exception is BECCS, which is clearly recognised and included as a negative emission technology within IPCC guidance (IPCC 2006; Table 2-2) and is somewhat better represented within the current suite of developing country NDCs.

The present situation notwithstanding, VCM credits have recently been issued to an enhanced weathering (EW) project in Brazil, and two more EW projects are seeking issuance in India. The Great Rift Valley in Kenya is also fast becoming a hotspot for pioneering DACCS.

5.1.3 Methodological and governance aspects

There is a rapidly expanding suite of eCDR methodologies from which to originate carbon credits, implying that an approach could likely be found for many different circumstances and applications. However, current eCDR methodologies, which are primarily being promulgated by ICPs in the VCM, exhibit some issues and challenges for wider uptake. These include:

1. **Complexity in design**, especially in respect of the following:
    - The requirement to characterise, assess and quantify the lifecycle GHG emissions associated with eCDR methods, as well as the methodological approaches being applied to mitigate or account for potential leakage effects.
    - The reliance in some cases on bespoke digital simulation models ('digital twins'), rather than observations, to determine whether a CO_2 drawdown effect and/or a carbon reversal is occurring (primarily alkalinity methods, where drawdown or oceanic outgassing cannot be readily observed).
2. **Variability in requirements,** especially in respect of the following:
    - Approaches to monitoring, in particular, reservoir monitoring and measurement and accounting for fluxes therefrom (i.e. carbon reversals) spanning: (i) no monitoring (carbonated products) (ii) no monitoring and conservative assumptions over fluxes (EW and other alkalinity methods) (iii) comprehensive reservoir monitoring, including in the post-crediting phase (geological CO_2 storage; potentially some alkalinity methods). In some cases, monitoring is reliant on computer simulations.

- The means to remediate carbon reversals, covering different risk assessment approaches, different discounting methods, and variable approaches to the establishment and operation of buffer accounts.
- The cost of project development and operation (e.g. monitoring, buffer contributions, insurance).

3. **Lack of methodologies and metrics** assessed by the IPCC and approved by the CMA.

Variations also exist in the eCDR governance landscape. While eCDR methods involving geological CO_2 storage have established a global regulatory standard, there is limited experience in implementation, and few developing countries have established the types of laws and regulations that could underpin deployment today. Conversely, eCDR methods not involving geological CO_2 storage have so far only established piecemeal and ad hoc governance requirements, yet projects are pushing ahead (e.g. EW in Brazil and India).

The complexity of methodologies, the absence of clear governance structures and the lack of MRV guidance in IPCC guidelines can all impact upon the capacity of host countries to consider eCDR within their NDCs and to originate and trade units under Article 6 (in respect of e.g. methodologies and metrics, public statements of support for mitigation types, and ITMO authorizations).

The IPCC Methodologies Report on CDR due in 2027 is urgently needed to clarify methodological and governance approaches that can unlock wider inclusion of eCDR in Paris-aligned targets and markets (Box 2-1).

Broader barriers and challenges to eCDR in developing countries include:

- **Low levels of awareness and capacity**. The review of NDCs suggest that most developing countries have only low levels of awareness, and/or perhaps interest, in eCDR. They are therefore also likely to have only limited competencies to consider eCDR and will be poorly equipped to develop knowledge and a deeper understanding of national mitigation potentials. This will also impact public acceptance of projects.
- **Lack of guidance and support**. There is an absence of methods and tools that can be used to help establish better estimates of national eCDR mitigation potential and to understand methodological design, approaches and issues. Presently, per ICTU, assumptions and methodological approaches used for NDCs design shall use IPCC methodologies, assumptions and sector reporting categories (i.e. Energy; Industrial Process and Product Use; Agriculture, Forestry and Land Use; Waste). With the exception of BECCS, the IPCC sector categories—as well as the BTR reporting approaches—lack clear placeholders for the inclusion of eCDR mitigation within NDCs.

Also, tools such as the GHG Abatement Cost Model (GACMO),[47] which is widely advocated for use in NDC design, also lacks the capability to include eCDR.

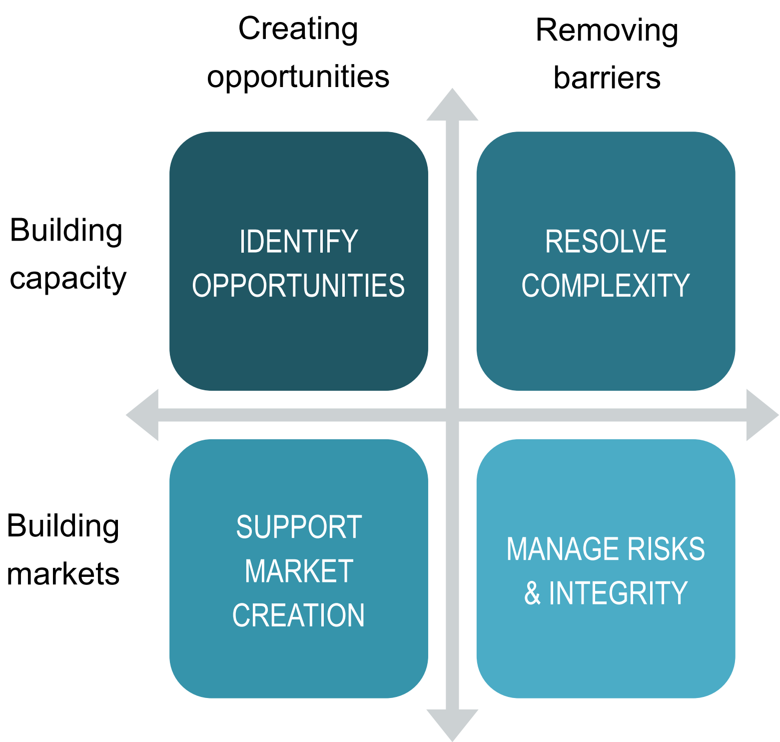
In all cases, improved understanding and more political will can support the implementation of stronger national governance frameworks.

Based on these broad conclusions, the next sections consider several actions and a strategy for implementation that could help catalyse eCDR implementation in developing countries over coming years.

5.2 Recommendations

Four key action areas are outlined below that can create opportunities, remove barriers and build capacity and markets for eCDR development, as summarised below (Figure 5-1).

Figure 5-1 Recommended action areas for eCDR upscaling



International organisations can play a crucial role across all four areas.

5.2.1 Identifying eCDR opportunities and road-mapping

Developing countries likely lack knowledge and understanding of the mitigation potential of eCDR. As such, there is overall limited understanding of domestic opportunities

[47] https://unepccc.org/gacmo-tool/

to use eCDR, which hinders development and deployment: how can countries include eCDR in NDCs when there is no sense of whether, or at what scale, such methods could be used?

Technical support from international organisations can raise levels of basic understanding of eCDR methods including their characteristics, their technical features, the potential methodologies and metrics, and approaches to appraise national mitigation potential and mobilise deployment (e.g. via carbon markets). Providing greater understanding of the benefits (e.g. for the climate and in terms of trading value), the risks, and the safeguards to control risks, would greatly improve the outlook for wider consideration of eCDR.[48]

5.2.2 Resolving eCDR complexity

Developing countries may struggle to understand the fit and alignment of eCDR methodologies within their NDCs and approaches to carbon market development. They may also struggle to issue authorisations to eCDR projects, especially if the activity was not included within its NDC, in Initial Reports on cooperative approaches or PACM public indication to the UNFCCC, and if national authorities have had little if any involvement in project permitting and approvals.

Awareness and understanding of methodological approaches can be elevated through broader inclusivity and consensus in eCDR methodology design, and more participatory decision-making in eCDR methodology application. A deeper understanding of these needs is incumbent on host countries, ICPs and the SBM that are all promulgating eCDR guidance, methodologies and tools.

Technical support from international organisations offers an established and trusted conduit by which to help close knowledge gaps and to build confidence, consensus and capacity.

5.2.3 Managing eCDR risks and integrity

Developing countries hosting durable eCDR projects will in many cases be required to host enhanced carbon sinks and reservoirs within their territory for extended periods of time (i.e. permanent storage over hundreds to thousands of years). If eCDR activities are developed cognizant of ICTU, any fluxes of carbon from these reservoirs (e.g. leaks, reverse reactions, outgassing) will need to be monitored and reported in NGHGIs and counted against the NDC making the host country the de facto underwriter of non-permanence and reversal risk. [49]

Host countries therefore need to be aware and informed of such requirements and the associated risks, as well as the safeguards to control such risks. This can include an understanding of the legal status, barriers and means to establish supporting rules and

[48] A recent example of such an initiative is the launch of the *Network of National Centres of CCUS Excellence in the Global South (NNCCE)* https://ieaghg.org/news/1st-meeting-of-the-network-of-national-ccus-centres-of-excellence-in-the-global-south/

[49] ICTU states that, in respect of NDCs, “once a source, sink or activity is included, [Parties should] continue to include it” (Box 2-1)

regulations to allow eCDR activities to go ahead. Yet, the current suite of eCDR methodologies and project standards do not always offer a clear means or role for host countries in eCDR project governance.

Awareness raising and capacity building must therefore include improvements to governance arrangements for eCDR activities in developing countries

5.2.4 Supporting market creation

Developing countries need strong price signals from trusted institutions in order to have confidence in carbon markets that can drive eCDR deployment. Presently, most eCDR transactions are occurring in the VCM with limited engagement of public institutions, which can undermine trust.[50]

Trusted delivery partners in the international community could establish eCDR credit buying programmes to support market creation. Buying carbon credits can provide the demand signals for eCDR in developing countries and catalyse knowledge and capacity developments through learning-by-doing.

There may be various ways of establishing the programme, as outlined below.

