CARBON REMOVALS IN THE EU

Review of current carbon removal projects and early-stage financing

Ramboll Management Consulting
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Contact: *Lucia CAUSEY-HUGECOVA*

E-mail: lucia.causey-hugecova@ec.europa.eu

European Commission
B-1049 Brussels

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Review of current carbon removal projects and early-stage financing

Client

European Commission, DG CLIMA

Project

Support for the development of a strategy for the financing of permanent carbon removals

Authors

Evert Witteveen, Ramboll

Christopher Marton, Ramboll

Nicolas Bert, Ramboll

Jacob Steinmann, Ramboll

Jonathan Gardiner, Ecologic

Reviewers

Xavier Le Den, Ramboll

David Rusnok, Climate & Company

Maarten de Vries, CE Delft

Paul Zakkour, Carbon Counts

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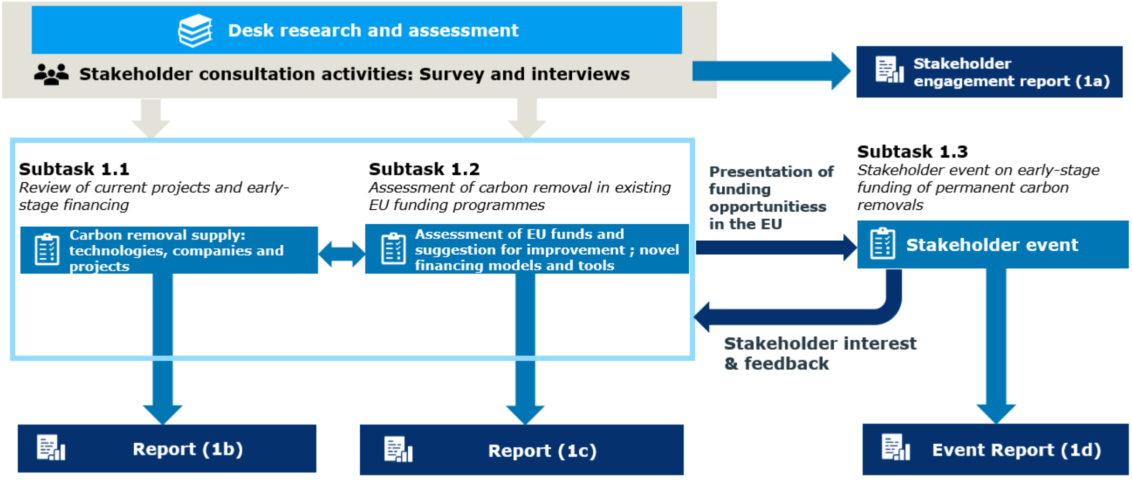
Abbrevations

CAPEX	Capital expenditure
BEC	Breakthrough Energy Catalyst
CDR	Carbon dioxide removal
CRCF	Carbon Removal Certification Framework
CCS	Carbon capture and storage
CO_2	Carbon dioxide
BECCS	Bioenergy with carbon capture and storage
BioCCS	Biomass with carbon capture and storage
DACCS	Direct air carbon capture and storage
EEA	European Economic Area
ERW	Enhanced rock weathering
EU	European Union
MRV	Monitoring, reporting and verification
OPEX	Operational expenditure
TRL	Technology readiness level

1. Introduction

This report (1b) is part of the European Commission DG CLIMA study ‘Support for the development of a strategy for the financing of permanent carbon removals’. It presents the findings from project Subtask 1.1: review of current projects and early-stage funding (see Figure 1 below).

Figure 1 - Approach to Task 1 activities



1.1. Background and context

Achieving climate neutrality in Europe by mid-century requires significantly reducing greenhouse gas emissions and offsetting any remaining unavoidable emissions through carbon dioxide removals (CDR). As defined by the EU Carbon Removal Certification Framework (CRCF) (2024), CDR are ‘the anthropogenic removal of carbon from the atmosphere and its durable storage in geological, terrestrial or ocean reservoirs, or in long-lasting products’, encompassing a variety of technologies and approaches.

An important aspect of CDR is the ability to store carbon securely during an adequate time horizon, i.e., to ensure permanence. To account for this aspect when comparing different approaches for sequestering and storing carbon, the CRCF differentiates between:

- Permanent carbon removals
- Carbon farming and soil emission reduction
- Carbon storage in long-lasting products

This study focuses on permanent carbon removals, defined in the CRCF EU Carbon Removal Certification Framework (2024) 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’. While there is not yet one agreed classification of permanent CDR technologies, this report focuses on the following activities:

- Biochar carbon removal
- Biogenic emission capture with permanent carbon storage (BioCCS), focusing on Bioenergy with carbon capture and storage (BECCS)
- Direct air carbon capture and storage (DACCS)
- In-situ mineralisation
- Ex-situ mineralisation (and Enhanced Rock Weathering (ERW))
- Ocean-based approaches (Direct Ocean Capture (DOC), Ocean Alkalinity Enhancement (OAE))

The EU permanent CDR sector is evolving, driven by the growing recognition of the necessity for negative emissions to meet climate targets. Germany, Sweden, and the Netherlands are at the forefront within the EU, hosting a significant share of companies in the global CDR sector; a sector with the estimated potential to grow into a € 1.1 trillion market by 2050 (McKinsey, 2023). However, companies looking to expand CDR deployment face significant challenges at every stage, from research and development to demonstration and scale-up. In the scale-up phase, high investment costs and access to financing is widely acknowledge as a major barrier. And while voluntary private sector demand has been important and catalytic, public-sector support is understood by stakeholders to be critical to enable long-term growth (Merchant *et al.*, 2022).

The European Commission’s impact assessment for the EU’s 2040 climate target (2024) indicates industrial (permanent) CDR of more than 100 MtCO$_2$ per year in 2050 will be required to reach net-zero emissions under some scenarios. By way of comparison, permanent CDR supplies amount to approximately 1.3 MtCO$_2$ per year globally (Smith *et al.*, 2024), representing only 1.3% of the estimated EU requirements in 2050.

Hence, there is an urgent need to create more favourable market conditions for deploying permanent CDR in the EU. To develop and implement policies that support CDR, it is essential to gain a deeper understanding of the industry’s dynamics and the challenges it faces.

1.2. Report objectives

The purpose of this report is to provide a summary of the current state and future potential of permanent CDR in Europe. More specifically, the report will:

- Assess permanent CDR technologies and key considerations associated with each technology, including removal potential (future supply), costs, funding needs and opportunities and current deployment barriers.
- Analyse and map existing and planned carbon removal projects across the EU, with a focus on understanding the region's current capabilities and future needs.

The research presented in this report is guided by three questions:

- What is the potential supply of permanent CDR from ongoing and planned projects in Europe in 2030 and 2035, and their expected prices?
- What are the financing needs and the funding available to support the development of CDR technologies, organisations and projects, in the EU?
- What are the key barriers for industry scale up for each carbon removal technology?

1.3. Report outline

Following the introduction, **Chapter 2** explains the methodological approach used, detailing the data sources and analytical techniques, while also addressing key limitations that frame the study.

The findings are presented in Chapter 3 and 4. **Chapter 3** helps frame the analysis by overview of the permanent CDR technologies studied in this report, including key characteristics, estimated TRL, and deployment challenges. Next, **Chapter 4** provides an overview on CDR projects and organisations across Europe, provides estimations on current and future CDR supplies, costs, funding needs and availability, and the barriers that limit the scaling of CDR technologies. Finally, **Chapter 5** concludes with a summary of the report's key takeaways.

2. Our approach

2.1. Methodology

The analysis presented in this report was conducted following a stepwise process.

Step 1: High-Level assessment of the CDR sector and technologies

The first step involved a general assessment of the CDR sector and the specific CDR technologies within scope (Biochar, BioCCS, DACCS, in-situ and ex-situ mineralisation including enhanced rock weathering, and ocean-based CDR, such as direct ocean capture and ocean alkalinity enhancement). An Excel matrix (See Appendix 1) was developed to guide the data collection process, with main categories outlined in Table 1.

Table 1 - Categories for assessing CDR technologies

Component	Categories
Technology	Description Maturity level (technology readiness level, TRL)
Volumes of carbon removals	Scope (global/Europe) Current volumes (year, min/max/estimates) Future volumes (year, min/max/estimates)
Costs of carbon removals	Current costs (year, min/max/estimates) Future costs (year, min/max/estimates)
Investment needs and funding	Investment needs for technology readiness and up-scaling Sources of funding available
Barriers to industry scale up	Type of barriers (technical, financial, regulatory, cultural/social, etc.) Description of barriers

Data was then collected and added to the matrix through desktop research covering both academic and grey literature sources. Relevant sources were identified with the aim of gathering comprehensive evidence on each of the different CDR technologies and their specific characteristics.

Step 2: Mapping Review of CDR Organisations and Projects

The second step focused on mapping relevant European CDR organisations and projects. A second matrix was established to organise this process, as outlined below.

Table 2 - Categories for mapping European CDR organisations and projects

Component	Categories
Identification	• Project name • Company name • Country • Location (name, latitude, longitude)
Project description	• Carbon removal technology • Project status (active/ completed/ in development/ on hold/ potential) • Project phase (feasibility study/ planning/ site characterisation/ engineering design/ plant design/ permitting/ developing infrastructure/ capture ongoing …) • Project type (pilot or commercial) • Type of funding • Project start date - end date • Carbon removal capacity • Project description (short)
Project costs	• Total project costs (total CAPEX, upfront investment costs, ongoing investment costs) • Cost per tCO_2 of carbon removal
Further information	• Short project description • Project website

Relevant sources to perform a mapping of CDR organisations and projects where then identified, including online databases and interactive maps, see Table 3. The projects and organisations found in these sources were further investigated by looking into their specific websites and other targeted material and compiling the information into the Excel file (See Appendix 1).

It should be acknowledged that the gained overview on identified organisations and projects is comprehensive but not exhaustive, as rapid developments throughout the CDR sector likely led to the omission of several projects and organisations across all CDR technologies.

Table 3 - Sources for initial mapping of CDR organisations and projects

Title, author, year	Information of relevance for review
Carbon Removal Map. Cdr.fyi. (n.d.)	Map of carbon removal projects (all CDR)
Project Map. Carbon Removals at COP. (n.d.)	Map of carbon removal projects (all CDR)
Facilities database. Global CCS Institute. (n.d.)	Map of DACCS and BioCCS projects, as well as CO_2 transport and storage (and CCS)
Global DAC Deployments. Direct Air Capture Coalition via Felt. (n.d.)	Map of DACCS projects
Operations Map. Enhanced Weathering Alliance (EWA). (n.d.)	Map of Enhanced Weathering projects

Step 3: Integrating findings from stakeholder consultation activities

Next, the general assessment of CDR technologies (step 1) and the mapping of European CDR organisations and projects (step 2) were complemented with information received through stakeholder consultation, namely by a questionnaire and interviews targeting industry representatives and CDR experts (developers, technology providers, investors, NGOs, etc.). This contributed to more comprehensive understanding of the sector, challenges and opportunities for different CDR technologies and the types of actors operating in this space. The consultation also helped to contextualise and confirm the findings from step 1 and 2 and to highlight important perspectives that merit further consideration, such as on barriers to scaling and investment needs. However, due to the small sample size of the survey (N = 103), the survey estimates on the costs and capacity were primarily used to contextualise the initial findings and the cost and capacity projections. While the survey findings served as an important supplementary data source to gain insights on the perspective of (European) CDR organisations, they were primarily regarded as indicative of subjective assessments. Detailed information on the stakeholder consultation activities and analysis of the collected input is found in project report 1c.

Step 4: Data Consolidation and Analysis

In the final step, the collected data was systematically consolidated and analysed to address the research questions outlined in the report. This involved synthesising findings from the high-level sectoral assessment and the mapping exercise for an overview of the CDR landscape, as well as compiling and presenting data on future European CDR supply, funding needs and deployment barriers.

2.2. Limitations

This study is subject to several limitations that should be considered when interpreting and applying its findings:

- **Data gaps on CDR costs and financing.** The report identifies a lack of detailed project-level data, particularly regarding total costs, the breakdown between capital expenditures (CAPEX) and operational expenditures (OPEX), and the specifics of financing structures. This absence of granular financial information limits the depth of economic analysis, making it challenging to provide actionable insights for investors and policymakers, especially on commercial operations. Addressing this gap would require CDR to be more open and transparent about costs, e.g. through enhanced transparency and reporting standards within the CDR sector.
- **Potentially incomplete mapping of CDR organisations and projects.** The rapid evolution of the CDR industry in Europe, with a high share of small and innovative organisations, combined with lack of publicly accessible information, may have resulted in some less well-known and/or lower profile enterprises being excluded.
- **Non-comprehensive or biased responses from stakeholders**. Despite efforts to triangulate literature sources with survey and interview findings where appropriate, the findings may systematically under- or overestimate CDR supply, costs, and investment needs. The direction of bias is difficult to identify, but can arise from, inter alia: data collection methods, subjective views by stakeholders operating in the space, and limited availability of verifiable cost information. While triangulation helps address these issues, reliance on potentially unreliable input data may still affect the accuracy of the findings.
- **Limited granularity in data**. To accommodate a diversity of perspectives, the survey design permitted multiple responses for certain key questions. While this approach enhanced inclusivity, it constrained the ability to certain disaggregate data by specific CDR technologies, thereby limiting the granularity of insights on cost structures, capacity, and other technology-specific metrics.
- **Finally, uncertainty on the future composition of CDR technologies remains high.** As the future support of CDR technologies depends on several variables, such as policy pathways, funding and available feedstock, the presented figures cannot be used to infer the composition CDR technologies in Europe. Rather, they give an indication on the scalability of the technologies based on maturity and current activities.