5.3 Strategy

Drawing on the information and analysis presented in this report and in Annex B, the strategy of multilateral organisations towards eCDR development and deployment may be guided by, among others, the following features:

1. **Maturity**: the readiness of a method to be deployed; the extent to which credits are being issued today; the ease of methodological development and implementation etc
2. **Acceptability**: whether the method is legal or subject to legal ambiguity; whether social and environmental safeguards are in place; whether host countries can effectively participate in project decision-making and approvals.
3. **Measurability**: whether activities can be robustly measured; whether the monitoring of enhanced carbon reservoirs is feasible and readily achievable so as to provide assurances over safety, durability and environmental integrity of units.
4. **Accountability**: whether activities can be accounted for within the Paris Agreement framework as currently structured, including standing up to the PACM requirements and to the scrutiny of the TER of BTRs under the ETF.

Mindful of these conditions, a three-part international development strategy is proposed building from the recommendations above.

[50] National legislation on carbon credit origination in developing countries is increasingly requiring authorisations for all carbon credit project types, even those purportedly under the umbrella of the VCM (e.g. in Ghana's Framework on international carbon markets and non-market approaches).

5.3.1 Part 1 – Raise awareness, build capacity, implement training

Capacity building is a core activity under the UNFCCC and Paris Agreement, which also encompasses the Paris Committee on Capacity Building established at COP21. Yet, a time of writing, the resources linked to the UNFCCC capacity building portal do not include much in the way of information on eCDR methods etc.[51] Equally, the UNFCCC Climate Technology Centre and Network (CTCN) does not offer any resources on CDR.

International organisations should seek to close this gap and support the components for eCDR capacity building with developing countries. Capacity-building activities can focus on, among others, **information, training and outreach** components to help enhance basic knowledge and understanding. Basic topics to be addressed could include: What is eCDR? What is the current the status? How can it contribute to national mitigation? What are the risks and safeguards needed?

Information and training products can include:

- Brochures and webpages
- Infographics
- Web resources
- Training and education programmes

Engagement and education of policymakers at COPs and Subsidiary Body meetings under the UNFCCC could also help to raise awareness and build trust (e.g. in-session workshops under mitigation and technology tracks).

5.3.2 Part 2 – Develop tools and guidance

The absence of clear guidance on eCDR assessment or means to include these mitigation methods within NDCs and LT-LEDS suggests a need for more tools and guidance to support eCDR appraisal. Key tools and support could include:

- A crediting/quantification methodologies summary report/booklet and web resources (drawing from information and analysis in this report).
- An MRV summary report/booklet and web resource (in respect of NDC accounting)
- Development of an eCDR national assessment/screening tool
- Development of an eCDR 'bolt-on' for inclusion in NDCs and LT-LEDs

Aspects to be addressed include:

- The potential candidate countries in which these could be piloted.
- Which existing agencies, tools, products and procedures could be expanded or updated to include eCDR method and methodologies.

[51] Based on searches for "carbon capture" and "carbon removal" at: https://unfccc.int/resources

- Whether there are existing programmes where eCDR could be more strongly embedded (e.g. UNFCCC CTCN; Partnership on Transparency in the Paris Agreement; Article 6 Implementation Partnership; Partnership for Market Implementation).

5.3.3 Part 3 – Pilot eCDR carbon crediting

Presently several eCDR credit buyer programmes exist, albeit primarily in the private sector. Examples include that of Microsoft, the advanced market commitment of Frontier and the NextGen buyers club (see IEAGHG 2024). Some governments are also implementing a direct eCDR credit acquisition approach, including multilaterally through the First Movers Coalition (alongside the World Economic Forum),[52] and domestically. The latter includes the U.S. Department of Energy CDR prize programme[53] and similar approaches being mooted by the European Commission.[54] None of these actions are focussed on developing countries.

International organisations and donors could establish an eCDR credit buying programme focussed on developing countries to help catalyse interest and action. This could encompass public-private coalitions that can help existing programmes by adding the weight and trust that comes the backing of intergovernmental relationships. Given the variability in maturity/readiness, MRV, safeguards and governance arrangements across the landscape of eCDR methods, the approach could be multi-faceted.

Drawing on the features that can guide development actions, the buying approach could be structured as follows:

Tranche 1 – Credit procurement for accounting against NDCs or international mitigation purposes (IMP)

This tranche of buying would focus on the core, proven, eCDR activities with high levels of readiness. The focus here would be on engineered geological CO_2 storage solutions, especially BECCS and DACCS. These eCDR methods are characterised by elements that can support the accounting of actions against NDCs and IMP, including:

- *Measurability*: readily observable and measure carbon removal effect (e.g. CO_2 flows can be measured using meters)
- *Accounting*: IPCC guidance on methodologies and metrics exist or can be readily applied. Multilaterally agreed precedents exist for the treatment of non-permanence and carbon reversals (e.g. under CDM; Box 2-3).

[52] https://initiatives.weforum.org/first-movers-coalition/home
[53] The US$35 million Carbon Dioxide Removal Purchase Pilot Prize (https://www.energy.gov/fecm/funding-notice-carbon-dioxide-removal-purchase-pilot-prize)
[54] https://climate.ec.europa.eu/citizens-stakeholders/events/workshop-perspectives-purchasing-programme-crcf-permanent-carbon-removal-credits-2025-05-21_en

- *Governance and safeguards*: long-standing, well-aligned, expectations for regulatory and accounting frameworks established for CCS. Existence of precedents by which to assign liability to compensate for carbon reversals.

Tranche 2 – Credit procurement for other purposes (OP) – a results-based finance framework

This tranche would focus on eCDR methods with known challenges, but also where experience is growing rapidly through the VCM. The application of results-based finance would avoid accounting risks as the credits would not be counted against NDC achievement or for IMP purposes. Therefore, the exposure to governance concerns would be reduced. The focus here could be on EW, biochar use and concrete curing using captured CO_2, which are characterised by the following:

- *Measurability*: some methods can be readily observed and measured (e.g. biochar; concrete treatment) although the reservoirs cannot be easily monitored. In the case of EW, observation of CO_2 drawdown is difficult and relies on computer simulations and field measurements to calibrate predictions. The open and transient nature of DIC in the environment means more field trials and empirical evidence from monitoring of both the drawdown effect and to the resulting carbon reservoirs is needed to further build trust in these methods.
- *Accounting*: IPCC guidance on methodologies and metrics is largely absent but could evolve through practical experience and empirical evidence.
- *Governance and safeguards*: environmental and social risks are identifiable and manageable. Further experience could help build trust and confidence in the methods.

Tranche 2 could also include bio-oil injection into geological formations, albeit with the need for further assessment of the methodological approaches, which are currently restricted to use in the U.S only.

Others

Other eCDR methods, in particular those involving alkalinity enhancement (e.g. dosing of rivers, wastewater plants and coastal outfalls) and direct ocean CO_2 removal, are less mature and pose wider uncertainties over measurability, accounting towards NDCs and governance and legality under international marine protection laws. These methods should rather be monitored for developments in MRV and governance, with a view to potential inclusion within an expanded credit purchase programme in the future.

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Annex A –eCDR methodologies, protocols, standards, modules and tools

CDR Method	Methodology/Protocol Title	ICP/Standard-Setter	Type of Standard	Version	Date
DACCS	Methodology for the Quantification, Monitoring, Reporting and Verification of Greenhouse Gas Emissions Reductions and Removals from Carbon Capture and Storage Projects	ACR	Methodology	v1.1	Sep-21
DAC	Direct Air Capture	Isometric	Methodology	v1.0.0	Dec-23
DACCS+BECCS	Methodology for Project Activities Involving the Capture, Transport and Geological Storage of Carbon Dioxide	Global Carbon Council	Methodology	v1.0.0	Dec-23
DACCS+BECCS	VM0049 Methodology for Carbon Capture and Storage	Verra/VCS	Methodology	v1.0	Jun-24
DACCS+BECCS	Geologically Stored Carbon Methodology	Puro.earth	Methodology	v2.0	Aug-24
Mineral geostorage	Permanent and Secure Geological Storage of CO_2 by In-Situ Carbon Mineralization	[CarbonFix, Climeworks, DNV]	Methodology	v1.0	Jun-22
EW	Methodology for Atmospheric Carbon Removal through use of Volcanic Basalt Soil Treatments	Verra/VCS	Proposal/ Idea note	v0	Sep-23
EW	Global Rock C-Sink	Carbon Standards International AG	Methodology	v0.9	Oct-22
EW	Enhanced Rock Weathering Methodology	Puro.earth	Methodology	v1.0	Mar-23
EW	Enhanced Weathering in Agriculture	Isometric	Methodology	v1.1	Jan-25
Carbonate materials (BECCU)	Carbon Sequestration Through Accelerated Carbonation of Concrete Aggregate	Gold Standard	Methodology	v1.1	Mar-23
Carbonate materials (BECCU/DACCU)	Carbonated Materials	Puro.earth	Methodology	v2	May-23
Mineralisation	Open System Ex-situ Mineralization	Isometric	Methodology	v1.0	Jan-25
BECCS	Methodology for Biomass Fermentation with Carbon Capture and Geologic Storage	Gold Standard	Methodology	v1.0	Apr-24
BECCS	Biogenic Carbon Capture and Storage	Isometric	Methodology	v1.1.2	Sep-24
BECCS	Methodology for measuring net carbon dioxide removal through bioenergy with carbon capture and storage	[Drax/Stockholm Exergi/EcoEngineers]	Methodology	V09	Nov-23
Biochar (construction)	Global Construction C-Sink	Carbon Standards International AG	Proposal/ Idea note	v0	Feb-25
Biochar (soil + construction)	Biochar Methodology (edition 2022)	Puro.earth	Methodology	v3	Feb-24
Biochar (soil + construction)	Biochar Methodology (edition 2025)	Puro.earth	Methodology	v1	Jun-25
Biochar (soil + construction)	VM0044 Methodology for Biochar Utilization in Soil and Non-Soil Applications	Verra/VCS	Methodology	v1.1	Jul-23
Biochar (soil + construction)	Biochar Production and Storage	Isometric	Methodology	V1.1	Apr-25
Bio-oil geostorage	Bio-oil Geological Storage	Isometric	Methodology	v1.1	Sep-24
Bio-oil geostorage	Bio-oil Sequestration	[Carbon Direct]	Methodology	v1	Aug-22