3. Overview of permanent CDR technologies

This section provides an overview for each of the permanent CDR technologies covered in this report, including a brief description, maturity level (TRL), investment requirements, and main funding sources. This overview is provided as the listed permanent CDR technologies represent a diverse set of approaches offering solutions for long term CO_2 capture and storage. The section provides summarised data and information collected through desktop research and stakeholder consultation activities.

3.1. BioCCS

Category	Description
Description	**BioCCS** leverages biological processes to permanently sequester CO_2 through the capture and storage of CO_2 from a broad range of biomass conversion processes (e.g. pulp and paper mills, fuels production, electricity and hear generation, fermentation industry). Advanced methods can include converting biomass into stable forms, ensuring carbon remains sequestered over extended periods. **BioCCS is an overarching term covering BECCS and other bioconversion processes,** but does not include non-CCS based approach to use biomass for removals, such as bio-oil or biomass burial. **BECCS** is a CDR method that combines bioenergy production with carbon capture and storage. In this process, biomass (e.g., crops, forests) is burned or processed to generate energy, and the resulting CO_2 emissions are captured and stored underground or in long-term storage systems. BECCS not only provides renewable energy but also results in net negative CO_2 emissions, as the carbon absorbed by the biomass during growth is offset by the carbon stored during capture. BECCS storage includes geological carbon sequestration, where CO2 is injected into deep rock formations such as saline aquifers or depleted oil fields, and carbonation in concrete, where CO_2 is absorbed into the material during its lifecycle.
Maturity level (TRL)	BioCCS technologies exhibit varying Technology Readiness Levels (TRLs) depending on the specific application, ranging between **4 and 9**. Specifically focusing on bioenergy with carbon capture and storage (BECCS), the maturity level is considered to be at developmental stage, with a Technology Readiness Level between **4 and 6** (Bey *et al.*, 2021; Babiker *et al.*, 2023; Cobo *et al.*, 2023; European Scientific Advisory Board on Climate Change, 2025). When it comes to storage of removed CO_2 through geological carbon sequestration the maturity level is understood to be higher, between 7-9 (Kearns, Liu and Consoli, 2021; Cobo *et al.*, 2023; Rocky Mountain Institute, 2023), indicating that the storage component associated with BECCS is relatively mature.
Investment needs	BioCCS is characterised by high CAPEX, due to the high investments needed to set up each plant. This carbon removal method also entails high OPEX costs for CO_2 transport and storage, but costs can be lower for highly concentrated CO_2 streams within plants. Additionally, as the technology requires biomass feedstock, OPEX might increase over time.

Category	Description
Key considerations	- Limited biomass feedstock in Europe, now and in the future. - Land use change to carbon capture and storage outside of agricultural areas could transgress several planetary boundaries (Braun *et al.*, 2025).

3.2. Biochar carbon removal

Category	Description
Description	Biochar is a carbon-rich material produced by pyrolysing organic biomass under low-oxygen conditions. It sequesters carbon by stabilising biomass-derived carbon into a solid form that can be stored in soils or other media (e.g., construction), potentially for centuries. Biochar can also improve soil fertility through organic carbon and water retention. Beyond CDR, biochar has several other applications, such as steel and construction.
Maturity level (TRL)	Biochar carbon removal in Europe is currently between **TRL 6-9**, indicating advanced development and commercialisation, both in terms of biochar production and application (Bey *et al.*, 2021; Babiker *et al.*, 2023; Rocky Mountain Institute, 2023; Geden, Smith and Cowie, 2024; The European Biochar Industry Consortium, 2024). Major European companies are now considering distributing biochar for agricultural use in the Global South.
Investment needs	Biochar carbon removal primarily involves higher CAPEX, but can entail high OPEX costs due to labour-intensive feedstock preparation, pyrolysis operation, and post-processing.
Key considerations	- MRV can be challenging for biochar, due to differences in texture, structure, and organic matter content. Especially after distribution of biochar on sites, monitoring is difficult, meaning that MRV is limited to biochar production and application only. These factors influence how biochar interacts with the soil environment and whether it remains in place or is more prone to movement and loss. - Limited sustainable biomass feedstock in Europe, now and in the future. - Biochar has agricultural co-benefits when used as a soil amendment.

3.3. DACCS

Category	Description
Description	Direct Air Capture and Carbon Storage (DACCS) is a CDR technology that extracts CO_2 directly from the atmosphere. The captured CO_2 is then compressed and either stored permanently in underground geological formations, such as saline aquifers, or chemically bound into construction products like concrete aggregates.

Category	Description
Maturity level (TRL)	DACCS technologies are still maturing in the EU, with only a few companies nearing commercial deployment. Most DACCS technology is in early to mid-stages of development, with TRLs typically ranging from **4 to 6** (Babiker *et al.*, 2023; Cobo *et al.*, 2023; Geden, Smith and Cowie, 2024; European Scientific Advisory Board on Climate Change, 2025). As shared by stakeholders, few providers are further along, with TRLs of 7-8, indicating that they are nearing commercial readiness and have been tested in operational environments. When it comes to storage of removed CO_2 through geological carbon sequestration, the maturity level is understood to be higher, between 7-9, indicating that the storage component associated with DACCS is relatively mature.
Investment needs	DACCS is both **CAPEX and OPEX intensive**; with innovation, especially CAPEX is expected to go down, lowering economic barriers to development. OPEX costs for energy and water are expected to remain high.
Key considerations	● High energy, water and heat demand ● Single purpose of climate mitigation/lack of co-benefits ● Limited plant locations, ideally needs to be close to renewable energy supply.

3.4. In-situ mineralisation

Category	Description
Description	In-situ mineralisation refers to the natural or enhanced process where CO_2 is captured and mineralised directly within geological formations. This occurs in the environment without external processing.
Maturity level (TRL)	In-situ mineralisation demonstrates a range of TRLs, depending on the specific process, ranging between **2 and 6** (Kearns, Liu and Consoli, 2021; Maesano *et al.*, 2022).
Investment needs	In-situ mineralisation requires substantial CAPEX for site preparation and infrastructure development. While the OPEX is lower compared to other carbon capture technologies, the process relies on natural geological formations, but ongoing monitoring and maintenance are necessary to ensure long-term stability and efficiency.
Key considerations	● High initial capital investment for site selection and geological assessments ● Geographically dependent, requiring suitable geological formations ● Injectivity (e.g. injection of fluids into basalts is typically hampered by low porosity and permeability)

3.5. Ex-situ mineralisation

Category	Description
Description	Ex-situ mineralisation involves the processing of materials outside their natural setting to accelerate CO2 sequestration. This method typically requires the extraction and alteration of rocks to enhance their weathering rates. A common example, also referred to as surficial mineralisation, is **enhanced rock weathering**, where crushed basalt is spread over land to capture CO2, and **carbonated construction products**, where CO2 is used to ex-situ mineralise materials such as concrete and aggregates in controlled environments.
Maturity level (TRL)	The maturity of ex-situ mineralisation varies between medium- and high-TRL levels (**TRL 4 to 8**) (Kearns, Liu and Consoli, 2021; Cobo *et al.*, 2023; Rocky Mountain Institute, 2023). Whereas mineralisation through carbonated construction products is considered to be further developed (TRL 6-8), enhanced rock weathering is generally understood to have a TRL between 3 and 5 (Bey *et al.*, 2021; Babiker *et al.*, 2023; Cobo *et al.*, 2023; Geden, Smith and Cowie, 2024). Stakeholder consultation suggested that enhanced rock weathering is between 4 and 6.
Investment needs	Ex-situ mineralisation and enhanced rock weathering primarily involve high OPEX and lower CAPEX due to the need for mining, material processing, and reactor infrastructure. These costs remain significant, driven by energy-intensive grinding, transportation, and chemical processing. Innovations in process efficiency and the use of waste materials could help reduce costs over time.
Key considerations	● High energy demand for material extraction, grinding, and reaction acceleration ● Sourcing of raw materials remains can be challenging, as well as transport from extraction to application sites. ● Long term-environmental impacts due to mining activities and infiltration into groundwater remain unknown. ● For ex-situ mineralisation MRV is relatively straightforward compared to in-situ methods, but remains a challenge. In the case of ERW, MRV remains complex, as weathering rates, soil composition, and environmental factors can vary substantially.

3.6. Ocean-based CDR

Category	Description
Description	Ocean-based carbon dioxide removal (CDR) encompasses a range of techniques aimed at enhancing the ocean's natural ability to absorb and store carbon dioxide (CO_2) from the atmosphere. In this study the ocean-based CDR approaches include ocean alkalinity enhancement, which involves adding alkaline minerals to increase carbon sequestration, and direct ocean capture, through which CO_2 is extracted from sea water.
Maturity level (TRL)	Ocean-based CDR is still in its early stages with a TRL ranging from 1 to 6. Specifically, for both ocean alkalinity enhancement and direct ocean capture, the maturity level is estimated to be between **1 and 3** (Babiker *et al.*, 2023; Cobo *et al.*, 2023; Geden, Smith and Cowie, 2024; European Scientific Advisory Board on Climate Change, 2025).

Category	Description
Investment needs	These methods generally involve high OPEX costs due to the infrastructure necessary for dissemination in the ocean, especially for ship-based methods.
Key considerations	● The environmental effects of ocean-based CDR methods deployed on a large scale are still unknown. ● Ocean-based approaches offer difficult conditions for effective MRV to take place.

4. State of the European CDR sector

4.1. Overview of European CDR projects and organisations

Desktop research, triangulated with survey findings, indicated that there are 175 organisations and 148 projects operating within the CDR field in Europe (EEA, the United Kingdom, Serbia and Switzerland), as presented in the table below. Whereas the number of organisations refers to companies and other stakeholders active in the in-scope CDR technologies, projects are specific sites where carbon is being removed. This distinction was made as some projects are developed by a consortium of companies (e.g. project developer, technology provider and storage actor), while some companies have not yet implemented on-site projects (e.g., due to early-stage development of technologies with low TRLs). The higher number of identified CDR organisations compared to projects could also be explained by the presence of actors based in Europe that conduct operations internationally (e.g., several operators within the biochar sector).

Table 4 - Overview on CDR organisations and projects in Europe (1)

CDR technology	Number of organisations in Europe	Number of projects in Europe
BioCCS	25	34
Biochar	71	62
DACCS	46	30
In-situ mineralisation	3	3
Ex-situ mineralisation	10	13
Enhanced rock weathering	13	3
Direct ocean capture	2	1
Ocean alkalinity enhancement	5	2
Total	**175**	**148**

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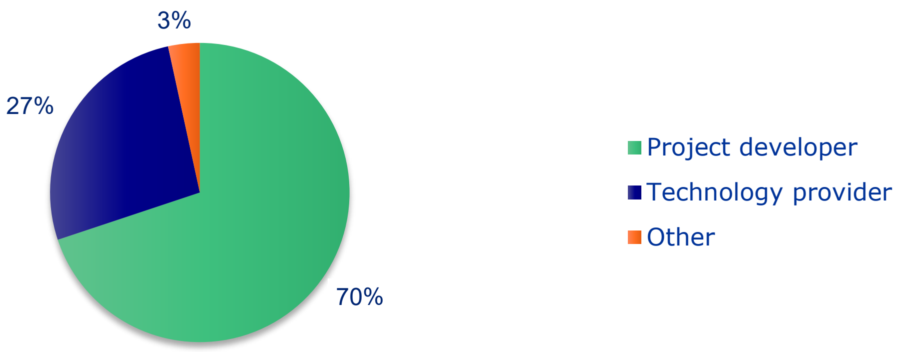
(1) In this overview, only projects planned to be operational by 2030 are included in this assessment. This is due to the high uncertainty associated with long-term projects, and the fact that these are only indicated for certain technologies (e.g. BECCS).

4.1.1. Insights on the European CDR landscape

Figure 2 - Type of CDR organisations in Europe, N = 175 (Ramboll compilation based on multiple sources) (2)



The landscape of identified CDR organisations in Europe reveals two main types of actors – technology providers and project developers. In terms of type of organisation, 70% of the identified organisations are technology providers compared against 27% are project developers and 3% others, as illustrated in the figure above.

The mapping suggests broad geographical representation of European CDR organisations. Of the 175 identified CDR organisations, 130 are based in the EEA, of which 120 are operating from the EU, see Table 5. The remainder are based in the United Kingdom, Serbia and Switzerland. This does not mean, however, that their projects are located in the same countries, with several developers having cross-continental operations.

The mapping does suggest that most CDR organisations operate from northern and western European countries, such as Germany, the Netherlands, France, Switzerland, Sweden and the United Kingdom. These are determined based on project sites and/or headquarter location. As several CDR organisations are expected to operate beyond national borders, these insights only give a limited indication of spatial distribution across the continent. Notable, while the UK is home to several organisations, not all have operations within the country, nor the continent of Europe.

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(2) As many organisations can be considered both, technology provider and project developer (e.g. technology providers that developed pilot sites, project developers that have their own technology), the organisations were divided based on their typical role in projects.

Table 5 - CDR organisations across Europe(3)

	Austria	Belgium	Bulgaria	Czechia	Denmark	Estonia	Finland	France	Germany	Iceland	Ireland	Italy	Netherlands	Norway	Poland	Portugal	Romania	Serbia	Spain	Sweden	Switzerland	United Kingdom	Grand Total
BioCCS					3			4	2				1	3						5	4	3	**25**
Biochar	3	1		1	3		3	6	12			5	2	1		1	2	1	5	7	7	11	**71**
DACCS	1	1				1	1	4	8	2	3	1	5	3	1				1	2		12	**46**
Enhanced rock weathering			1		1			1	4		1		3		1							1	**13**
Ex-situ mineralisation	1						1	2	3													3	**10**
In-situ mineralisation										1												2	**3**
Ocean Alkalinity Enhancement								2	1			1										1	**5**
Direct Ocean Capture													2										**2**
Grand Total	**5**	**2**	**1**	**1**	**7**	**1**	**5**	**19**	**30**	**3**	**4**	**7**	**13**	**7**	**2**	**1**	**2**	**1**	**6**	**14**	**11**	**33**	**175**

4.1.2. Technology-specific insights on the European CDR landscape

At the technology level, the following technology-specific insights have been identified:

BioCCS

Most BioCCS operators are based in northern European countries, such as Sweden, Denmark, and Norway. This is likely due to the better access to geological

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(3) Based on the project mapping conducted as part of this studies. Where applicable, the identified country corresponds to the project site(s). If (geo)data on a project is missing, or the data entry concerns a technology provider or other actor, the geolocation of the company's headquarters is referred to instead.

storage sites (e.g., North Sea basin) and higher biomass feedstock availability associated with these areas.

In the mapping process of BioCCS actors and projects, waste-to-energy plant operators were excluded. However, these actors are still relevant in terms of technology development, their operations focus on reducing net emissions, rather than extracting CO2 from the atmosphere, as is done through carbon removal. In cases where waste-to-energy plants process mixed waste with a biogenic fraction, the resulting CO_2 capture can qualify as carbon removal under the same principle as BioCCS and is creditable under the CRCF.

Biochar

Biochar accounts for the largest share of identified organisations (71) and projects (62), with operations distributed across a wide range of European countries. While projects are often not listed for every biochar organisation, all operating biochar organisations require a pyrolysis plant. As such, for the purposes of this study, it is assumed that each company engaged in biochar production has at least one associated project, corresponding to a single pyrolysis plant.

Access to data on annual CO_2 removal capacity for biochar was difficult to obtain, making it challenging to estimate the current and planned supply in Europe. This is likely due to several reasons, such as the uncertainty about the supply of eligible feedstocks, (disposal) pathways, and how future regulatory requirements (e.g. CRCF) may influence reporting obligations or eligibility criteria. While standardisation efforts are ongoing under the CRCF, uncertainty surrounding MRV also complicate the determination of capacity, both per t biochar produced and applied across soil types.

Additionally, several biochar organisations are headquartered in Europe but conduct operations internationally. Consequently, while the technology is developed in Europe, carbon removal occurs in countries elsewhere, such as Kenya, the United Arab Emirates, and Colombia.

DACCS

Europe hosts a substantial number of DACCS technology providers and projects. While DACCS companies do not necessarily develop or operate their project sites, their innovations contribute to the broader scaling of DACCS as a CDR technology.

Most DACCS organisations, primarily technology providers, are based in Germany (7). Project development primarily occurs in countries such as Iceland

and Norway, where energy and water needs can be met more easily (due to, e.g., availability of geothermal energy).

In-situ mineralisation

In-situ mineralisation is not widely developed in Europe, with only three identified operators, and two identified projects. The requirements associated with geological suitability, as well as regulatory constraints, are expected to result in limited deployment on the continent. Two identified projects are located in Iceland (Carbfix's Coda Terminal (4), Project Silverstone (5)). As a storage provider, these mineralisation projects are expected to accommodate both CDR and industrial CCUS activities.

Ex-situ mineralisation and enhanced rock weathering

In the field of ex-situ mineralisation, 10 organisations and 13 projects were identified. This technology is either deployed as a stand-alone project or integrated within the site of another CDR technology, such as DACCS.

While the number of operators for enhanced rock weathering is comparable, fewer projects were identified (three). This is expected to be related to the lower TRL of enhanced rock weathering (TRL 3-5) compared to ex-situ mineralisation approaches (TRL 6-8), meaning that operators are focused on foundational R&D.

Germany hosts the highest number of operators for both enhanced rock weathering (four) and ex-situ mineralisation (three). Other key locations for these technologies are also in western Europe, namely the Netherlands and the United Kingdom.

Ocean-based CDR approaches

Ocean alkalinity enhancement and direct ocean capture have the fewest associated organisations (7) and only 3 identified projects within European waters. Given the TRL of these technologies (1–3), most organisations engaged in ocean-based CDR primarily focus on R&D, with only a limited number of initial pilot tests deployed to date.

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(4) See also for a more detailed overview: https://climate.ec.europa.eu/system/files/2022-12/if_pf_2022_coda_en.pdf

(5) See also for a more detailed overview: https://climate.ec.europa.eu/system/files/2022-07/if_pf_2021_silverstone_en.pdf

4.2. Estimated supply of CDR

4.2.1. Overview: Methodology and results of Ramboll estimates

Current capacity was primarily estimated through the logging of geospatial data on CDR operations, which identified projects and their respective removal capacities within Europe. However, as mentioned, these mapped removal capacities reported alone do often not provide a comprehensive overview of total European removal capacity due to data gaps, particularly for technologies such as biochar. Thus, the estimated capacities were cross-checked against available literature at both global and European levels.

For future capacity estimation, exponential growth was assumed, taking into account global growth projections as well as sustainable (maximum capacity considering environmental factors) and technical (maximum capacity without environmental considerations) potentials on European level where possible. Finally, through our current understanding on the state of these technologies (on their maturity level, operational areas, etc.) we reflected critically on the feasibility of the estimations due to the high level of uncertainty.

Table 6 - Estimated supply of CDR (6)

	Current European CDR supply ($MtCO_2/y$) (7)	Estimated supply in 2030 in Europe ($MtCO_2/y$)	Estimated supply in 2035 in Europe ($MtCO_2/y$) (8)
BioCCS	0.4	3.2	10-15
Biochar	0.2	2.3	5-7
DACCS	0.0	0.8	5-10

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(6) Estimates on ocean-based CDR capacity are highly uncertain due to the early stage of the technology and limited available data on announced projects. As such, short-term deployment in Europe is expected to remain rather limited

(7) While the current European supply was triangulated with external data sources and survey findings, the main source of data for this is the conducted data mapping. In case of identified data gaps on removal capacity (e.g., biochar) the weight of external sources in this modelling exercise was increased.

(8) Estimates on capacity in 2035 largely based on the assumption of exponential growth.

In-situ mineralisation (9)	**0-0.04**	**0.8**	**1.5-2**
Ex-situ mineralisation (and ERW)			
Ocean-based CDR	**0.0**	**0-0.08***	**0-2.5***
Total	**0.0-0.6**	**7.1-7.2**	**22-37**

4.2.2. Removal capacity: Biogenic emission capture with permanent carbon storage (BioCCS)

Table 7 - Ramboll estimates on current and future European capacity of BioCCS based on project mapping and literature review

	Current European CDR supply (MtCO$_2$/y)	Estimated supply in 2030 in Europe (MtCO$_2$/y)	Estimated supply in 2035 in Europe (MtCO$_2$/y)
BioCCS (10)	**0.4**	**3.2**	**10-15**

Current capacity

Biogenic emission capture with permanent carbon storage (BioCCS) capacity has seen limited deployment in Europe so far, with 0.4 MtCO$_2$/a understood to be operational as of now. Currently operational projects in Europe include mainly BECCS as well as a few other BioCCS facilities (e.g., biogas plants), primarily based in Scandinavia. As per the literature, global BECCS capacity was between 0.5-2 MtCO$_2$ per year by 2023 (Rocky Mountain Institute, 2023; Pongratz *et al.*, 2024). Estimated capacity is largely represented BECCS facilities, with limited certainty on removal capacity of alternative BioCCS operations. Therefore, no further breakdown between estimated removal capacity for BECCS and BioCCS can be provided at this stage.

Future capacity

In Europe, BioCCS capacity is projected to grow in the coming years, with an estimated capacity of 3.2 MtCO$_2$ per year by 2030 (project mapping conducted

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(9) Due to the high-level of uncertainty on estimated capacities for both mineralisation approaches are estimated provided for both combined.

(10) Estimated capacity mainly reflects announced BECCS facilities. Due to uncertainty around other BioCCS methods, no further breakdown is currently possible.

in this study). This is only a fraction of the expected long-term capacity in the region, with expert elicitation based on future scenarios anticipating a future capacity between 36 $MtCO_2$ to 131 $MtCO_2$ per year by 2050 for BECCS alone (Reiner et al., 2023).

Assuming growth beyond 2030 at a rate that achieves the estimations for 2050, BioCCS capacity in Europe could reach 10–15 $MtCO_2$ per year by 2035, depending on policy support, technological advancements, and investment. Most of these volumes are expected to be BECCS removals. These estimates are in line with the technical potential in literature, referring to the maximum feasible capacity based on physical, resource and engineering constraints of 150–250 $MtCO_2$ per year within the EU by 2050.

As per the conducted project mapping and survey findings, BECCS and other BioCCS companies predict a further scaling up beyond 2030, bringing the expected removal up to around 15-20 Mt by 2035. However, as these projects are announced to be developed further into the future, there is more uncertainty on whether they are being build. As such, more weight is given to the estimated capacity based on the expert elicitation by Reiner et al. (2023) mentioned above.

Table 8 - Current and future capacity of BioCCS as per literature and the study

Source	Scope	Type of estimate	Year	Amount ($MtCO_2$/year)
Chapter 7: Current levels of CDR. in The State of Carbon Dioxide Removal 2024 – 2nd Edition (eds. Smith, S. M. et al.). https://www.stateofcdr.org, doi:10.17605/OSF.IO/ 7 ZXSKB (2024)	Global	Current capacity	2017-2023	0.5
McKinsey (2023) Carbon removals: How to scale a new gigaton industry. Available at: https://www.mckinsey.com/capabilities/sustainability/our-insights/carbon-removals-how-to-scale-a-new-gigatonindustry	Global	Sustainable potential	2050	2,000-4,000
Reiner, D. et al. (2023) Quantifying and Deploying Responsible Negative Emissions in Climate Resilient Pathways. Available at: https://www.negemproject.eu/wp-content/uploads/2023/08/NEGEM_D5.4-Expert-elicitation.pdf	Europe	Estimated capacity	2050	36-131
European Scientific Advisory Board on Climate Change (2025). Scaling up carbon dioxide removals - Recommendations for navigating opportunities and risks in the EU	EU	Technical potential	2050	150-250
Rocky Mountain Institute (2023). The Applied Innovation Roadmap for CDR	Global	Current capacity	2023	2

Source	Scope	Type of estimate	Year	Amount ($MtCO_2$/year)
	Global	Best-case scenario capacity	2030	10
	Global	Best-case scenario capacity	2035	40
Ramboll estimate based on project mapping conducted as part of the study	Europe	Current and planned capacity by 2030	2030	3.2

4.2.3. Removal capacity: Biochar carbon removal

Table 9 - Ramboll estimates on current and future European capacity of biochar based on project mapping and literature review

	Current European CDR supply ($MtCO_2$/y)	Estimated supply in 2030 in Europe ($MtCO_2$/y)	Estimated supply in 2035 in Europe ($MtCO_2$/y)
Biochar	0.2	2.3	5-7

Current capacity

The current biochar carbon removal capacity in the EU is estimated at around 0.2 $MtCO_2$ per year, based on the identified projects for section 4.1 and assessed literature (see Table 10). This is consistent with other sources, such as the European Biochar Industry Consortium's (2024) assessment.

Global biochar production is estimated to have nearly quadrupled between 2021 and 2023, indicating significant growth in biochar development and subsequent carbon removal capacity from biochar, as noted in Chapter 7 of *The State of Carbon Dioxide Removal 2024* (Pongratz *et al.*, 2024).

Future capacity

On a global level, the estimated biochar carbon removal capacity is projected to continue expanding. *The State of Carbon Dioxide Removal 2024* (Pongratz *et al.*, 2024) suggests an increase from 0.2 $MtCO_2$ per year in 2021 to 0.8 $MtCO_2$ per year in 2023, with an annual growth rate of approximately 0.3 $MtCO_2$. If this trend persists, global biochar carbon removal capacity could reach approximately 2.8 $MtCO_2$ per year by 2030 and 4.3 $MtCO_2$ per year by 2035. This growth does not exceed the sustainable potentials (maximum annual potential considering constraints e.g., available land, biomass) from McKinsey (2023) and Babiker et al. (2023) for potential scaling of carbon removal technologies by 2050, suggesting that these capacities are plausible.