CDR Method	Methodology/Protocol Title	ICP/Standard-Setter	Type of Standard	Version	Date
River alkalinity enhancement	Wastewater Alkalinity Enhancement	Isometric	Methodology	v1.0	Feb-25
River alkalinity enhancement	River Alkalinity Enhancement	Isometric	Methodology	v1.0	May-25
Marine eCDR (electrolytic)	Electrolytic Seawater Mineralization	Isometric	Methodology	v1.0	Aug-24
Marine eCDR (OAE)	Ocean Alkalinity Enhancement from Coastal Outfalls	Isometric	Methodology	v1.0	May-24
DACCS	Federal offset protocol: Direct air carbon dioxide capture and geological storage	ECCC (2025)	Proposal	v1.0	Jan-2025
DACCS+BECCS	Commission Delegated Regulation establishing the certification methodologies for permanent carbon removals activities (BECCS and DACCS)	European Union (EC 2025)	Methodology (Draft Delegated Regulation)		Jul-2025
BECCS	Bioenergy with carbon capture and storage (BECCS). Quantification of greenhouse gas emissions (GHG) and removals (BSI Flex 2006)	British Standards Institute (BSI) with UK Dept of Energy Security and Net Zero (DESNZ) (BSI 2025a; BSI 2025b)		v1.0	Jul-2025
DACCS	Direct air carbon capture and storage (DACCS). Quantification of greenhouse gas (GHG) emissions and removals (BSI Flex 2007)			v1.0	Jul-2025

CDR Element	Module Name	ICP/Standard-Setter	Type of Standard	Version	Date
(CO2 store)	- CO_2 Storage via Ex-situ Mineralization in Closed Engineered Systems	Isometric	Module	v1.1	Dec-24
(CO2 store)	- CO_2 Storage in Saline Aquifers	Isometric	Module	v1.0.0	Dec-23
(CO2 store)	- CO_2 Storage via In-Situ Mineralization in Mafic and Ultramafic Formations	Isometric	Module	v1.0.1	Apr-24
(CO2 store)	- CO_2 Storage via Carbonation in the Built Environment	Isometric	Module	v1.0	Dec-24
(biomass/bio-oil store)	- Biomass or Bio-oil Storage in Salt Caverns	Isometric	Module	v1.1	Sep-24
(bio-oil store)	- Bio-oil Storage in Permeable Reservoirs	Isometric	Module	v1.1	Sep-24
(biochar store)	- Biochar Storage in the Built Environment	Isometric	Module	V1.0	Jun-25
(ocean store)	- Dissolved Inorganic Carbon Storage in Oceans	Isometric	Module	v1.0	May-24
(MRV)	- Rock and Mineral Feedstock Characterization	Isometric	Module	v1.0.2	Jul-24
(MRV)	- Energy Use Accounting	Isometric	Module	v1.2	Nov-24
(MRV)	- Embodied Emissions Accounting	Isometric	Module	v1.0.3	Apr-24
(MRV)	- Air-Sea CO_2 Uptake	Isometric	Module	v1.0	May-24
(MRV)	- Biomass Feedstock Accounting	Isometric	Module	v1.2.1	Sep-24
(MRV)	- Carbonated Material Storage and Monitoring	Isometric	Module	v1.0	Oct-24

(MRV)	- Transportation Emissions Accounting	Isometric	Module	v1.1	Nov-24
(MRV)	- Biomass Sourcing Criteria	Puro.earth	Tool	V1.0	May-24
(CO2 store)	- Guidance for Geological CO_2 Storage	Global Carbon Council	Tool	v1.1	Apr-24
(CO2 store)	- Geologic Carbon Storage (GCS) Requirements	Verra/VCS	Requirements	v4.1	Apr-25
(Risk Tool)	- Geologic Non-Permanence Risk Tool	Verra/VCS	Tool	v4.0	Jan-23
(CO2 capture)	- VMD0056 CO_2 Capture from Air (Direct Air Capture)	Verra/VCS	Module	v1.0	Oct-24
(CO2 transport)	- VMD0057 CO_2 Transport for CCS Projects	Verra/VCS	Module	v1.0	Oct-24
(CO2 store)	- VMD0058 CO_2 Storage in Saline Aquifers and Depleted Hydrocarbon Reservoirs	Verra/VCS	Module	v1.0	Oct-24
(MRV)	- VT0010 Emissions from Electricity Consumption and Generation	Verra/VCS	Tool	V1.1	Mar-25
(MRV)	- VT0012 Accounting Non-VCS CO_2 in CCS Projects, v1.0	Verra/VCS	Tool	v1.0	Apr-25
(MRV)	- VT0013 Differentiating Reductions and Removals in CCS Projects	Verra/VCS	Tool	v1.1	Apr-25
(CO2 capture)	- VMD0059 CO_2 Capture from Bioenergy	Verra/VCS	Module	v1.0	Apr-25

Annex B - eCDR method fiches

Fiche 1 Direct Air Carbon Capture with Geological & Mineralization (in situ) Storage

Technology overview	
Summary	High-rate continuous capture of CO_2 from dilute concentrations in ambient air. Application of known and understood techniques involving the chemical capture of CO_2 and its subsequent transport and injection into geological reservoirs for long-term storage. Globally, the capture of fossil CO_2 emissions sources has been proven at various scales and in various settings. Examples of recent and under development projects: ➡ Climeworks Orca (2019) and Mammoth (2023), Iceland: nameplate capacity: respectively, 4,000 and 36,000 tCO_2/yr (mineralization in basalts) ➡ 1PointFive/Carbon Engineering Stratos (2025), TX, U.S.: nameplate capacity: 500,000 tCO_2/yr (geological reservoirs)
▶ CO_2 capture	CO_2 removed by forcing air through two main processes: (1) liquid sorbents (e.g. amines or potassium hydroxide, per Carbon Engineering). (2) solid sorbents (e.g. Climeworks)
▶ CO_2 transport	Limited as CO_2 capture typically co-located with storage.
▶ CO_2 storage	*Geological*: injection in supercritical phase into deep (>800 m) permeable/porous reservoirs (e.g. deep saline-water bearing formations; depleted hydrocarbon reservoirs) *Mineralization*: Often co-injection in aqueous phase into shallow (200-300 m depth), porous formations containing rapidly reactive minerals (e.g. basalts)
TRL/Readiness*	6-7 / Medium
Key system inputs	Energy and heat; materials for capture; water (in some systems)
Factors impacting CDR effect	*Energy use*: ~7.2-8.8 GJ (2,000-2,400 kWh) per tCO_2 captured (Beuttler et al 2019; Keith et al. 2018). 80% for heat and 20% for electricity. Source of electricity and heat, and related GHG emissions major factor impacting net negativity. *Non-permanence/reversal risk*: Geological storage site selection, liability for carbon reversal
Legal aspects	*National:* local permitting of geological storage using dedicated laws & regulations usually applied. Lack of legal clarity over subsurface geological pore space tenure, ownership rights and regulatory competence over such assets can hinder deployment. *International:* injection and storage of CO_2 into sub-seabed geological formations is allowed under international marine waste dumping prevention treaties, subject to the risk assessment requirements therein (e.g. London Convention & Protocol; Oslo-Paris Convention on Protection of the Marine Environment of the North East Atlantic (OSPAR Convention) or similar).
Methodologies & Projects overview	
Methodologies	5x ICPs: ACR; Verra; Global Carbon Council; Puro.earth; Isometric 2x domestic (draft): Canada/ECCC; EU (CRCF)
Modules & Tools etc	*Verra (7x)*: Geologic Carbon Storage (GCS) Requirements; Geologic Non-Permanence Risk Tool (NPRT); VMD0056 CO_2 Capture from Air; VMD0057 CO_2 Transport for CCS Projects; VMD0058 CO_2 Storage in Saline Aquifers and Depleted Hydrocarbon Reservoirs; VT0010 Emissions from Electricity Consumption and Generation; VT0012 Accounting Non-VCS CO_2 in CCS Projects. *Global Carbon Council (1x)*: Guidance for Geological CO_2 Storage *Isometric (8x)*: CO_2 Storage in Saline Aquifers; CO_2 Storage via In-Situ Mineralization in Mafic and Ultramafic Formations; CO_2 Storage via Ex-situ Mineralization in Closed Engineered Systems; CO_2 Storage via Carbonation in the Built Environment; GHG Accounting; Energy Use Accounting; Embodied Emissions Accounting; Transportation Emissions Accounting
NGHGI and NDC accounting	*Partially covered*: Transport and storage of CO_2 in Vol. 2, Chapter 5 of IPCC (2006). In-situ mineralization (with DAC) explicitly excluded in Vol 2, Chapter 5. Parties could propose own methodology (probably Tier 3), with negative emission by at the point of CO_2 capture from the air could be reported as memo item in the NGHGI of the host country.

Fiche 1 Direct Air Carbon Capture with Geological & Mineralization (in situ) Storage		
Crediting**	Developed country	Developing country
Projects on ICPs	*3*	*0*
Credits issued	*1,058*	*0*

Methodological features	
Eligibility/ Applicability	*Technical restrictions*: few. Isometric requires calibration against background CO_2 concentrations where DAC is located within 1km of fossil point source. *Geographical restrictions*: direct limitations on the country/region in which the methodology can be applied (ACR limited to the U.S. & Canada); indirect limitations through prescribing criteria/requirements for local geostorage permitting (e.g. Puro.earth, GCC and Verra (GCS Requirements)); Isometric prescribes equivalency of permitting with EU CCS Directive or US UIC Class VI requirements.
Boundary	*Typical*: full value chain: material inputs, energy inputs, water inputs, wastewater, CO_2 transport and CO_2 storage.
Baseline	All methodologies assume zero removals in the baseline
Additionality	*General*: all net removals are considered additional. Usually subject to demonstration of (1) regulatory surplus (2) financial additionality (some) (3) common practice *Exceptions*: none identified.
Project Emissions	*Upstream (supply chain)*: materials, water etc typically calculated from the following: Activity data (e.g. consumption) × emission factor (e.g. tCO_2/activity) *Downstream (transport & storage)*: depends (see Monitoring) *Energy use*: special measures usually included to allow for low/zero rate emission factors where low CI energy supplied/procured (see Box 3-4) Modules and Tools widely used to establish approaches (see Annex A)
Leakage	*General*: proponents to identify leakage sources and quantify. *Market-leakage*: low CI energy procurement managed through time limits on the vintage of power plants under procurement arrangements – usually 36 months (Box 3-4)
Monitoring	*General*: **Flow measurement + reservoir observations** Continuous monitoring of the mass of CO_2 injected provides basis for measuring gross removal (i.e. takes account of any zero-rated emissions from CO_2 losses during transport).
▶ CO_2 capture	*CO_2 captured*: continuous monitoring/measurement of the amount of CO_2 captured usually required as check. Sometimes *CO_2 transferred* to transport is measured, and fugitive emission deducted to estimate total CO_2 stored/gross removal. *Specific*: Evidence of low CI energy measures to be provided (e.g. renewable energy certificates – see Box 3-4).
▶ CO_2 transport	*Fugitive (losses)*: either accounted for by only measuring amount of CO_2 injected (i.e. everything upstream of the injection point is treated as a zero-rated emission) or monitored and deducted from CO_2 *transferred* from capture. *Energy use*: monitored and counted as project emissions included (pipeline boosters; trucks, ships etc).
▶ CO_2 storage	*General:* continuous monitoring/measurement of the mass of CO_2 injected. Permit conditions often used as basis for subsurface geological monitoring (see *Eligibility*). *Geological & Mineralization:* wells (injection pressure, integrity etc); subsurface plume (e.g. Isometric refers to UIC Class VI requirements; Puro.earth refers to U.S. or EU laws/rules).
Non-permanence & carbon reversal	*Assurance*: storage site permitting with under local rules (e.g. EU CCS Directive; US UIC Classi VI) covering geological storage site selection, oversight, closure, post closure etc. Additional technical guidance included in GCC and Isometric. *Post-injection:* monitoring required aligned with permit.

Fiche 1 Direct Air Carbon Capture with Geological & Mineralization (in situ) Storage	
	Compensation: buffer accounts are used by Verra (pooled for GCS), GCC (pooled) and Isometric (project-specific) to insure against reversals. Amount to be withheld typically based on reversal risk assessment (see Modules e.g. Verra NPRT).
Other notes	Energy use accounting is a significant issue for methodological design.

* Based on Smith et al. (2023) and Smith et al. (2024).

** Data sources as per Figure 2-1. 953 credits issued to Climeworks Orca and 105 credits issued to Climeworks Mammoth both by Puro.earth.

Fiche 2	Bioenergy with Carbon Capture with Geological Storage (BECCS)
Technology overview	
Summary	High-rate continuous capture of CO_2 from concentrated point sources of biogenic emissions (biomass fired power plants; waste-to-energy plants; biomass fermentation offgas) Application of known and understood techniques involving the chemical capture of CO2 and its subsequent transport and injection into geological reservoirs for long-term storage. Globally, the capture of fossil CO_2 emissions sources has been proven at various scales and in various settings. To date, the capture of CO_2 from biogenic sources and from waste incinerators has been piloted but is yet to be implemented at significant scale anywhere in the world. Examples: Operational: ➡ Archer-Daniels-Midland (ADM), Decatur, U.S., bioethanol) (0.5 $MtCO_2$/yr) ➡ Conestoga, U.S (Arkalon/Bonanza projects; bioethanol; 0.3 $MtCO_2$/yr) ➡ Red Trail Energy (Dakota, U.S.; bioethanol; 0.18 $MtCO_2$/yr). Under consideration: ➡ Stockholm Exergi (district heating; Sweden) ➡ Ørsted (NL+), Denmark ➡ Drax (grid power; UK)
▶ CO_2 capture	*Biological capture*: natural uptake absorption by trees through photosynthesis. *Chemical capture*: using solid or liquid sorbents. See Box 3-1.
▶ CO_2 transport	Pipeline, road, rail, ship
▶ CO_2 storage	*Geological*: injection in supercritical phase into deep (>800 m) permeable/porous reservoirs (e.g. deep saline-water bearing formations; depleted hydrocarbon reservoirs)
TRL/Readiness*	6-7 / Medium
Key system inputs	Biomass; energy penalty for capture; materials for capture; water (in some systems)
Factors impacting CDR effect	*Biomass source*: CDR effect depends on biomass being zero-rated (Box 3-1) *Non-permanence/reversal risk*: Geological storage site selection, liability for carbon reversal
Legal aspects	*As for DACCS (Fiche 1)*
Methodologies overview	
Methodologies	6x ICPs: Verra; Global Carbon Council; Puro.earth; Isometric, Gold Standard, Drax/Stockholm Exergi. 1x domestic (draft): EU (CRCF) (EU 2025)
Modules & Tools etc	*Verra (8x)*: Geologic Carbon Storage (GCS) Requirements; Geologic Non-Permanence Risk Tool (NPRT); VMD0057 CO_2 Transport for CCS Projects; VMD0058 CO_2 Storage in Saline Aquifers and Depleted Hydrocarbon Reservoirs; VMD0059 CO_2 Capture from Bioenergy; VT0010 Emissions from Electricity Consumption and Generation; VT0012 Accounting Non-VCS CO_2 in CCS Projects; VT0013 Differentiating Reductions and Removals in CCS Projects. *Global Carbon Council (1x)*: Guidance for Geological CO_2 Storage *Isometric (9x)*: CO_2 Storage in Saline Aquifers; CO_2 Storage via In-Situ Mineralization in Mafic and Ultramafic Formations; CO_2 Storage via Ex-situ Mineralization in Closed Engineered Systems; CO_2 Storage via Carbonation in the Built Environment; GHG Accounting; Biomass Feedstock Accounting; Energy Use Accounting; Embodied Emissions Accounting; Transportation Emissions Accounting
NGHGI and NDC accounting	*Covered*: Accounting for capture of biogenic CO_2 from energy generation covered in Volume 2, Chapter 2 (Energy) of IPCC (2006). Transport and storage of CO_2 in Vol. 2, Chapter 5 of IPCC (2006). Negative emission by at the point of CO_2 capture reported in Energy sector totals of the NGHGI of the host country.

Fiche 2	Bioenergy with Carbon Capture with Geological Storage (BECCS)	
Crediting**	Developed country	Developing country
Projects on ICPs	2	0
Credits issued	378,856	0

Methodological features	
Eligibility/ Applicability	*Technical restrictions*: Biomass source (Box 3-3) *Geographical restrictions*: direct limitations on the country/region in which the methodology can be applied (ACR limited to the U.S. & Canada); indirect limitations through prescribing criteria/requirements for local geostorage permitting (e.g. Puro.earth, GCC and Verra (GCS Requirements)); Isometric prescribes equivalency of permitting with EU CCS Directive or US UIC Class VI requirements.
Boundary	*Typical*: full value chain: material inputs, energy inputs, water inputs, wastewater, CO_2 transport and CO_2 storage.
Baseline	All methodologies assume zero removals in the baseline
Additionality	*General*: all net removals are considered additional. Usually subject to demonstration of (1) regulatory surplus (2) financial additionality (some) (3) common practice *Exceptions*: none identified.
Project Emissions	*Upstream (supply chain)*: materials, water etc typically calculated from the following: Activity data (e.g. consumption) × emission factor (e.g. tCO_2/activity) *Downstream (transport & storage)*: depends (see Monitoring) *Biomass source*: any land use change effects covered as leakage Modules and Tools widely used to establish approaches (see Annex A)
Leakage	*General*: proponents to identify leakage sources and quantify. *Activity-shifting*: risk mitigation through sustainability requirements (Box 3-3)
Monitoring	*General*: **Flow measurement + reservoir observations** Continuous monitoring of the mass of CO_2 injected provides basis for measuring gross removal (i.e. takes account of any zero-rated emissions from CO_2 losses/emissions during transport).
▶ CO_2 capture	*CO_2 captured*: continuous monitoring/measurement of the amount of CO_2 captured usually required as check. *Specific*: Evidence of biomass sustainability and traceability (Box 3-3)
▶ CO_2 transport	As for DACCS (Fiche 1)
▶ CO_2 storage	As for DACCS (Fiche 1)
Non-permanence & carbon reversal	As for DACCS (Fiche 1)
Other notes	Biomass source and controlling the risk of leakage effects (activity shifting and indirect land use change) are significant issues for methodological design.

* based on Smith et al. (2023) and Smith et al. (2024).