In Europe, the current capacity of 0.2 $MtCO_2$/a in 2023 is expected to increase to 2.3 $MtCO_2$/a by 2030, according to the European Biochar Industry Consortium (2024). As mentioned, project mapping conducted as part of this study did not result in identified increased capacity by 2030, highlighting uncertainty in meeting the higher estimate.

Data gaps on future biochar projects, might be explained by their shorter development timescales compared to technologies such as BioCCS and DACCS. This might explain why a large proportion of future capacity might not have been identified yet.

If growth continues in line with the estimated capacities for 2023 and 2030, and assuming an exponential trajectory, EU biochar carbon removal capacity could reach 5–7 $MtCO_2$ per year by 2035. These projections are consistent with those of the Rocky Mountain Institute (2023), which also anticipates significant scaling of biochar carbon removal capacity in the coming decades, albeit on a global scale. In the survey conducted for this study, European biochar companies indicated they aim to remove 2.4 $MtCO_2$ per year by 2030 and 5.3 $MtCO_2$ per year by 2035, however, the extent to which this estimated future capacity is feasible, remains to be seen. These estimates provided by stakeholders might be too optimistic, meaning these could reflect ambitions rather than realistic expectations.

However, as per the survey findings, several of the European biochar companies indicated they planned their large-scale operations outside of Europe, which would not contribute to European CDR capacity. As such, while Europe is expected to play a significant role in biochar deployment, a considerable share of future carbon removal capacity is expected to be established in other regions. While uncertainties persist, particularly regarding planned capacity within the EU, this overall trajectory aligns with broader expectations for biochar's role in global carbon dioxide removal.

Table 10 - Current and future capacity of Biochar as per literature and the study

Source	Scope	Type of estimate	Year	Amount ($MtCO_2$/year)
Chapter 7: Current levels of CDR. in The State of Carbon Dioxide Removal 2024 – 2nd Edition (eds. Smith, S. M. et al.). https://www.stateofcdr.org, doi:10.17605/OSF.IO/ 7 ZXSKB (2024)	Global	Current capacity	2021	0.21
	Global	Current capacity	2022	0.5
	Global	Current capacity	2023	0.79

Source	Scope	Type of estimate	Year	Amount ($MtCO_2$/year)
McKinsey (2023) Carbon removals: How to scale a new gigaton industry. Available at: https://www.mckinsey.com/capabilities/sustainability/our-insights/carbon-removals-how-to-scale-a-new-gigatonindustry.	Global	Sustainable potential	2050	500-1,200
Babiker, M. et al. (2023) 'Cross-sectoral perspectives', in IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change[P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. 1st edn. Cambridge University Press, pp. 295–408. Available at: https://doi.org/10.1017/9781009157926.005.	Global	Technical potential	2050	300-6,600
European Biochar Industry Consortium (2024). Market Report 2023	Europe	Current capacity	2023	0.2
	Europe	Estimated capacity	2030	2.3
	Europe	Estimated capacity	2040	40-70
European Scientific Advisory Board on Climate Change (2025). Scaling up carbon dioxide removals - Recommendations for navigating opportunities and risks in the EU	EU	Technical potential	2050	70-200
Rocky Mountain Institute (2023). The Applied Innovation Roadmap for CDR	Global	Current capacity	2023	0.5
	Global	Best-case scenario capacity	2030	8
	Global	Best-case scenario capacity	2035	30
Ramboll estimate based on project mapping conducted as part of the study.	Europe	Current capacity	2025	0.2

4.2.4. Removal capacity: Direct air carbon capture and storage (DACCS)

Table 11 - Ramboll estimates on current and future European capacity of DACCS based on project mapping and literature review

	Current European CDR supply ($MtCO_2$/y)	Estimated supply in 2030 in Europe ($MtCO_2$/y)	Estimated supply in 2035 in Europe ($MtCO_2$/y)
DACCS	0.0	0.8	5-10

Current capacity

Similar to BioCCS, current DACCS capacity both in Europe and global remains limited (0.0 $MtCO_2$/y on global level), but there are several projects under development. According to *The State of Carbon Dioxide Removal 2024* (Pongratz *et al.*, 2024), and the IEA (2024) global current DACCS capacity is effectively negligible (0.0 Mt).

While the project mapping did identify multiple DACCS projects, these are largely pilot and demonstration plants with limited capacity. This limited current capacity is expected to be a result of the low TRL (4-6), high cost, scarcity of low carbon inputs (i.e. electricity to maintain net negativity), all leading to the lack of a clear business case.

Future capacity

By 2030, total European DACCS capacity is expected to be 0.8 MtCO2/a, with several projects currently already under development. Of these projects, multiple large-scale projects are announced, which are expected to expand DACCS capacity. One of these projects includes the DAC plant under development in Øygarden, Norway, which will have a removal capacity of 0.5 $MtCO_2$ per year from 2027 onwards.

Estimated global capacity is substantially larger, with estimated global capacities of 60–65 $MtCO_2$ per year by 2030 if all currently planned projects are developed (Rocky Mountain Institute, 2023; IEA, 2024; Nemet *et al.*, 2024). By 2035, capacity could increase to 180 $MtCO_2$ per year (Rocky Mountain Institute, 2023), aligning with broader expectations for rapid technological deployment.

By 2035, extrapolating from projected growth rates while assuming exponential growth, DACCS capacity in Europe could reach 5-10 $MtCO_2$ per year, depending on deployment speed, policy support, and investment. These 2035 projections are a product of interpolation based on expert elicitation on estimated future capacity of DACCS under set scenarios, carried out during the NEGEM project, under the assumption of exponential growth through technological innovation. The experts consulted through the NEGEM project indicated a capacity range 39 $MtCO_2$ to 353 $MtCO_2$ per year by 2050 (Reiner *et al.*, 2023). The European Scientific Advisory Board on Climate Change (2025) projects a technical potential of 20–60 $MtCO_2$ per year within Europe by 2050.

However, it should be noted that future capacity is dependent on the future business case of DACCS, which requires further technological breakthroughs optimising absorption through membranes. The extent to which this is likely to occur in the short-medium future remains to be seen.

Table 12 - Current and future capacity of DACCS as per literature and the study

Source	Scope	Type of estimate	Year	Amount ($MtCO_2$/year)
Chapter 7: Current levels of CDR. in The State of Carbon Dioxide Removal 2024 – 2nd Edition (eds. Smith, S. M. et al.). https://www.stateofcdr.org, doi:10.17605/OSF.IO/ 7 ZXSKB (2024)	Global	Current capacity	2023	0.0
IEA (2024) Direct Air Capture. Available at: https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage/direct-air-capture (Accessed: 3 March 2025).	Global	Current capacity	2024	0.01
	Global	Maximum estimated capacity	2030	65
McKinsey (2023) Carbon removals: How to scale a new gigaton industry. Available at: https://www.mckinsey.com/ capabilities/sustainability/our-insights/carbon-removals-how-to-scale-a-new-gigatonindustry.	Global	Sustainable potential	2050	2,000-5,000
Nemet, G. F., Edwards, M. R., Greene, J., Dayathilake, L., Thomas, Z. H., Surana,K., Kennedy, K. M., Zaiser, A., Probst, B. S. Chapter 3: Demonstration and upscaling. In The State of Carbon Dioxide Removal 2024 – 2nd Edition (eds. Smith, S. M. et al.). https://www.stateofcdr.org, doi:10.17605/OSF.IO/DPKSB (2024).	Global	Estimated capacity	2030	61
Reiner, D. et al. (2023) Quantifying and Deploying Responsible Negative Emissions in Climate Resilient Pathways. Available at: https://www.negemproject.eu/wp-content/uploads/2023/08/NEGEM_D5.4-Expert-elicitation.pdf.	Europe	Estimated capacity	2050	39-353
European Scientific Advisory Board on Climate Change (2025). Scaling up carbon dioxide removals - Recommendations for navigating opportunities and risks in the EU	EU	Technical potential	2050	20-60
Rocky Mountain Institute (2023). The Applied Innovation Roadmap for CDR	Global	Current capacity	2023	0
	Global	Best-case scenario capacity	2030	60
	Global	Best-case scenario capacity	2035	180
Ramboll estimate based on project mapping conducted as part of the study.	Europe	Current and planned capacity by 2030	2030	0.8

4.2.5. Removal capacity: In-situ and ex-situ mineralisation (including enhanced rock weathering)

Table 13 - Ramboll estimates on current and future European capacity of in-situ and ex-situ mineralisation based on project mapping and literature review (11)

	Current European CDR supply ($MtCO_2/y$)	Estimated supply in 2030 in Europe ($MtCO_2/y$)	Estimated supply in 2035 in Europe ($MtCO_2/y$)
In-situ mineralisation	**0-0.04**	**0.8**	**1.5-2**
Ex-situ mineralisation			
Surficial mineralisation (Enhanced rock weathering)			

Current capacity

The current deployment of mineralisation-based CDR in Europe remains limited to 0.0-0.04 $MtCO_2$/a, with only a small number of projects identified. According to *The State of Carbon Dioxide Removal 2024* (Pongratz *et al.*, 2024), the global capacity of ex-situ mineralisation, including enhanced rock weathering, was estimated at 0.04 $MtCO_2$ per year in 2023. Similarly, in-situ mineralisation remains at an early stage, with no large-scale operational projects in Europe currently identified, suggesting negligible current capacity.

Due to the high uncertainty of in-situ, ex-situ and surficial (enhanced rock weathering) mineralisation deployment in Europe, it is not possible to make estimations for both mineralisation approaches separately. As such, despite their different technological characteristics, the potential of these CDR methods was grouped under one overarching mineralisation category.

Future capacity

By 2030, in-situ mineralisation, enhanced rock weathering and ex-situ mineralisation are understood to amount to in total 0.8 $MtCO_2$ per year in Europe, based on announced projects, and projects under development. Of this, 0.1 $MtCO_2$/a stems from ex-situ mineralisation projects, including ERW, and 0.7

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(11) Due to the high-level of uncertainty on estimated capacities for mineralisation approaches, the figures are presented jointly.

$MtCO_2$ from in-situ mineralisation projects. These numbers are considered plausible, as near-term deployment is expected to remain limited, due to the maturity of enhanced weathering (TRL 3-5) and mineralisation (TRL 2-8).

Using a growth trajectory based on estimated capacities today and in 2030, European capacity for mineralisation and ERW could reach approximately 1.5–2 $MtCO_2$ per year by 2035. Survey respondents anticipate 1.6 $MtCO_2$ per year by 2030 and 10.2 $MtCO_2$ per year by 2035, but these figures appear optimistic in light of current project tracking and best-case global scenarios. While these projections suggest potential growth, they remain significantly below the technical potential provided by the European Scientific Advisory Board on Climate Change (2025) of 50-200 $MtCO_2$/a. In sum, while mineralisation offers considerable long-term potential, its near-term scalability in Europe remains uncertain.

On a global scale, the Rocky Mountain Institute (2023) projects a best-case scenario of 3 $MtCO_2$ per year for in-situ mineralisation and 5.2 $MtCO_2$ per year for ex-situ mineralisation and enhanced rock weathering by 2030. By 2035, these figures rise to 23 $MtCO_2$ and 22 $MtCO_2$ per year, respectively, reflecting an increase in capacity if favourable conditions for deployment are met.

Table 14 - Current and future capacity of mineralisation as per literature and the study

Source	Scope	Type of estimate	Year	Amount ($MtCO_2$/year)
In-situ mineralisation				
Rocky Mountain Institute (2023). The Applied Innovation Roadmap for CDR	Global	Estimated capacity	2026	0.6
	Global	Best-case scenario capacity	2030	3
	Global	Best-case scenario capacity	2035	23
Ramboll estimate based on project mapping conducted as part of the study.	Europe	Current and planned capacity by 2030	2030	0.7
Ex-situ mineralisation (including enhanced rock weathering)				
Chapter 7: Current levels of CDR. in The State of Carbon Dioxide Removal 2024 – 2nd Edition (eds. Smith, S. M. et al.). https://www.stateofcdr.org, doi:10.17605/OSF.IO/ 7 ZXSKB (2024)	Global	Current capacity (both ex-situ mineralisation and ERW)	2023	0.04

Source	**Scope**	**Type of estimate**	**Year**	**Amount (MtCO$_2$/year)**
European Scientific Advisory Board on Climate Change (2025). Scaling up carbon dioxide removals - Recommendations for navigating opportunities and risks in the EU	EU	Technical potential	2050	50-200 (12)
McKinsey (2023) Carbon removals: How to scale a new gigaton industry. Available at: https://www.mckinsey.com/capabilities/sustainability/our-insights/carbon-removals-how-to-scale-a-new-gigatonindustry.	Global	Sustainable potential (enhanced rock weathering)	2050	500-4,000
Rocky Mountain Institute (2023). The Applied Innovation Roadmap for CDR	Global	Estimated capacity (both ex-situ mineralisation and ERW)	2025	0.18
	Global	Best-case scenario capacity (both ex-situ mineralisation and ERW)	2030	5.16
	Global	Best-case scenario capacity (both ex-situ mineralisation and ERW)	2035	22
Ramboll estimate based on project mapping conducted as part of the study.	Europe	Current and planned capacity by 2030	2030	0.1

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(12) Based on limited estimates.