** Data sources as per Figure 2-1. All credits issued to Red Trail Energy, Canada, by Puro.earth.

Fiche 3	Mineral product storage	
Technology overview		
Summary	High-rate continuous capture of CO_2 from concentrated point sources of biogenic emissions (biomass fired power plants; waste-to-energy plants; biomass fermentation offgas) or direct air capture CO_2. Use of captured CO_2 to produce mineral products/carbonated materials through contacting with metal oxides or hydroxides to produce minerals such as calcium carbonate ($CaCO_3$) or magnesium carbonate ($MgCO_3$). May include precipitated calcium carbonate (PCC), use of CO_2 in concrete curing or in the stabilisation of wastes products within a reactor. Operational: ➡ Neustark, Switzerland (concrete waste treatment) ➡ O.C.O Technology Limited, UK (air pollution control residue treatment)	
▶ CO_2 capture	*Chemical capture*: using solid or liquid sorbents from either DAC or BEC sources.	
▶ CO_2 transport	Pipeline, road, rail, ship	
▶ CO_2 storage	*Product*: encapsulation of CO_2 as carbon within a mineral product.	
TRL/Readiness*	7 / Medium	
Key system inputs	*CO_2 source*: feedstock material source/status (waste or other)	
Factors impacting CDR effect	*Efficacy*: extent to which captured CO_2 is taken up by materials or lost to atmosphere during reaction process. *Non-permanence/reversal risk*: End-of-life pathway for products to avoid thermal or chemical decomposition and release of stored carbon.	
Legal aspects	No legal or regulatory issues identified. Construction codes may limit certain uses.	
Methodologies overview		
Methodologies	3x ICPs: Puro.earth; Isometric; Gold Standard	
Modules & Tools	None	
NGHGI and NDC accounting	*Not covered*: Product carbon storage largely assumed to be temporary under IPCC (2006) Parties could propose own methodology (probably Tier 3).	
Crediting**	Developed country	Developing country
Projects on ICPs	4	0
Credits issued	66,394	0
Methodological features		
Eligibility/ Applicability	*Technical restrictions*: feedstock materials (Gold Standard only applies to demolition concrete); product quality (Puro.earth requires document product quality information; Gold Standard requires concrete product to be equivalent to conventional); permits (e.g. EIA). Normal use and disposal of the product not to lead to reversal (thermal/chemical decomposition) and therefore is *a priori* permanent (e.g. filler material). Product not be used in clinker production. *Geographical restrictions*: none	
Boundary	*Typical*: full value chain: material inputs, energy inputs, water inputs, wastewater, CO_2 transport and CO_2 storage. Waste materials feedstocks may apply "cut-off"	
Baseline	Gold Standard: Realistic and credible alternatives for disposal of demolition concrete. Puro.earth: requires potential natural CO_2 drawdown of the material over 50 year timeframe absent of the activity to included in baseline. Generally, amount sequestered in product is applied to determine the baseline/amount stored (i.e. the amount that would otherwise be emitted to atmosphere)	

Fiche 3	Mineral product storage
Additionality	*General*: (1) regulatory surplus (2) financial additionality (some) (3) common practice. Gold Standard applies CDM Tool 02 (Combined baseline and additionality).
Project Emissions	*Upstream and site*: Gold Standard: only site level emissions included (upstream covered as leakage). Puro.earth: LCA provides basis for estimating emissions from souring of CO_2; sourcing other materials (e.g. feedstocks); production of materials *Downstream*: Storage considered permanent (therefore excluded). Puro.earth: excludes product distribution emissions; requires statement on end use (purpose, conditions, utilisation). Gold Standard (as leakage)
Leakage	*Upstream*: Gold Standard: emissions from CO_2 supply and demolition concrete treatment to site (e.g. energy consumption for crushing & CO_2 capture; transport) *Downstream:* Gold Standard: product transport (storage excluded)
Monitoring	*General*: **Batch measurement of capture; no reservoir observation** Mass of feedstock and CO_2 in reactor feed, CO_2 vented from reactor, onsite energy, transport energy use etc. Storage: no monitoring, but proof of use upon which to assume no reversal
▶ CO_2 capture	*CO_2 in feedstock*: continuous monitoring/measurement of CO_2 fed to batch process. Measurements of CO_2 losses from reactor used to create mass balance.
▶ CO_2 transport	*None applied*
▶ CO_2 storage	*None applied*
Non-permanence & carbon reversal	*Assurance*: proof of product end use and end of life. *Compensation*: none
Other notes	

* based on Smith et al. (2023) and Smith et al. (2024).

** Data sources as per Figure 2-1. 149 credits issued to Neustark, Switzerland (concrete waste treatment), by Gold Standard, and 66,694 credits issued to O.C.O Technology Limited, UK (air pollution control residue treatment), by Puro.earth.

Fiche 4 Bio-oil injection and geological storage

Technology overview		
Summary	Production of biogenic oil from waste biomass residues, and its injection into subsurface geological reservoirs. Bio-oil or bio crude is derived from the pyrolysis of biogenic materials in the range 350-600°C.Methodology from Isometric includes salt cavern storage (although not yet applied). Examples: 2 x operational (both **Charm Industrial).** Projects apply pyrolysis to heat biomass (e.g. agricultural residues such as corn stover or forestry trimmings) to release biogenic oil-like substance. ➡ U.S only (Kansas and Fort Lupton; CO) Isometric so far issued almost 2000 tCO_2 of credits (Isometric Registry) Several forward offtake agreement signed: Frontier = \$53m for 112 $ktCO_2$ rem; JP Morgan = 28.5 $ktCO_2$ rem over 5 years	
▶ CO_2 capture	*Biological capture*: natural uptake absorption by trees through photosynthesis. *Chemical capture*: conversion of biomass to bio-crude, which is injected for storage. See Box 3-1.	
▶ CO_2 transport	Pipeline, road, rail, ship	
▶ CO_2 storage	*Geological*: injection as oil into permeable/porous reservoirs or salt caverns	
TRL/Readiness*	7-8 / Medium	
Key system inputs	Biomass; energy penalty for capture; materials for capture; water (in some systems)	
Factors impacting CDR effect	*Biomass source*: CDR effect depends on biomass being zero-rated (Box 3-1) *Non-permanence/reversal risk*: Geological storage site selection, liability for carbon reversal	
Legal aspects	*National:* local permitting of geological stores using dedicated laws & regulations. Current methodology limited to sites permitted under U.S. EPA UIC Class V well rules, which seemingly constrains eligibility to the U.S., at least for permeable reservoir storage. Also only allows for storage sites located in the U.S. (see below) *International:* not applicable	
Methodologies overview		
Methodologies	1x ICP: Isometric (plus pre-curser methodology from Carbon Direct)	
Modules & Tools etc	*Isometric (7x)*: Bio-oil Storage in Permeable Reservoirs; Biomass or Bio-oil Storage in Salt Caverns; Embodied Emissions Accounting; Biomass Feedstock Accounting; Energy Use Accounting; Transportation Emissions Accounting; GHG Accounting	
NGHGI and NDC accounting	*Not covered*: Parties could propose own methodology (probably Tier 3)	
Crediting**	Developed country	Developing country
Projects on ICPs	2	0
Credits issued	1,950	0
Methodological features		
Eligibility/ Applicability	*Technical restrictions*: Salt Caverns: U.S. UIC Class V (or equivalent); Permeable reservoir: U.S. UIC Class V permit (no equivalent). Sustainable agricultural or forestry waste as feedstock, converted using pyrolysis or similar. 1000+ years of storage *Geographical restrictions*: Geologic storage site must be located in the U.S.; UIC permit.	
Boundary	*Typical*: full value chain: material inputs, energy inputs, water inputs, wastewater, CO_2 transport and CO_2 storage.	
Baseline	Amount of bio-oil injected would otherwise be emitted. Amount subject to Isometric 'ineligible biomass' rule for carbon storage in biomass >15 years, absent of the project.	
Additionality	*General*: subject to (1) regulatory surplus (2) financial additionality (some) (3) common practice	

Fiche 4 Bio-oil injection and geological storage	
Project Emissions	*Upstream (supply chain)*: materials, water etc. *Downstream (transport & storage)*: *Biomass source*: any land use change effects covered as leakage *Construction and end-of-life.* Modules used to establish accounting approach (see Annex A)
Leakage	Proponents to identify leakage sources and quantify. *Activity-shifting*: risk mitigation through sustainability requirements (Box 3-3) per Isometric Biomass Feedstock Accounting module
Monitoring	*General*: **Flow measurement + reservoir observations** Monitoring of the mass of bio-oil injected provides basis for measuring gross removal
▶ CO_2 capture	*CO_2 captured*: monitoring/measurement of the mass bio-oil injected on a batch basis (weigh bridge). Analysis of carbon content. *Specific*: Evidence of biomass sustainability and traceability (Box 3-3)
▶ CO_2 transport	*Fugitive (losses)*: process upsets and boil-oil spills should; be monitored for each batch. *Energy use*: Transportation Emissions Accounting module.
▶ CO_2 storage	*General:* injectant flows as above. *Geological:* UIC Class V requirements. Offers three methods following 3x storage modules. Include: injectant monitoring; well integrity monitoring; migration detection (e.g. caverns/reservoir pressure; sonar; sump depth, gas in brine; seismic inf necessary)
Non-permanence & carbon reversal	*Assurance*: storage site permitting with under UIC Class V rules. *Post-injection:* monitoring required (density contrast, to determine polymerization of bio-oil; bio-gas emissions; rock interactions; plume spread), requirements to align with UIC permit *Compensation*: Contribution to the project buffer pool (see above), as follows: Permeable reservoirs: 5% to buffer Salt caverns: 2% to buffer
Other notes	Exclusively for use in the U.S. (as currently published) Biomass Storage in Permeable Reservoirs module states reversal risk to be assessed on project-by-project basis, which determines the buffer contribution. Unclear whether this applies to the protocol – that module is listed within the Protocol.

* based on Smith et al. (2023) and Smith et al. (2024).

** Data sources as per Figure 2-1. All credits issued to Charm Industrial, U.S., by Isometric

Fiche 5 Biochar (use)

Technology overview	
Summary	Capture and storage of biogenic carbon from purpose-grown or waste biomass by its pyrolysis techniques into more purportedly more stable chemical and biological forms that are resistant to degradation. Long-term storage away from the atmosphere may be achieved through integrating the biochar into engineered structures (e.g. construction materials, insulation, concrete, etc.) Example projects: none identified
▶ CO_2 capture	Carbon capture by biomass growth. Transformation of biomass into (bio)char in a low oxygen environment (pyrolysis).
▶ CO_2 transport	Limited transportation takes place. Transport only includes transportation of biomass and transportation of produced biochar.
▶ CO_2 storage	Engineered storage options include cement, asphalt, surface water barrier, insulation material, landfill/mine absorber, soil additive.
TRL/Readiness*	4-7 /Medium
Key system inputs	Biomass or other applicable sources of biogenic carbon including wastes/sludges etc, limited fuels for pyrolysis, water for quenching the pyrolysis process, fuel for transport.
Factors impacting CDR effectiveness	*Durability*: char process/temperature and feedstock type has significant impacts upon inertinite fraction, and therefore decay rates. IPCC (2019) indicates 100-year retention rates of biochar in soil (inverse of decay rates) of 0.65-0.89, suggesting some fractions will decay over on decadal timescales. Usually depends on pyrolysis temperature. Recent studies suggest biochars with high fractions of inertinite are highly stable over 1000+ year timescales. Limited data for durability in construction. *Biomass leakage*: apply relevant tools. Energy use for feedstock acquisition and transportation. Particulate and GHG emissions from production; biodiversity and carbon stock loss from unsustainable biomass harvest. Use of potentially contaminated biomass residues (e.g. post-consumer wood waste) can pose pollution risks. Wastes may also contain traces of fossil materials (e.g. plastics, oil in wastewater biosolids)
Legal aspects	None identified. Construction codes may restrict certain materials or applications.

Methodologies overview		
Methodologies	4 x ICPs: Carbon Standard International, Puro.earth, Verra, Isometric	
Modules & Tools etc	Verra (5x): CDM Tool 03: Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion, CDM Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation, CDM Tool 09: Tool to determine the baseline efficiency of thermal or electric energy generation systems, CDM Tool 12: Project and leakage emissions from transportation of freight, CDM Tool 16: Project and leakage emissions from biomass, v04.0 Isometric: Biochar Storage in the Built Environment (v1.0)	
NGHGI and NDC accounting	*Not covered*: Product carbon storage largely assumed to be temporary under IPCC (2006) Parties could propose own methodology (probably Tier 3).	
Crediting**	Developed country	Developing country
Projects on ICPs	n/a	n/a
Credits issued	n/a	n/a

Methodological features	
Eligibility/ Applicability	*Technical restrictions*: restrictions on eligible types and characteristics of biomass, including sustainable sourcing or classification as waste biomass. Verra (VM0044) only allows "high-technology production" with engineered emissions control allowed for use of the biochar in construction applications. Biomass certification feature in some (Puro.earth, Verra).

Fiche 5	Biochar (use)
	Geographical restrictions: no direct limitations on countries/regions, however some restrictions (Verra) on import of biomass feedstock from non-host countries. Puro.earth: jurisdictional biochar requirements and regional guidelines (e.g. International Biochar Initiative Certification Program (IBI) or European Biochar Certificate guidelines (ECB))
Boundary	*Typical*: boundary often defined as cradle-to-grave (Verra, Puro.earth). Where biomass may be characterized as sustainable or waste biomass, biomass sourcing not included in the project boundary (Puro.earth).
Baseline	Baseline assumes project does not take place and waste biomass is left to decay or combusted for purposes other than energy production (i.e. baseline emissions = 0).
Additionality	*General*: Regulatory surplus and financial additionality required (Puro.earth). *Exceptions*: Verra treats the applicability conditions laid out in its methodology as a positive list.
Project Emissions	Upstream (supply chain): limited if sustainable/waste biomass characterization conditions are met, also limited emissions from energy or water use to convert biomass to biochar. Downstream (transport & storage): emissions from transport considered. Limited emissions arising from other sources.
Leakage	Leakage emissions primarily attributed to transport. Leakage: zero when waste or sustainable biomass. Verra formula considers leakage sources: activity shift, biomass diversion, transportation of biomass, transportation of biochar.
Monitoring	*General*: **Batch measurement of capture; no reservoir observation** Monitoring carried out at sourcing, production, and application. Limited monitoring carried out after proof of application of biochar to storage (e.g. construction material, concrete). For non-soil applications (construction): proof of application of biochar ends when the biochar is mixed into the long-lasting material. Geodetic coordinate must be provided for the application site (Puro.earth).
▶ CO_2 capture	Mass of biochar produced (continuous) and chemical properties of biochar. Continuous monitoring of pyrolysis process (e.g. temperature, hydrogen ratio, waste heat).
▶ CO_2 transport	Verra (VM0044): calculation of emissions from transportation of biomass/biochar if transport distance is more than 200km. Requires use of CDM TOOL 12.
▶ CO_2 storage	No monitoring.
Non-permanence & carbon reversal	*Assurance*: Puro.earth: "Proof that the end-use of the product does not cause CO_2 returning to the atmosphere (it is not used as fuel or reductant) must be kept in records", which include offtake agreements and/or sale and shipment details of product indicating intended use. Any amounts expected to be incinerated rather than in a mineral matrix at end of life should be taken into account. Verra (VM004; construction use): refers to a one paper (Gupta and Kua; 2019) highlighting that incorporation into building materials (mineral plasters; gypsum; clay) is not prone to incineration and is rather protected against biological and chemical decay. Concludes that reversal risk is negligible. Seemingly assumes zero emissions from reversal, but unclear how applied in practice as no registered projects under the VM0044 methodology (Section 2.2) *No ex post monitoring or measures*.
Other notes	ICPs commonly reference voluntary biochar certification standards providing guidelines on biochar production methods, feedstocks etc. Two most common: International Biochar Initiative (IBI) Certification Program and European Biochar Certificate (EBC) Guidelines.

* based on Smith et al. (2023) and Smith et al. (2024).

** Data sources as per Figure 2-1. Biochar project records do not clearly indicate whether the activity involves use or soil application, and hence, are excluded to avoid overstating the estimated deployment.

Fiche 6	Enhanced rock weathering
Technology overview	
Summary	Chemical weathering is the natural breakdown of minerals in rocks through chemical transformation. Weathering by hydrolysis and carbonation involves CO_2 dissolved in rainwater acting as a weak carbonic acid to break down silicate minerals in rocks (the silicate - carbonate geochemical cycle). Carbonate rocks (e.g. limestone) are also weathered by hydrolysis and carbonation reactions. Mafic and ultramafic (basaltic) rocks (e.g. gabbro, dunite, peridotite, websterite) contain large amounts of silicate bearing minerals (e.g., olivine, serpentine), which are naturally weathered through hydrolysis-carbonation (acid-base) reactions. Calcite rocks (metamorphosized limestones) are a source of wollastonite, which also absorbs CO_2 in weathering to calcium carbonate ($CaCO_3$) and silica (SiO_2). Liming of cropland soil (addition of calcium-bearing rock e.g. calcium carbonate, dolomitic lime, quicklime, slaked lime) is widely practised worldwide to provide Ca, increase soil pH, and improve soil structure. In most circumstances, the degradation of the limestone leads to CO_2 formation (i.e. emissions), but the reaction may also result in incidental CO_2 drawdown by in situ weathering. Example EW developers/projects include: ➡ Mati (India); ➡ Alt Carbon (India); ➡ UNDO (UK); ➡ Carbon Drawdown Initiative (Germany and Malaysia); ➡ ZeroEx (Germany)
▶ CO_2 capture	*Chemical capture*: EW involves the amending of soil with acquired, crushed/commutated and spread calcium- and magnesium-rich silicate rocks (per above) to accelerate CO_2 sequestration that would otherwise occur over geologic timescales. Hydrolysis and carbonation reactions liberates base cations, which leads to conversion of atmospheric CO_2 to DIC (primarily bicarbonate; HCO3-).
▶ CO_2 transport	*Drainage waters/run-off*: DIC leaves fields in drainage water. *Rivers*: DIC is anticipated to be primarily transported by rivers to the ocean.
▶ CO_2 storage	*Oceanic DIC reservoir:* after runoff from land and transport via river. *Rivers and lakes*: calcium carbonate may also be deposited in the aquatic environment (river and lake sediments. *Soil:* DIC may also be sequestered through formation of soil carbonate minerals (with lower sequestration rates – pedogenic carbon)
TRL*	3-4
Key system inputs	Minerals for weathering
Factors impacting CDR effect	*Efficacy of drawdown*: uncertain. Several field trials proving inconclusive, although some recent studies suggest positive results. Climatic and environmental conditions thought to impact efficacy *Other deposition*: limited data on DIC dissolution/deposition in soils and during transport. *Non-permanence/reversal risk*: reverse reactions in open environment; stability of ocean DIC reservoir
Legal aspects	*National:* Existing environmental laws may apply: (1) air pollution control may pose limits on material spreading due to airborne particulates (dust) (2) soil and agricultural soil controls may impose restrictions on certain materials that may be present within the applied weathering rock (e.g. heavy metals) (3) water pollution prevention laws may apply to run-offs into waterways. *International:* transport of materials into waterways and ultimately the ocean may be subject to marine conservation laws that restrict dumping of materials into the ocean, including from land-based sources (e.g. OSPAR Convention, and similar marine protection treaties). Currently no legal opinions on the topic.
Methodologies overview	
Methodologies	3x ICP: Isometric; Puro.earth; Carbon Standards International AG
Modules & Tools etc	*Isometric (4x)*: Embodied Emissions Accounting; Rock and Mineral Feedstock Accounting; Energy Use Accounting; Transportation Emissions Accounting