4.2.6. Removal capacity: Ocean-based approaches (Direct Ocean Capture, Ocean Alkalinity Enhancement)

Table 15 - Ramboll estimates on current and future European capacity of ocean-based CDR based on project mapping and literature review

	Current European CDR supply ($MtCO_2/y$)	Estimated supply in 2030 in Europe ($MtCO_2/y$)	Estimated supply in 2035 in Europe ($MtCO_2/y$)
Ocean-based CDR (13)	0.0	0-0.08*	0-2.5*

Current capacity

Of the two considered ocean-based CDR approaches, both ocean alkalinity enhancement and direct ocean capture are still at an early stage of development (TRL 1-3), with no identified current capacity. According to the Rocky Mountain Institute (2023), there is no established operational capacity for ocean-based CDR on a global scale either.

The project mapping conducted as part of this study indicates that Europe has no identified or planned capacity by 2030, with only few organisations based in Europe. These companies largely focus on R&D, rather than commercialisation.

Future capacity

Given the high uncertainty due to the low TRL of ocean-based CDR, no reliable estimations can be made for 2030 and 2035 in Europe only. Instead, global capacity is expected to fall between the current capacity (0.0 $MtCO_2/a$) and the projected global capacity of 0.08 $MtCO_2/a$ by 2030 and 2.5 $MtCO_2/a$ by 2035, as indicated as best-case scenario by the Rocky Mountain Institute (2023).

In the survey, ocean-based CDR companies indicated that they anticipate removing 1.1 $MtCO_2$ per year by 2030 and 9.1 $MtCO_2$ per year by 2035 through ocean-based approaches. While these figures reflect ambition, they appear overly optimistic in light of current estimates and identified projects. These factors suggest that, while the long-term deployment of ocean-based CDR has potential, deployment in Europe is likely to be limited in the short to medium term.

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(13) Future estimates on ocean-based CDR capacity are highly uncertain due to the early stage of the technology and limited available data on announced projects. As such, short-term deployment in Europe is expected to remain rather limited.

Long-term potential for ocean-based CDR is considered to be substantial, with estimates suggesting the technology could have a significant role in global carbon removal by 2050, with the IPCC report (Babiker *et al.*, 2023) stating a technical potential ranging (for ocean alkalinity enhancement) between 1,000 $MtCO_2$ to 100,000 $MtCO_2$ per year by 2050. However, in terms of deployment in Europe by 2035, expectations remain modest, due to the size of the ocean-based CDR subsector.

Table 16 - Current and future capacity of ocean-based CDR as per literature and the study

Source	Scope	Type of estimate	Year	Amount ($MtCO_2$/year)
Ocean alkalinity enhancement				
Babiker, M. et al. (2023) 'Cross-sectoral perspectives', in IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change[P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. 1st edn. Cambridge University Press, pp. 295–408. Available at: https://doi.org/10.1017/9781009157926.005.	Global	Technical potential	2050	1,000-100,000
Rocky Mountain Institute (2023). The Applied Innovation Roadmap for CDR	Global	Current capacity	2023	0
	Global	Best-case scenario capacity	2030	0.08
	Global	Best-case scenario capacity	2035	2.5
Ramboll estimate based on project mapping conducted as part of the study.	Europe	Current and planned capacity by 2030	2030	0.0
Direct ocean capture				
Rocky Mountain Institute (2023). The Applied Innovation Roadmap for CDR	Global	Current capacity	2023	0
	Global	Best-case scenario capacity	2030	0.0-0.1
Ramboll estimate based on project mapping conducted as part of the study.	Europe	Current and planned capacity by 2030	2030	0.0

4.3. Estimated cost of CDR

4.3.1. Overview: Methodology and results of Ramboll estimates

The cost estimates for the CDR technologies (see table below) are based on a comprehensive literature review, supplemented by survey findings and conducted interviews. Literature sources provided baseline estimates for current and future costs, while survey responses provided a means for partial validation and refinement.

Given the uncertainty surrounding the current and future costs of all CDR technologies, costs were represented as ranges, with most likely upper- and lower bound limits. These uncertainties made precise forecasting challenging. Additionally, we provided a shared cost estimate for all mineralisation methods, including enhanced rock weathering. Future cost projections for ocean-based CDR were omitted due to a lack of reliable data.

Overall, as deployment scales up and technological efficiencies improve, costs are expected to decline for all CDR technologies, but the rate and extent of this reduction remain difficult to predict. With several variables at play, (e.g., energy prices, technological advancements, economies of scale, biomass feedstock availability, funding and (national) policy support), the estimated costs are bound to change.

Table 17 - Estimated global removal cost of CDR (14)

CDR tech	Current cost of removal (€$_{2023}$/tCO$_2$)	Estimated cost of removal in 2030 (€$_{2023}$/tCO$_2$)	Estimated cost of removal in 2035 (€$_{2023}$/tCO$_2$)
BioCCS (all)	**55-465**	*45-550*	*37-500*
BECCS	**172-314**	*167-261*	*163-228*
Biofuel production with CCS	**83-94**	*No data*	*No data*
Biochar	**83-251**	*66-215*	*50-175*
DACCS	**462-1,256**	*288-567*	*201-402*

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(14) For biofuel production with CCS no data on future costs were found. Estimates on mineralisation, ERW and ocean-based CDR costs are highly uncertain due to the early stage of the technology and limited available data on removal costs.

CDR tech	Current cost of removal (€$_{2023}$/tCO$_2$)	Estimated cost of removal in 2030 (€$_{2023}$/tCO$_2$)	Estimated cost of removal in 2035 (€$_{2023}$/tCO$_2$)
In-situ mineralisation	**168-747**	*132-141*	*113-122*
Ex-situ mineralisation	**232-747**	*195-400*	*172-350*
ERW	**94-740**	*94-250*	*92-200*
Ocean-based CDR technologies	**38-302**	*No data*	*No data*

4.3.2. Cost estimates: Biogenic emission capture with permanent carbon storage (BioCCS)

Table 18 - Estimated global removal cost of BioCCS

CDR tech	Current cost of removal (€$_{2023}$/tCO$_2$)	Estimated cost of removal in 2030 (€$_{2023}$/tCO$_2$)	Estimated cost of removal in 2035 (€$_{2023}$/tCO$_2$)
BioCCS (all)	**55-465**	*55-550*	*37-500*
BECCS	**172-314**	*167-261*	*163-228*
Biofuel production with CCS (15)	**83-94**	*No data*	*No data*

Current costs

For BioCCS, we estimate a current cost range of €55–465 per tCO$_2$ removed (Babiker *et al.*, 2023; McKinsey, 2023). As BioCCS is an umbrella term covering several technologies, the range of estimated costs is understood to be larger than that of specific BioCCS technologies included in this review, i.e., BECCS and biofuels production with CCS.

This observed variability in costs for BioCCS stems from several factors, such as e.g. technology maturity and available supply chains. Many BioCCS projects

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(15) For biofuel production with CCS no data on future costs were found.

(especially BECCS projects) currently remain at pilot or early commercial stages, leading to higher per-unit costs due to limited economies of scale.

For BECCS specifically, we estimate a current cost range of €17–314 per tCO_2 removed, based on several literature sources (Reiner et al., 2023; European Scientific Advisory Board on Climate Change, 2025). Similar to this removal cost, the carbon credit price of BECCS is reported to fall between €205-277/tCO_2 (CDR.fyi, 2024, 2025).

For biofuel production with CCS, current costs are estimates around €80-95 per tCO_2 removed. This figure is based on two individual studies (Gentile et al., 2022; Dees et al., 2023) and should be considered with certain caution.

Importantly for BioCCS removals, biomass feedstock availability plays a key role – while CCS facilities focused on reducing emissions through waste biomass tend to have lower costs, those reliant on purpose-grown crops to facilitate carbon removal face higher expenses.

Future costs

Over time, BioCCS costs are projected to decrease due to technological development and scaling of the technology. BECCS expert elicitation from Reiner et al. (2023) conducted as part of the NEGEM project estimates a removal cost of €153 per tCO_2 for BECCS by 2050, suggesting a steady decrease from current levels.

Based on this expert elicitation, a reasonable range for BECCS by 2030 would seemingly be in the range of €167-261 per tCO_2 and €163–228 per tCO_2 by 2035. These cost reductions reflect expected early cost reductions driven by early-on scaling and efficiency improvements, assuming exponential reduction through technological innovation.

For bio-based technologies in general, removal costs are estimated to fall within a broad range of €55 to €550 per tCO_2 by 2030 and €37 and €500 per tCO_2 by 2035, based on modelling done by McKinsey (2023) on the future costs of removals from biomass conversion processes combined with the cost estimates from the survey conducted as part of this study. Based on the estimations for the year 2035 in McKinsey (2023), the expected cost by 2030 was determined by applying exponential reduction of costs between the current and 2035 levels.

While the estimates from the two sources are broadly consistent, survey respondents tend to be more conservative, especially on their 2035 estimates. The survey results indicate a median cost of approximately €250 per tCO_2 for both

2030 and 2035 (N = 11 and N = 9, respectively), with an estimated total removal cost range of €20–550 per tCO_2 by 2030 and €20–500 per tCO_2 by 2035.

The existing discrepancies between literature estimates and survey responses suggest potential regional and technological variations between European and global BioCCS systems (as the survey focused on European operators). Additionally, differences in assumptions regarding deployment speed, feedstock availability, and carbon market incentives may account for these variations. As the CDR sector grows, competition for feedstock and geological storage space will increase, which may negatively impact upon overall costs and offset anticipated technological innovations and efficiency savings.

Table 19 - Current and future costs of BioCCS as per literature and the study

Source	Type of cost	Year	Amount (€$_{2023}$/ tCO_2)
BECCS			
European Scientific Advisory Board on Climate Change (2025). Scaling up carbon dioxide removals - Recommendations for navigating opportunities and risks in the EU	Removal cost	2024	**188-314**
Reiner, D. et al. (2023) Quantifying and Deploying Responsible Negative Emissions in Climate Resilient Pathways. Available at: https://www.negemproject.eu/wp-content/uploads/2023/08/NEGEM_D5.4-Expert-elicitation.pdf.	Removal cost	2023	**172**
	Removal cost	2050	**153**
Fuss, S., Johnstone, I., Höglund, R., Walsh, N. Chapter 4: The voluntary carbon market in The State of Carbon Dioxide Removal 2024 – 2nd Edition (eds. Smith, S. M. et 4 al.). https://www.stateofcdr.org, doi:10.17605/OSF.IO/MG3CY (2024)	Carbon credit price	2023	**277**
CDR.fyi (2024) Trending on Track? - CDR.fyi 2023 Year in Review. Available at: https://www.cdr.fyi/blog/2023-year-in-review	Carbon credit price	2023	**277**
CDR.fyi (2025) Keep Calm and Remove On - CDR.fyi 2024 Year in Review. Available at: https://www.cdr.fyi/blog/2024-year-in-review	Carbon credit price	2024	**205**
Biofuel production with CCS			
Gentile, V. et al. (2022) Production of biogas with CCS in Norway. In *Proceedings of the 16th Greenhouse Gas Control Technologies Conference (GHGT-16)* (pp. 23-24).	Removal cost	2022	**94**

Source	Type of cost	Year	Amount (€$_{2023}$/ tCO$_2$)
Dees, J. et al. (2023) Cost and life cycle emissions of ethanol produced with an oxyfuel boiler and carbon capture and storage. Environmental Science & Technology, 57(13), 5391-5403.	Removal cost	2023	**83**
BioCCS (all)			
Babiker, M. et al. (2023) 'Cross-sectoral perspectives', in IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. 1st edn. Cambridge University Press, pp. 295–408. Available at: https://doi.org/10.1017/9781009157926.005.	Removal cost	2022	17-465
McKinsey (2023) Carbon removals: How to scale a new gigaton industry. Available at: https://www.mckinsey.com/capabilities/sustainability/our-insights/carbon-removals-how-to-scale-a-new-gigatonindustry.	Removal cost	2023	**55-250**
	Removal cost	2035	**37-170**
	Removal cost	2050	**33-150**
Ramboll estimate based on survey results	Removal cost (Median, N = 11)	2030	**250 (20-550)**
	Removal cost (Median, N = 9)	2035	**250 (20-500)**

4.3.3. Cost estimates: Biochar carbon removal

Table 20 - Estimated global removal cost of biochar

CDR tech	Current cost of removal ($€_{2023}/tCO_2$)	Estimated cost of removal in 2030 ($€_{2023}/tCO_2$)	Estimated cost of removal in 2035 ($€_{2023}/tCO_2$)
Biochar	**83-251**	*66-215*	*50-175*

Current costs

Current carbon removal costs per tCO_2 of biochar show variation, with an estimated interval between €83 and €251 per tCO_2. Literature suggests an even wider range between €9 to €555 per tCO_2, but these contain some outliers. More typical estimates fall between €83 and €251 per tCO_2 (McKinsey, 2023; Rocky Mountain Institute, 2023; European Scientific Advisory Board on Climate Change, 2025).