Fiche 6	Enhanced rock weathering	
NGHGI and NDC accounting	*Not covered*: may be scope to integrate some elements into inorganic soil carbon models used to construct NGHGI at Tier 3 level.	
Crediting**	Developed country	Developing country
Projects on ICPs	2	4
Credits issued	0	236
Methodological features		
Eligibility/ Applicability	*Technical restrictions*: only on agricultural land and applied to soil (not waterbodies or vicinity such as beaches); must use silicate feedstock; must export drainage via rivers to oceans; must not decrease crop yields; *Geographical restrictions*: none	
Boundary	*Typical*: full value chain: material inputs, energy inputs. Storage partially excluded.	
Baseline	No EW activities, equipment or feedstocks. Baseline (counterfactual) CO_2 drawdown rate absent of the project activity is determined from control plots (Puro.earth, Isometric). Natural weathering of the feedstock absent of activity (e.g. in situ) (Isometric).	
Additionality	*General*: subject to (1) regulatory surplus (2) financial additionality (some) (3) common practice. Demonstrate that removals are the result of carbon finance (Puro.earth)	
Project Emissions	*Upstream (supply chain)*: mineral acquisition and transport emissions etc. *Waste feedstock*: can be accounted for and cut-off/zero-rated *Site*: energy use in field application *Downstream (transport & storage)*: losses of captured CO_2 back to atmosphere mostly estimated through modelling of potential downstream reverse reactions. Some "conservative estimation" allowed (Puro.earth)	
Leakage	*Activity-shifting*: dLUC must be accounted for (Puro.earth) and crop yield changes are not acceptable (Isometric)	
Monitoring	*General*: **Modelling of CO_2 drawdown + field observations; no reservoir monitoring** *Onsite/drawdown*: modelling of CO_2 drawdown rates, with calibration by field measurement and control plots. Overall uncertainty is unclear. *Offsite/downstream*: modelling of reverse reactions.	
▶ CO_2 capture	*CO_2 captured*: Based on comparative analysis of field site drainage chemistry relative to control plot drainage chemistry	
▶ CO_2 transport	*Losses*: reverse reactions to be modelled or conservatively estimated	
▶ CO_2 storage	Modelled or assumed using conservative estimates (of up to 15%; see above)	
Non-permanence & carbon reversal	*Assurance*: not applied. Only predictive modelling of potential reverse reactions. *Ocean DIC:* not monitored	
Other notes		

* Based on Smith et al. (2023) and Smith et al. (2024).

** Data sources as per Figure 2-1. All credits issued to the InPlanet, Project Serra da Mantiqueira in Brazil, by Isometric.

Fiche 7	River / Wastewater Alkalinity Enhancement	
Technology overview		
Summary	*Wastewater alkalinity enhancement* projects involve the removal of CO2 through alkalinity addition to wastewater in a wastewater treatment plant, resulting in the generation of bicarbonate ions. Effluent is then discharged into the ocean or river systems discharging to the ocean, resulting in oceanic carbon storage as dissolved inorganic carbon. Wastewater alkalinity enhancement projects involve the retrofitting of an existing wastewater treatment plant. *River alkalinity enhancement* aims to add alkalinity directly to a river system discharging in the ocean, resulting in increased oceanic carbon storage. Example activities: ➡ CREW Carbon (U.S.) ➡ Captura Corporation (U.S.) ➡ Equatic (U.S.).	
▶ CO_2 capture	CO_2 is removed by adding alkalinity to an effluent from a wastewater treatment plant discharging to the ocean, or to a river discharging to the ocean.	
▶ CO_2 transport	*Limited*. Effluent must reach ocean from the project location, which is assumed to occur as a result riverine transport rather than through the project intervention itself.	
▶ CO_2 storage	*Riverine and oceanic carbon pools*: CO_2 is directly stored as DIC in the ocean.	
TRL/Readiness*	3-6 / Low	
Key system inputs	Alkaline feedstocks, e.g. minerals, energy and fuels for mining feedstocks in case of purpose-mined feedstock.	
Factors impacting CDR effectiveness	Emissions of CO_2 from mining, transport and deployment operations. Rate of air-sea gas exchange Re-equilibration and reverse reactions; carbonate precipitation, natural alkalinity reduction, biotic calcification. *Additionality*: alkalinity addition to watercourses and effluents is already carried out as established practice carried out for e.g. pollution control and acid rain mitigation.	
Legal aspects	*National:* Existing environmental laws may apply. In the US, for example, the Marine Protection, Research and Sanctuaries Act (MPRSA) or the Clean Water Act apply and implement international requirements under London Convention and Protocol. *International:* London Convention and Protocol tightly control the addition of materials to the marine environment, yet do not directly cover land-based sources. Transport of materials into waterways and ultimately the ocean may be subject to marine conservation laws that restrict dumping of materials into the ocean, including from land-based sources (e.g. OSPAR Convention, and similar marine protection treaties). Currently no legal opinions on the topic.	
Methodologies overview		
Methodologies	Isometric (2x): River Alkalinity Enhancement, Wastewater Alkalinity Enhancement.	
Modules & Tools etc	Isometric (5x): Transportation Emissions accounting, Embodied Emissions Accounting, Dissolved Inorganic Carbon Storage in Oceans, Energy Use Accounting, Rock and Mineral Feedstock Characterization.	
NGHGI and NDC accounting	*Not covered*: *River*: emissions from aquatic ecosystems lie outside of the scope of IPCC reporting. *Wastewater:* CO_2 emissions from wastewater treatment are not counted or reported in NGHGIs (biogenic and therefore assumed as zero-rated).	
Crediting**	Developed country	Developing country
Projects on ICPs	1	0
Credits issued	104	0

Fiche 7	River / Wastewater Alkalinity Enhancement
Methodological features	
Eligibility/ Applicability	*Technical restrictions*: eligibility of feedstock (sourcing, chemical composition, applicability). Scope of the activity. Definitions of river hydrological features and discharge locations (e.g. effluents must discharge into ocean. Wastewater projects only in existing facilities). *Geographical restrictions*: permitting through relevant regulatory bodies, including riverine regulations or ocean regulations or treaties, or operate within existing permits (wastewater). Can restrict applicability to some geographies.
Boundary	*Typical*: full value chain: material inputs, energy inputs, water inputs etc.. *Wastewater projects*: GHG emissions impacted by alkalinity (CH4, N2O); energy efficiency improvements in wastewater treatment plant not included in boundary.
Baseline	*Baseline*: assume no activity takes place and no infrastructure built. *River:* uses a model to estimate counterfactual CO_2 drawdown. *Wastewater*: BaU of treatment plant and (e.g. any alkalinity addition). Also BaU operations where high carbon intensity feedstock may be used (e.g. NaOH), where feedstock manufacturing emissions exceed potential CO_2 drawdown, carbon removal potential of BaU operation may be considered zero.
Additionality	*General*: subject to (1) regulatory surplus (2) financial additionality (some) (3) common practice
Project Emissions	Calculated for the lifecycle of the project, from project establishment, project operation, and end-of-life. Includes sources such as staff travel and project surveys. Losses through reversal reactions downstream of dosing site (carbonate precipitation; alkalinity reduction; biotic carbonation) to be estimated and included if material.
Leakage	*General*: proponents to identify leakage sources and quantify. Methodology specifies that two leakage sources must be considered as a minimum: feedstock replacement and consumables replacement.
Monitoring	*General:* **Modelling of CO_2 drawdown + some limited reservoir observation** *River*: Calls for direct measurement of river chemistry to quantify carbon removal, demonstrate compliance with permits, monitor environmental conditions, and identify negative impacts. Monitoring is recommended upstream of dosing site, dosing site, river transport zone, and in ocean discharge zone *Wastewater*: Monitoring of wastewater and effluent coming in and out of the plant, including all other inputs and outputs (e.g. feedstock, waste activated sludge). Also, monitoring required in mixing zone of effluent in receiving waters.
▶ CO_2 capture	*River and wastewater chemistry*: Monitoring to quantify CO_2 capture, directly measure water parameters and effluent chemistry.
▶ CO_2 transport	*Riverine transport*: Monitoring of water chemistry at various points (particularly for river alkalinity enhancement). Monitoring to support estimation of reverse reactions, where material.
▶ CO_2 storage	*Direct measurement at discharge*: solid feedstock or dissolved weathering products, for wastewater projects, direct measurements within wastewater treatment plant and subtraction of losses due to riverine and oceanic processes.
Non-permanence & carbon reversal	*Compensation*: Isometric buffer. OAE projects are classified as 'Very Low Risk Level of Reversal' = 2% contribution to the buffer pool.
Other notes	Uncertainty over reservoir monitoring requirements.

* Based on Smith et al. (2023) and Smith et al. (2024).

** Data sources as per Figure 2-1. All credits issued to CREW Carbon, Greater New Haven Municipal WAE Project, U.S, by Isometric

Fiche 8 Ocean Alkalinity Enhancement (from coastal outfalls)

Technology overview	
Summary	Direct addition of alkaline feedstock to surface ocean in order to modify partial pressure of CO_2 in seawater, increasing air-sea gas exchange and removing CO_2 from atmosphere. Electrochemical OAE projects are also in-scope when seawater is electrochemically split into acid and base streams, and the alkaline stream is added back to the ocean Example projects: Planetary Corporation (Canada/UK; OAE at outfalls).
▶ CO_2 capture	Reaction of alkaline materials (silicate) feedstocks with dissolved CO_2 in seawater to form DIC, leading to the drawdown of atmospheric CO_2 into solution in the water column to re-equilibrate ocean-atmosphere CO_2 partial pressure.
▶ CO_2 transport	*None.* Reactions occur in situ in water column and surface through air-sea gas exchange. Alkaline feedstocks may need to be transported to dosing location.
▶ CO_2 storage	*Oceanic carbon pools*: DIC remains in the oceanic reservoir for 1,000-10,000 years.
TRL / Readiness*	4 / Low
Key system inputs	Alkaline feedstocks (silicate minerals) Emissions associated with feedstock extraction, commutation, transport and delivery to dosing locations.
Factors impacting CDR effectiveness	*Upstream (supply chain)*: materials acquisition etc. *In situ*: rate of air-sea gas exchange Reverse reactions: re-equilibration (e.g. conversion of bicarbonate to carbon leads to CO_2 emissions, such as carbonate precipitation, natural alkalinity reduction, biotic calcification).
Legal aspects	*National:* Existing environmental laws may apply. In the US, for example, the Marine Protection, Research and Sanctuaries Act (MPRSA) or the Clean Water Act apply and implement international requirements under London Convention and Protocol (LC/LP). *International:* LC/LP tightly control the addition of materials to the marine environment. Direct addition of materials to the ocean for geoengineering purposes is prohibited, except for scientific research. LC/LP "Statement on Marine Geoengineering" issued by Parties says that the techniques have "...the potential for deleterious effects that are widespread, long-lasting or severe" [and that] "there is considerable uncertainty regarding their effects on the marine environment, human health, and on other uses of the ocean." (IMO 2023). The statement also reaffirms that marine eCDR activities should be deferred other than in connection with "legitimate scientific research" (IMO 2023). Transport of materials into waterways and ultimately the ocean may be subject to marine conservation laws that restrict dumping of materials into the ocean, including from land-based sources (e.g. OSPAR Convention, and similar marine protection treaties).

Methodologies overview		
Methodologies	Isometric (1x): Ocean Alkalinity Enhancement from Coastal Outfalls	
Modules & Tools etc	Isometric (6x): Rock and Mineral Feedstock Characterization, Air-Sea CO_2 Uptake, Dissolved Inorganic Carbon Storage in Oceans, Embodied Emissions Accounting, Transportation Emissions Accounting, Energy Use Accounting	
NGHGI and NDC accounting	*Not covered*: emissions from aquatic ecosystems lie outside of the scope of IPCC reporting	
Crediting**	Developed country	Developing country
Projects on ICPs	1	0
Credits issued	626	0

Fiche 8 Ocean Alkalinity Enhancement (from coastal outfalls)	
Methodological features	
Eligibility/ Applicability	*Technical restrictions*: must use certain feedstocks. *Geographical restrictions*: None. Projects must be permitted and in compliance with applicable regulations and ocean conventions.
Boundary	*Typical and end-of-life*: Includes all GHG sources, sinks, and reservoirs from activities related to the project, establishment, operations, and end-of-life activities occurring even after the end of the reporting period.
Baseline	Assumes that activities do not take place. Baseline accounts for background removals by ocean absent of the project in the same boundary.
Additionality	*General*: subject to (1) regulatory surplus (2) financial additionality (some) (3) common practice. *Exception*: A project is considered financially additional if removals are the only source of revenue of the project.
Project Emissions	Project emissions calculated for the full lifecycle of the project, from project establishment, project operation, and end-of-life. Isometric includes non-typical project emissions sources such as travel and emissions from surveys.
Leakage	*General*: proponents to identify leakage sources and quantify. Methodology specifies that two leakage sources must be considered as a minimum: feedstock replacement and consumables replacement.
Monitoring	*General:* **Modelling of CO_2 drawdown + some limited reservoir observation** Requirements for the establishment of a monitoring plan with required and recommended monitoring parameters, and the inclusion of thresholds on parameters to determine safe limits for operation and identify negative environmental impact. Monitoring to be carried out spanning pre-deployment, dosing, and post-dosing. Periodic ecological surveys recommended.
▶ CO_2 capture	Ongoing measurement required in effluent and edge of mixing zone during deployment. Range of parameters to be monitored. Notes the difficulty of measuring signals of uptake of CO_2 beyond the mixing zone, particularly in small-scale deployments, and therefore recommends monitoring to take place in edge of mixing zone.
▶ CO_2 transport	In case of effluent pipe, several monitoring requirements required for ongoing monitoring of parameters in effluent.
▶ CO_2 storage	As storage takes place in open ocean, monitoring for storage is effectively the same as capture monitoring. Isometric requires the use of a purpose-built model to calculate CO_2 drawdown effect.
Non-permanence & carbon reversal	*Compensation*: Isometric buffer: OAE projects are classified as 'Very Low Risk Level of Reversal' = 2% contribution to the buffer pool.
Other notes	

* Based on Smith et al. (2023) and Smith et al. (2024).

** Data sources as per Figure 2-1. 626 credits issued by Isometric to Planetary Technologies, Nova Scotia Mineral OAE Project, Canada.

Fiche 9 Oceanic Removal (Electrochemical)

Technology overview	
Summary	Utilization of electrolysis on pre-processed seawater in order to precipitate dissolved inorganic carbon (DIC) from electrolysis products, while also adding alkalinity to neutralize acidic outputs. Creates H_2 as a byproduct. Method involves the application of pilot techniques and various inputs (energy, alkaline feedstocks) in order to achieve CDR. To date, only a few pilots. Similar to OEA except CDR occurs within one facility and not in the open ocean (i.e. CO_2 is directly extracted from seawater and processed seawater is returned to the ocean). Example projects: Captura Corp (U.S.); SeaO2 (NL); SeaCURE (UK); Ebb Carbon (U.S.)
▶ CO_2 capture	Drawdown of atmospheric CO_2 in alkaline stream from electrolysis, precipitating CaCO3, in addition to further DIC uptake in stream. Precipitated CaCO3 may be captured and stored (geologically) Alkaline stream and acidic stream are recombined. Further CO_2 capture may be quantified from re-addition of combined stream into ocean, where additional DIC (air-sea gas exchange). Share of removal: DIC = 90%; physical CO_2 removal = 10% (as carbonate minerals).
▶ CO_2 transport	*Limited*: transport may take place of carbonate precipitate on land.
▶ CO_2 storage	*Oceanic carbon pool:* DIC and solid carbonate *Geologic / products*: carbonate (CaCO3) separated & stored on land (incl. within concrete)
TRL/Readiness*	<3 / Low
Key system inputs	Seawater, alkaline feedstock for neutralization of anolyte, energy for electrolysis process.
Factors impacting CDR effectiveness	Emissions of CO_2 from mining, transport and deployment operations. Emissions from energy use: sweater pumping; electrolysis plant Rate of air-sea gas exchange Re-equilibration and reverse reactions; carbonate precipitation, natural alkalinity reduction, biotic calcification. EDF reports that electrochemical ocean CO2 removal requires large quantities of reactants, seawater, and energy. Removal of 0.001 to 0.002 $GtCO_2$/year would require treatment of as much water as currently goes through every desalination plant in the world.
Legal aspects	*National:* The need to release water via outfall means that existing environmental laws and permits may apply. In the US, for example, the Marine Protection, Research and Sanctuaries Act (MPRSA) or the Clean Water Act apply and implement international requirements under London Convention and Protocol (LC/LP). *International:* LC/LP "Statement on Marine Geoengineering" issued by Parties says that the techniques have "...the potential for deleterious effects that are widespread, long-lasting or severe" [and that] "there is considerable uncertainty regarding their effects on the marine environment, human health, and on other uses of the ocean." (IMO 2023). The statement also reaffirms that marine eCDR activities should be deferred other than in connection with "legitimate scientific research" (IMO 2023).
Methodologies overview	
Methodologies	1x ICP: Isometric (Puro.earth "DACOS" under development)
Modules & Tools etc	*Isometric* (6x): Energy Use Accounting; Dissolved Inorganic Carbon Storage in Oceans; Embodied Emissions Accounting; Carbonated Material Storage and Monitoring; Rock and Mineral Feedstock Characterization; Transportation Emissions Accounting
NGHGI and NDC accounting	*Not covered*: emissions from aquatic ecosystems lie outside of the scope of IPCC reporting

Fiche 9	Oceanic Removal (Electrochemical)	
Crediting**	Developed country	Developing country
Projects on ICPs	0	0
Credits issued	0	0

Methodological features	
Eligibility/ Applicability	*Technical restrictions*: feedstock types. *Geographical restrictions*: None. Projects must be permitted and in compliance with applicable regulations and ocean conventions.
Boundary	Wide (cradle-to-grade). CDR is only quantified within the project facility (i.e. a closed system). Additional ocean uptake not eligible for crediting.
Baseline	Baseline scenario assumes that activities do not take place and any infrastructure is not built.
Additionality	*Typical*: The project must demonstrate financial additionality, pass a common practice test, demonstrate regulatory additionality, and demonstrate environmental additionality (net CO2 removals). *Exception*: A project is considered financially additional if removals are the only source of revenue of the project.
Project Emissions	Calculated for the full lifecycle of the project, from project establishment, project operation, and end-of-life. Includes sources such as staff travel and project surveys. Losses through ocean CO_2 outgassing may be included in the removal quantification (assessment)
Leakage	*General*: proponents to identify leakage sources and quantify. Methodology specifies that two leakage sources must be considered as a minimum: feedstock replacement and consumables replacement.
Monitoring	*General:* **Modelling of CO_2 drawdown + some limited reservoir observation**
▶ CO_2 capture	Detailed process monitoring required for electrolysis facility as well in ocean mixing zone and deployment area.
▶ CO_2 transport	*Limited*: transport of carbonated minerals takes place on land, other transportation is directly in oceanic carbon pool.
▶ CO_2 storage	*Oceanic carbon pool:* some measurements around mixing zone (see above) *Geologic / products*: carbonated minerals monitoring according to Modules for various storage reservoirs (Saline Aquifer; Mineralization; Carbonation in Built Environment etc)
Non-permanence & carbon reversal	*Compensation*: Isometric buffer, with separate pools for separate storage reservoirs: → Ocean DIC: 'Very Low Risk Level of Reversal' = 2% contribution to the buffer pool. → carbonated material: saline aquifer = 2% contribution to the buffer pool. Alternative storage reservoir: according to specific type and assessed reversal risk.
Other notes	Complex methodology which is challenging to follow.

* Based on Smith et al. (2023) and Smith et al. (2024).

** Data sources as per Figure 2-1.