Several factors that contribute to this variability, among which, feedstock availability. The cost of biomass feedstock (such as biogenic waste) can vary by region, influencing the overall cost of biochar production and subsequent carbon removal. Other factors include production scale and technology optimisation – Larger biochar facilities with advanced pyrolysis systems can achieve greater efficiency, lowering costs per tCO_2. In contrast, smaller-scale operations often face higher costs due to limited automation, lower throughput, and higher relative capital expenditures.

Future costs

Due to economies of scale, we estimate that the global cost of biochar carbon removal drops to €66-215/tCO_2 by 2030 and €50-175/tCO_2 by 2035. These estimates are based on expected linear cost reduction based on both modelling through literature and the consolidation with survey findings. McKinsey (2023) projects a significant reduction, estimating costs in the range of €50 to €122 per tCO_2 by 2035 (in their best-case scenario), assuming rapid scaling and innovation. In contrast, survey estimates (N = 8) indicate more moderate cost reductions, with projected costs of €215 per tCO_2 in 2030 and €175 per tCO_2 in 2035.

While available literature suggests that biochar production costs are expected to decline over time, the extent to which this is the case in Europe remains to be seen. As several European biochar companies indicate they plan to operate in the global south, economies of scale are understood to be set up in the global south. As such, the extent to which biochar carbon removal costs will similarly reduce is Europe is not expected. Following expert consultation conducted as part of this study, a removal cost range by 2035 of €100-200 for European biochar might be more likely.

Table 21 - Current and future costs of biochar as per literature and the study

Source	Type of cost	Year	Amount (€$_{2023}$/ tCO$_2$)
European Scientific Advisory Board on Climate Change (2025). Scaling up carbon dioxide removals - Recommendations for navigating opportunities and risks in the EU	Removal cost	2024	**126-251**
McKinsey (2023) Carbon removals: How to scale a new gigaton industry. Available at: https://www.mckinsey.com/capabilities/sustainability/our-insights/carbon-removals-how-to-scale-a-new-gigatonindustry.	Removal cost	2023	**83-203**
	Removal cost	2035	**50-122**
	Removal cost	2050	**37-90**
Babiker, M. et al. (2023) 'Cross-sectoral perspectives', in IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. 1st edn. Cambridge University Press, pp. 295–408. Available at: https://doi.org/10.1017/9781009157926.005.	Removal cost	2022	**12-401**
Rocky Mountain Institute (2023). The Applied Innovation Roadmap for CDR	Removal cost	2023	**9-555**
Ramboll estimate based on survey results	Removal cost (Median, N = 8)	2030	**215 (100-406)**
	Removal cost (Median, N = 8)	2035	**175 (80-397)**
Supercritical (no date) 'How much do carbon removal credits cost in 2024?' Available at: https://gosupercritical.com/blog?p=how-much-do-carbon-removal-credits-cost-in-2024 (Accessed: 3 March 2025).	Carbon credit price	2024	**167**
CDR.fyi (2024) Trending on Track? - CDR.fyi 2023 Year in Review. Available at: https://www.cdr.fyi/blog/2023-year-in-review	Carbon credit price	2022	**196**
	Carbon credit price	2023	**121**

Source	Type of cost	Year	Amount (€$_{2023}$/ tCO$_2$)
CDR.fyi (2025) Keep Calm and Remove On - CDR.fyi 2024 Year in Review. Available at: https://www.cdr.fyi/blog/2024-year-in-review	Carbon credit price	2024	**149**
Fuss, S., Johnstone, I., Höglund, R., Walsh, N. Chapter 4: The voluntary carbon market in The State of Carbon Dioxide Removal 2024 – 2nd Edition (eds. Smith, S. M. et 4 al.). https://www.stateofcdr.org, doi:10.17605/OSF.IO/MG3CY (2024)	Carbon credit price	2022	**196**
	Carbon credit price	2023	**121**

4.3.4. Cost estimates: Direct air carbon capture and storage (DACCS)

Table 22 - Estimated global removal cost of DACCS

CDR tech	Current cost of removal (€$_{2023}$/tCO$_2$)	Estimated cost of removal in 2030 (€$_{2023}$/tCO$_2$)	Estimated cost of removal in 2035 (€$_{2023}$/tCO$_2$)
DACCS	462-1,256	288-567	201-402

Current costs

Recent literature places current removal costs of DACCS between €462–1,256 per tCO$_2$ in 2023–2024 ((McKinsey, 2023; Reiner *et al.*, 2023; European Scientific Advisory Board on Climate Change, 2025)). The size of the range is largely attributed to the low maturity associated with the technology, and the lack of commercialisation.

Currently, rather than full-scale commercial operations, most DACCS activities involve demonstration and pilot plants, with DACCS efforts led mainly by technology providers rather than project developers. This low level of commercialisation is also reflected in the carbon credit prices, which show similarly high variability, with values ranging from €285 to over €1,100 per tCO$_2$ (Fuss *et al.*, 2024; CDR.fyi, 2025). This broad range highlights uncertainties related to deployment scale, energy prices, and operational efficiency due to the immaturity of DACCS as a CDR technology.

Future costs

Future cost estimates for DACCS are expected to face a downward trend, largely driven by technological advancements and increased scaling. As per DACCS expert elicitation by Reiner et al. (2023) as part of the NEGEM project, costs of removal through DACCS are estimated to reduce to €280 per tCO_2 by 2050, while McKinsey (2023) provides a range of €153–306 by then.

Interpolating these estimates, expected costs in 2035 fall between €201–402 per tCO_2, with a potential decrease to €288-576 per tCO_2 by 2030 if current scaling trends hold. However, cost projections remain uncertain due to energy costs, energy price fluctuations and infrastructure requirements. Survey data suggests median costs of €288 per tCO_2 in 2030 (N = 8) and €150 per tCO_2 in 2035 (N = 7), though these figures appear optimistic when compared to broader literature. In a similar way as for BioCCS, it may be that costs do not decrease over time as anticipated. As the sector grows, competition for low carbon energy sources and geological storage space will increase, which may negatively impact upon overall costs and offset anticipated technological innovations and efficiency savings.

Additionally, the potential for major cost reductions in terms of energy requirements in the short to medium term remains uncertain as these require further breakthroughs to improve scalability and economic viability. If these technological breakthroughs do not occur, future costs might turn out to be higher than anticipated.

Table 23 - Current and future costs of DACCS as per literature and the study

Source	Type of cost	Year	Amount (€$_{2023}$/ tCO_2)
European Scientific Advisory Board on Climate Change (2025). Scaling up carbon dioxide removals - Recommendations for navigating opportunities and risks in the EU	Removal cost	2024	**628-1,256**
Reiner, D. et al. (2023) Quantifying and Deploying Responsible Negative Emissions in Climate Resilient Pathways. Available at: https://www.negemproject.eu/wp-content/uploads/2023/08/NEGEM_D5.4-Expert-elicitation.pdf.	Removal cost	2023	**581**
	Removal cost	2050	**280**
McKinsey (2023) Carbon removals: How to scale a new gigaton industry. Available at: https://www.mckinsey.com/capabilities/sustainability/our-insights/carbon-removals-how-to-scale-a-new-gigatonindustry.	Removal cost	2023	**462-925**
	Removal cost	2035	**201-402**
	Removal cost	2050	**153-306**

Source	Type of cost	Year	Amount ($€_{2023}$/ tCO_2)
Babiker, M. et al. (2023) 'Cross-sectoral perspectives', in IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. 1st edn. Cambridge University Press, pp. 295–408. Available at: https://doi.org/10.1017/9781009157926.005.	Removal cost	2022	**116-349**
Ramboll estimate based on survey results	Removal cost (Median, N = 8)	2030	**288 (100-450)**
	Removal cost (Median, N = 7)	2035	**150 (50-250)**
Supercritical (no date) 'How much do carbon removal credits cost in 2024?' Available at: https://gosupercritical.com/blog?p=how-much-do-carbon-removal-credits-cost-in-2024 (Accessed: 3 March 2025).	Carbon credit price	2024	**480**
CDR.fyi (2024) Trending on Track? - CDR.fyi 2023 Year in Review. Available at: https://www.cdr.fyi/blog/2023-year-in-review	Carbon credit price	2022	**1,166**
	Carbon credit price	2023	**661 (407-1,900)**
CDR.fyi (2025) Keep Calm and Remove On - CDR.fyi 2024 Year in Review. Available at: https://www.cdr.fyi/blog/2024-year-in-review	Carbon credit price	2024	**285**
Fuss, S., Johnstone, I., Höglund, R., Walsh, N. Chapter 4: The voluntary carbon market in The State of Carbon Dioxide Removal 2024 – 2nd Edition (eds. Smith, S. M. et 4 al.). https://www.stateofcdr.org, doi:10.17605/OSF.IO/MG3CY (2024)	Carbon credit price	2022	**1,170**
	Carbon credit price	2023	**661**

4.3.5. Cost estimates: In-situ and ex-situ mineralisation (including enhanced rock weathering)

Table 24 - Estimated global removal cost of mineralisation (in-situ and ex-situ, including ERW) (16)

CDR tech	Current cost of removal (€$_{2023}$/tCO$_2$)	Estimated cost of removal in 2030 (€$_{2023}$/tCO$_2$)	Estimated cost of removal in 2035 (€$_{2023}$/tCO$_2$)
In-situ mineralisation	168-747	132-141*	113-122*
Ex-situ mineralisation	232-747	195-400*	172-350*
ERW	94-740	94- 250*	92-200*

Current costs

Current costs for in-situ mineralisation, ex-situ mineralisation and enhanced rock weathering (ERW) vary significantly due to differences in methodologies, energy requirements, and technological readiness, both between operators and technologies (TRL in-situ mineralisation = 2-6, TRL ex-situ mineralisation = 4-8). Mineralisation as CDR technology is still largely under development, and cost estimates can fluctuate depending on the scale of implementation, and market and geological conditions.

For all mineralisation, CDR.fyi (2025) indicated an overarching figure of €747 per tCO$_2$ for mineralisation-based carbon credits in 2024, covering both in-situ and ex-situ pathways. However, as these carbon credit ranges only reflect preliminary data, these were largely left outside of consideration.

As per modelling by Mühlbauer et al. (2024), cost of in-situ mineralisation by 2025 amounts to €168-176/tCO$_2$, and €232-239/tCO$_2$ for ex-situ mineralisation. In both cases, these costs refer to mineralisation as part of direct air capture, hence reflecting the cost of mineralisation as storage method. These estimates are in line with other literature, through which it is understood that costs associated with ex-situ approaches are generally considered to be higher than in-situ alternatives (Kelemen *et al.*, 2019).

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(16) Cost estimations on mineralisation, including ERW, are highly uncertain due to the early stage of the technology and limited available data on removal costs.

Similar to both in- and ex-situ mineralisation, ERW also exhibits a broad range of associated costs. According to McKinsey (2023) the removal cost of ERW ranges between €111–740 per tCO_2, indicating substantial uncertainty in the costs depending on specific technologies and locations used for ERW. The European Scientific Advisory Board on Climate Change (2025) provides a range on ERW removal costs between €314–377 per tCO_2 removal. This broad range is reflective of the varying costs of different projects and geographies involved. The carbon credit price for ERW generally ranges between €281 and €343 per tCO_2 in 2023-2024 (Fuss *et al.*, 2024; Supercritical, 2024; CDR.fyi, 2025).

Considering these high uncertainties, the ranges of current costs considered for in-situ and ex-situ mineralisation are €168-747/tCO_2 and €232-747/tCO_2, while the cost for ERW is expected to range between €111-740/tCO_2. These ranges reflect the high level of uncertainty and acknowledge that more research is required to make more specific estimates. This variability makes it challenging to establish definitive cost projections, and the cost ranges given in the literature reflect this uncertainty.

Future costs

By 2030, ERW costs could decline to €94 per tCO_2, as projected by Mühlbauer et al. (2024), while estimates for mineralisation (both in-situ and ex-situ) could range from €132–203 per tCO_2. These estimates on mineralisation take into account required Direct Air Capture (DAC) integration for both mineralisation approaches. Survey respondents (N =2) indicate higher cost expectations for ex-situ mineralisation (€250–400 per tCO_2) and ERW (€200–250 per tCO_2 compared to these projections, highlighting continued uncertainty in future cost reductions.

By 2035, Mühlbauer et al. (2024) project a further decline in costs for mineralisation (ex-situ mineralisation €172-179/tCO_2, in-situ mineralisation €113-122/tCO_2) and slight reduction in costs for ERW (€92 per tCO_2). Meanwhile, survey respondents (N = 2) offer a more conservative perspective, with a maximum cost by 2035 of €350/tCO_2 for ex-situ mineralisation and €200/tCO_2 for ERW. The cost projections outlined by Mühlbauer et al. (2024) are considered plausible, given that the scaling and advancement of these low-TRL CDR technologies are anticipated to lead to significant cost reductions (e.g., in MRV costs, infrastructure expenses, etc.) (Rocky Mountain Institute, 2023). However, the extent to which these reductions can be achieved within the proposed timeframe remains highly uncertain.

However, due to the uncertainty associated with current estimated costs of in-situ and ex-situ mineralisation, as well as ERW, projections for 2030 and 2035 remain highly uncertain. This uncertainty is further exacerbated by the uncertainty surrounding costs associated with MRV, which will be necessary to verify carbon sequestration efficacy of mineralisation and ERW, as well as assessing their environmental impacts.

Table 25 - Current and future costs of mineralisation as per literature and the study

Source	Type of cost	Year	Amount (€$_{2023}$/ tCO$_2$)
CDR.fyi (2025) Keep Calm and Remove On - CDR.fyi 2024 Year in Review. Available at: https://www.cdr.fyi/blog/2024-year-in-review (Accessed: 3 March 2025).)	Carbon credit price, in-situ and ex-situ mineralisation	2024	**747**
In-situ mineralisation			
Rocky Mountain Institute (2023). The Applied Innovation Roadmap for CDR	Removal cost, terrestrial in-situ mineralisation	2023	**9-46 ([17])**
	Removal cost, marine in-situ mineralisation	2023	**185-370**
Mühlbauer, A., Keiner, D. and Breyer, C. (2024) 'Techno-economic insights and deployment prospects of permanent carbon dioxide sequestration in solid carbonates', Energy & Environmental Science, 17(22), pp. 8756–8775. Available at: https://doi.org/10.1039/D4EE03166K.	Removal cost, in-situ mineralisation	2025	**168-176**
	Removal cost, in-situ mineralisation	2030	**132-141**
	Removal cost, in-situ mineralisation	2035	**113-122**
	Removal cost, in-situ mineralisation	2050	**49-57**
Ex-situ mineralisation (including enhanced rock weathering)			
European Scientific Advisory Board on Climate Change (2025). Scaling up carbon dioxide removals - Recommendations for navigating opportunities and risks in the EU	Removal cost, ERW	2024	**314-377**
Rocky Mountain Institute (2023). The Applied Innovation Roadmap for CDR	Removal cost, ex-situ mineralisation	2023	**10-600**
	Removal cost, ERW	2023	**23-176**
McKinsey (2023) Carbon removals: How to scale a new gigaton industry. Available at: https://www.mckinsey.com/capabilities/sustainability/our-insights/carbon-removals-how-to-scale-a-new-gigatonindustry.	Removal cost, ERW	2023	**111-740**

([17]) High degree of uncertainty, based on initial demonstration project data.

Source	Type of cost	Year	Amount (€$_{2023}$/ tCO_2)
Strefler, J. et al. (2018) 'Potential and costs of carbon dioxide removal by enhanced weathering of rocks', Environmental Research Letters, 13(3), p. 034010. Available at: https://doi.org/10.1088/1748-9326/aaa9c4.	Removal cost, ERW	2022	**66-221**
Babiker, M. et al. (2023) 'Cross-sectoral perspectives', in IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. 1st edn. Cambridge University Press, pp. 295–408. Available at: https://doi.org/10.1017/9781009157926.005.	Removal cost, ERW	2022	**58-323**
Mühlbauer, A., Keiner, D. and Breyer, C. (2024) 'Techno-economic insights and deployment prospects of permanent carbon dioxide sequestration in solid carbonates', Energy & Environmental Science, 17(22), pp. 8756–8775. Available at: https://doi.org/10.1039/D4EE03166K.	Removal cost, ex-situ mineralisation	2025	**232-239**
	Removal cost, ex-situ mineralisation	2030	**195-203**
	Removal cost, ex-situ mineralisation	2035	**172-179**
	Removal cost, ex-situ mineralisation	2050	**77-90**
	Removal cost, ERW	2025	**94**
	Removal cost, ERW	2030	**94**
	Removal cost, ERW	2035	**92**
	Removal cost, ERW	2050	**73**
Ramboll estimate based on survey results	Removal cost, ex-situ mineralisation (N = 2)	2030	**250-400**
		2035	**250-350**
	Removal cost, ERW (N = 2)	2030	**200-250**
		2035	**150-200**
Fuss, S., Johnstone, I., Höglund, R., Walsh, N. Chapter 4: The voluntary carbon market in The State of Carbon Dioxide Removal 2024 – 2nd Edition (eds. Smith, S. M. et 4 al.). https://www.stateofcdr.org, doi:10.17605/OSF.IO/MG3CY (2024)	Carbon credit price, mineral products and ERW	2022	**401-435**
	Carbon credit price, ERW	2023	**343**

Source	Type of cost	Year	Amount ($€_{2023}$/ tCO_2)
Supercritical (no date) 'How much do carbon removal credits cost in 2024?' Available at: https://gosupercritical.com/blog?p=how-much-do-carbon-removal-credits-cost-in-2024 (Accessed: 3 March 2025).	Carbon credit price, ERW	2024	**281**
CDR.fyi (2024) Trending on Track? - CDR.fyi 2023 Year in Review. Available at: https://www.cdr.fyi/blog/2023-year-in-review	Carbon credit price, ERW	2022	**401**
	Carbon credit price, ERW	2023	**343 (122-1,458)**
CDR.fyi (2025) Keep Calm and Remove On - CDR.fyi 2024 Year in Review. Available at: https://www.cdr.fyi/blog/2024-year-in-review	Carbon credit price, ERW	2024	**334**

4.3.6. Cost estimates: Ocean-based CDR approaches (Direct Ocean Capture, Ocean Alkalinity Enhancement)

Table 26 - Estimated global removal cost of ocean-based CDR

CDR tech	Current cost of removal ($€_{2023}/tCO_2$)	Estimated cost of removal in 2030 ($€_{2023}/tCO_2$)	Estimated cost of removal in 2035 ($€_{2023}/tCO_2$)
Ocean-based CDR technologies (18)	38-302	No data	No data

Current costs

As mentioned in Chapter 3, Ocean Alkalinity Enhancement (OAE) and Direct Ocean Capture (DOC) are both emerging ocean-based CDR technologies, currently in the early stages of development (TRL 1-3). This indicates that while the fundamental principles are understood, large-scale implementation remains distant. As a result, these technologies are currently still associated with considerable costs, reflecting their current experimental status and the lack of mature infrastructure.

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(18) Estimates on mineralisation and ocean-based CDR costs are highly uncertain due to the early stage of the technology and limited available data on removal costs. The estimate is only provided for ocean alkalinity enhancement, due to lack of data on direct ocean capture.

The cost of CO2 removal for OAE is uncertain, but typically ranges from €38 to €302 per tCO_2, depending on the specific technique and location (Babiker *et al.*, 2023; European Scientific Advisory Board on Climate Change, 2025). This variability reflects the exploratory nature and early state of OAE, with limited large-scale projects and significant unknowns surrounding its environmental impact and regulatory challenges (European Scientific Advisory Board on Climate Change, 2025). However, the carbon credit price associated with OAE is considerably higher, around €1,500/tCO_2 in 2023 (CDR.fyi, 2024; Fuss *et al.*, 2024).

For direct ocean capture, no informed estimate can be provided on current costs. Its carbon credit price currently ranges between €910-1,297/tCO_2 (Fuss *et al.*, 2024), but this is not considered reliable to make an estimate on expected current cost of removal.

Future costs

Future cost estimations for both Direct Ocean Capture and Ocean Alkalinity Enhancement remain highly uncertain due to the early-stage development of these technologies. Both OAE and DOC face significant technical, economic, and scalability challenge. While OAE has a clearer pathway to cost reductions through process optimisation and alternative feedstocks, uncertainties around full-scale implementation persist for both ocean-based approaches. Further research will be critical in determining the feasibility and cost-competitiveness of these technologies in the coming decades.

For Direct Ocean Capture, there is a high risk that the technology will not be cost-competitive in the near future (Rocky Mountain Institute, 2023) (19). The process remains highly capital- and energy-intensive, with key cost drivers including energy demand, material efficiency, and infrastructure requirements, all of which present significant barriers to large-scale cost reductions. While a single survey respondent projects a cost decline to €100 per tCO_2 by 2035, this estimate lacks broader empirical support. Given the low TRL and the limited number of actors currently engaged in DOC development, such cost reductions appear implausible in the short to medium term. Savings through tactical deployment (e.g. linked to existing activities such as coastal power station cooling water systems) could drive some efficiencies in niche circumstances.

In the case of OAE, there is understood to be a medium risk the technology will not be cost-competitive in the near future, but cost reductions appear to be more feasible, especially when MRV and infrastructure costs are not considered

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(19) The Rocky Mountain Institute (2023) made this evidence-based risk-assessment on the likelihood that costs per tCO_2 for a given technology can reduce to the threshold cost of €92/tCO_2. This cost reflects both, capture and storage dimensions.

(Rocky Mountain Institute, 2023). The survey provided no cost estimates for 2035, with only a single respondent projecting a cost of €158 per tCO_2 by 2030.

However, for both ocean alkalinity enhancement and direct ocean capture, future MRV costs might also turn out to be significant. While these costs remain highly uncertain as of now, they may encompass expenses related to extensive in situ monitoring, remote sensing technologies, and advanced modelling to track carbon sequestration and potential environmental impacts. The complexity of oceanic processes necessitates rigorous validation frameworks, which could further elevate costs, particularly for large-scale deployments.

Table 27 - Current and future costs of ocean-based CDR as per literature and the study

Source	Type of cost	Year	Amount (€$_{2023}$/ tCO_2)
CDR.fyi (2025) Keep Calm and Remove On - CDR.fyi 2024 Year in Review. Available at: https://www.cdr.fyi/blog/2024-year-in-review	Carbon credit cost, all marine CDR	2024	**361**
Ocean alkalinity enhancement			
European Scientific Advisory Board on Climate Change (2025). Scaling up carbon dioxide removals - Recommendations for navigating opportunities and risks in the EU	Removal cost, OAE and ocean fertilisation	2024	**38-289 (20)**
McKinsey (2023) Carbon removals: How to scale a new gigaton industry. Available at: https://www.mckinsey.com/capabilities/sustainability/our-insights/carbon-removals-how-to-scale-a-new-gigatonindustry.	Removal cost	2023	**Uncertain**
Babiker, M. et al. (2023) 'Cross-sectoral perspectives', in IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. 1st edn. Cambridge University Press, pp. 295–408. Available at: https://doi.org/10.1017/9781009157926.005.	Removal cost	2022	**46-302**
Ramboll estimate based on survey results		2030	**158 (21)**

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(20) High uncertainty.

(21) Ibid.

Source	**Type of cost**	**Year**	**Amount (€$_{2023}$/ tCO$_2$)**
	Removal cost (N = 1)	2035	**No data**
Fuss, S., Johnstone, I., Höglund, R., Walsh, N. Chapter 4: The voluntary carbon market in The State of Carbon Dioxide Removal 2024 – 2nd Edition (eds. Smith, S. M. et 4 al.). https://www.stateofcdr.org, doi:10.17605/OSF.IO/MG3CY (2024)	Carbon credit price	2023	**1487**
Supercritical (no date) 'How much do carbon removal credits cost in 2024?' Available at: https://gosupercritical.com/blog?p=how-much-do-carbon-removal-credits-cost-in-2024 (Accessed: 3 March 2025).	Carbon credit price	2024	**769**
CDR.fyi (2024) Trending on Track? - CDR.fyi 2023 Year in Review. Available at: https://www.cdr.fyi/blog/2023-year-in-review	Carbon credit price	2023	**1519 (1481-1594)**
Direct ocean capture			
McKinsey (2023) Carbon removals: How to scale a new gigaton industry. Available at: https://www.mckinsey.com/capabilities/sustainability/our-insights/carbon-removals-how-to-scale-a-new-gigatonindustry.	Removal cost	2023	**Uncertain**
Ramboll estimate based on survey results	Removal cost (N = 1)	2030	**150***
		2035	**100***
CDR.fyi (2024) Trending on Track? - CDR.fyi 2023 Year in Review. Available at: https://www.cdr.fyi/blog/2023-year-in-review	Carbon credit price	2022	**1,297 (1156-3468)**
Fuss, S., Johnstone, I., Höglund, R., Walsh, N. Chapter 4: The voluntary carbon market in The State of Carbon Dioxide Removal 2024 – 2nd Edition (eds. Smith, S. M. et 4 al.). https://www.stateofcdr.org, doi:10.17605/OSF.IO/MG3CY (2024)	Carbon credit price	2022	**910**
		2023	**1,297**

4.4. Funding needs

Assessment of funding needs

Further scaling and deployment of CDR in Europe will require additional funding relative to current levels. Despite the growing relevance of the CDR sector in achieving carbon neutrality, detailed and reliable estimates of the funding requirements for CDR remain relatively scarce in existing literature.

Table 28 - Summary on global and EU funding needs for CDR

Source	Funding scope	Years	Value	Unit
Global				
Rocky Mountain Institute (2023)	Investment needs to reach technical viability at scale (including CDR technologies in scope, see also Annex 1)	2023-2038/2043	10-21	Billion EUR
EU				
Carbon Gap (2024)	Investment needs on research, innovation and deployment of CDR (all CDR, not only permanent CDR)	2023-2038/2043	2.9-5.9	Billion EUR
	CDR research, innovation and deployment	2028-2034	2.6	Billion EUR
Ecologic Institute (2025)([22])	EU investment required until 2030 (based on potential EU CDR portfolio scenarios)	2025-2030	2.6-6.1	Billion EUR

The following paragraphs provide detailed information on the estimated funding requirements, incorporating data from external sources as well as calculations conducted within this study.

([22]) McDonald, H., Gardiner, J., Görlach, B., & Tarpey, J. (2025). An EU Purchasing Programme for Permanent Carbon Removals: Assessment of policy options and recommendations for short-term policy design. (Task 2, report 2b). Prepared for the European Commission, DG CLIMA

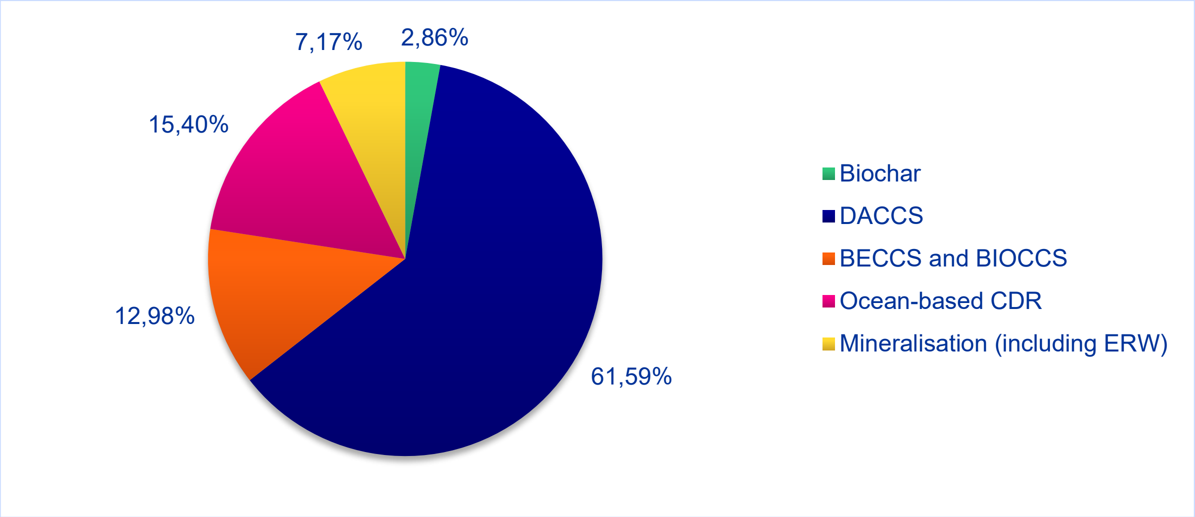
Global estimated funding need

On a global level, the Rocky Mountain Institute (2023) estimates that €10-21 billion are required over the next 15 to 20 years for CDR technologies to reach technical viability at scale and support the IPCC scenarios for net zero in 2050 and beyond (including pre-demonstration and demonstration activities). This estimate only includes CDR in scope of this study.

The composition of these global needs as per the Rocky Mountain Institute (2023), are distributed among different approaches, as illustrated in the figure below and highlights that:

- **Direct Air Carbon Capture and Storage (DACCS) accounts for the largest share (62%) of global investment needs.** This is primarily due to the existence of multiple DACCS pathways, such as absorption with heat regeneration and electrochemical separation, which could be developed at scale. While it is unlikely that all DACCS technologies will reach commercial maturity, the estimated funding required per DACCS pathway at the global level ranges between €0.7 billion and €1.4 billion, reflecting their current TRL.
- **BioCCS together represent 13% of the total investment needs.** However, the funding required per technology—whether for bioenergy or fuel production—is comparable to that of DACCS' pathways. This is plausible, as both DACCS and BioCCS involve high CAPEX, necessitating significant investment for each new facility.
- **Similarly, due to the low TRL of ocean-based CDR, the anticipated funding needs for these approaches (ocean alkalinity enhancement and direct ocean capture) amounts to 15% of global investment need for the considered CDR approaches**. Biochar carbon removal on the other hand, with a TRL between 6 and 9, represents a smaller portion, at 3%. As biochar does not need CO_2 capture installations or geological storage, upfront investment costs are lower, reducing this investment need.

Figure 3 - Global investment need divided by CDR technology (Rocky Mountain Institute, 2023)



In the survey conducted for this study, respondents (N = 103) further underscore these higher investment needs for these CAPEX intensive technologies such as DACCS and BioCCS; whereas biochar carbon removal, mineralisation and ocean-based CDR companies estimate their financing needs in the range of €30-200 million by 2030, DACCS and BioCCS operators indicate they expect total costs in the range of €300-600 million by then. The difference in investment needs partially stems from the lower CAPEX cost for biochar carbon removal and mineralisation and lower technology risks. An important factor in these differences, however, is the scalability and the expected removal capacity connected to this. The substantially higher projected removal capacities by 2030 for DACCS and BioCCS are aligned with higher fundings needs. Ocean-based CDR, however, has only limited expected capacity by then, limiting their required funding needs.

EU estimated funding need

Narrowing their focus to the EU, Carbon Gap (2024) approximate that €2.88-5.85 billion needs to be invested into research, innovation, and deployment of CDR (all CDR, not only permanent CDR in scope of this study). This estimation is based on the global figures from Rocky Mountain Institute and calculated based on GDP shares. Based on this, Carbon Gap advocates for dedicating around €2.6 billion in the next MFF (2028-2034) to CDR research, innovation, and deployment.

As part of this study, required funding is also calculated in Task 2 in terms of expected costs of a purchasing programme, using the cost estimates in section

4.3 and assuming that EU industrial removals(23) reach 5 $MtCO_2$ per year by 2030, as set out in the European Commission Sustainable Carbon Cycles Communication (2021):

- **Total EU investment requirements until 2030 would amount to €2.4-6.7 billion when considering possible scenarios for the composition of removal portfolios at EU level** (McDonald *et al.*, 2025).
    - The cost estimates for these portfolios are based on Table 17 above.
    - The average cost estimates for different portfolios are then used to estimate the total investment required between 2025-2030 to reach the EU's industrial removal target.
    - The lower bound represent a portfolio investing solely in biochar; higher bound of €6.7 billion is associated with a portfolio that invests in removals with medium TRL (4-6) technologies (ERW, DACCS and BECCS).

Type of funding required in the EU

CDR companies can seek funding through a variety of channels, tailored to the technology's TRL, the scale and financial viability of the project. Additionally, the size and bankability of the project influence funding sources, with some projects being able to secure high-risk investors or leverage revenue streams from co-products to obtain project finance. The expected revenue model, such as carbon credit sales or direct product monetisation, and the anticipated timeframe for returns also play crucial roles in determining the most appropriate funding strategy for a CDR company.

Early-stage technologies with low TRLs carry significant technology risks and often rely on grants, venture capital, or philanthropic funding to support research and development. In contrast, more mature technologies with higher TRLs may attract debt financing, equity investments, or partnerships with corporations seeking to meet climate goals. These mechanisms are not specific to CDR technologies. As desired contributions to meet policy objectives, public support is essential to develop a market for CDR, similar to past and ongoing efforts for e.g. renewable energy generation or low-carbon industrial production technologies.

Thus, the de-risking of technological and commercial developments should be a guiding principle for public funding. When considering the type of financial support most useful for CDR projects, the companies responding to the survey rank

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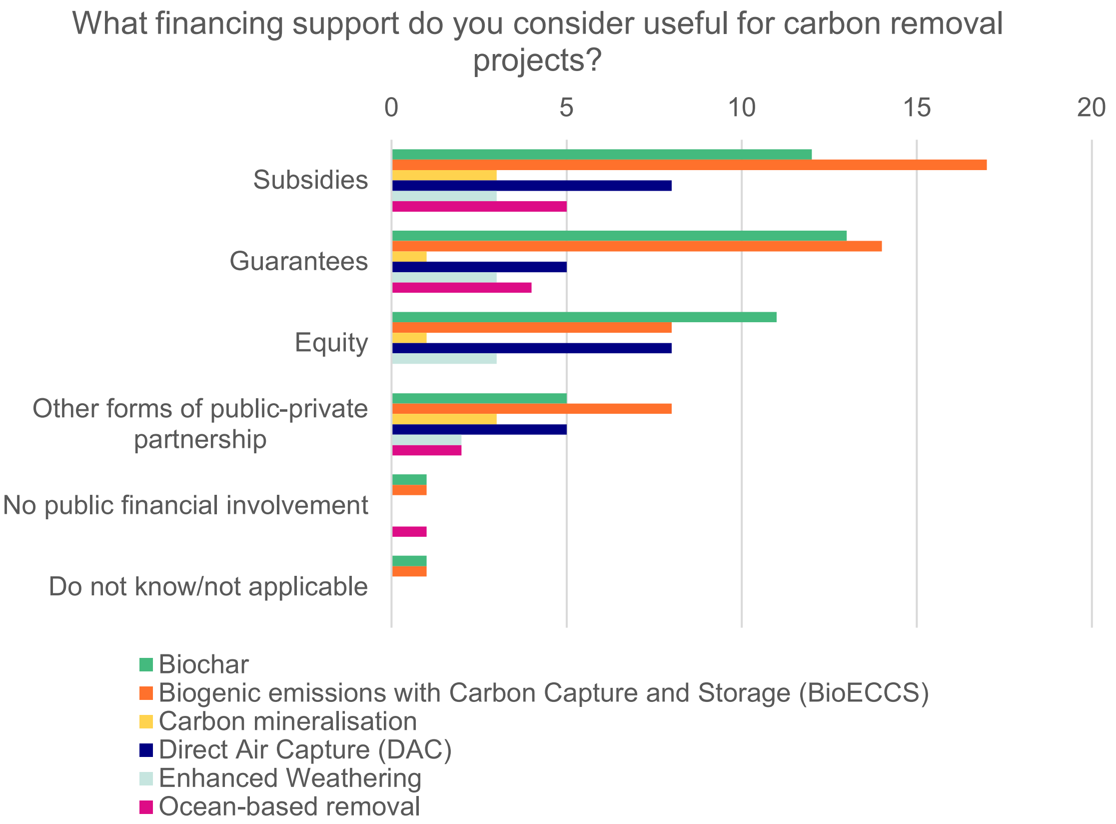
(23) The following permanent CDR technologies were considered for the estimates in Task 2: DACCS, BECCS; Biochar, Enhanced Rock Weathering, Mineralisation.

subsidies and **guarantees** the highest, followed by **equity** and other forms of **public-private partnerships** (see Figure 4). Moreover, there are only minor variations in financial support preferences among different CDR technologies. Notably, very few survey respondents indicated a preference for no public funding involvement, highlighting the strong demand for public financial support across the industry.

Figure 4 - Survey responses on most useful financial support, by CDR technology



In addition, the development of demand for CDR and the creation of a market are effective ways to support the scale-up of CDR technologies. The broad and long-term development of CDR capacities to meet policy objectives and balance residual emissions in a net-zero future relies strongly on a market in which demand for CDR credits and technologies leads to price levels that support the commercial implementation of projects. For this, structures that guide demand, give credibility to high-quality removals, and provide public support through e.g. a CDR credit procurement programme represent key support drivers to mobilise private financing for CDR projects. The EU has put in place legislation that enables the certification of carbon removal credits (CRCF) and is expected to substantially improve transparency and credibility. In addition, the possibility of an EU procurement programme to build public demand as part of a market is explored in a separate report by McDonald et al. (2025). These instruments deserve continuous attention as they will be essential for the long-term viability of CDR capacities and help secure private finance for technologies and projects.

4.5. Funding availability

While report 1.2 provides a detailed analysis of the CDR funding landscape by examining existing EU funding programmes and potential opportunities for further financial support, this section (4.5) focuses on stakeholder perceptions regarding funding availability. This assessment draws on literature to assess funding availability on both the global and EU level, while survey and interview findings offer additional context by providing stakeholder perception from a local, European perspective.

4.5.1. Assessment of available funding volumes

Like the estimates of funding needs provided above, current assessments of funding availability are fragmented and vary significantly in scope and methodology. Discrepancies in data sources, definitions of funding categories, and geographic or technological focus further complicate efforts to compare funding availabilities across the CDR landscape, globally and in Europe. CDR funding volumes identified through literature and compiled as part of this study are summarised in the Table below.

Table 29 - Summary on global and EU funding volumes for CDR

Source	Funding scope	Years	Value	Unit
Global				
The State of Carbon Dioxide Removals	Investments in CDR start-ups (broader than permanent CDR)	2009-2023	3.6	Billion EUR
	Value of CDR research grants (broader than permanent CDR)	2000-2022	2.4	Billion EUR
Oliver Wyman (2024) (consultancy firm)	Total funding allocated for engineered CDR[24]	To date (until 2024)	19.0	Billion EUR
EU				
Carbon Gap	Allocated funding to CDR projects (broader than permanent CDR)[25]	2020-2023	0.7	Billion EUR

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[24] DACCS, BECCS, biochar, enhanced weathering and ocean alkalinity enhancement.

[25] Contribution from EU funding programmes; Horizon Europe, the Innovation Fund, and the European Innovation Council.

Source	Funding scope	Years	Value	Unit
Ramboll assessment provided in report 1.2 as part of this study.	Allocated EU funding for permanent CDR	To date (until March 2025)	0.3	Billion EUR
	Allocated EU funding for CO_2 transport, CO_2 storage solutions, and MRV	To date (until March 2025)	1.9	Billion EUR

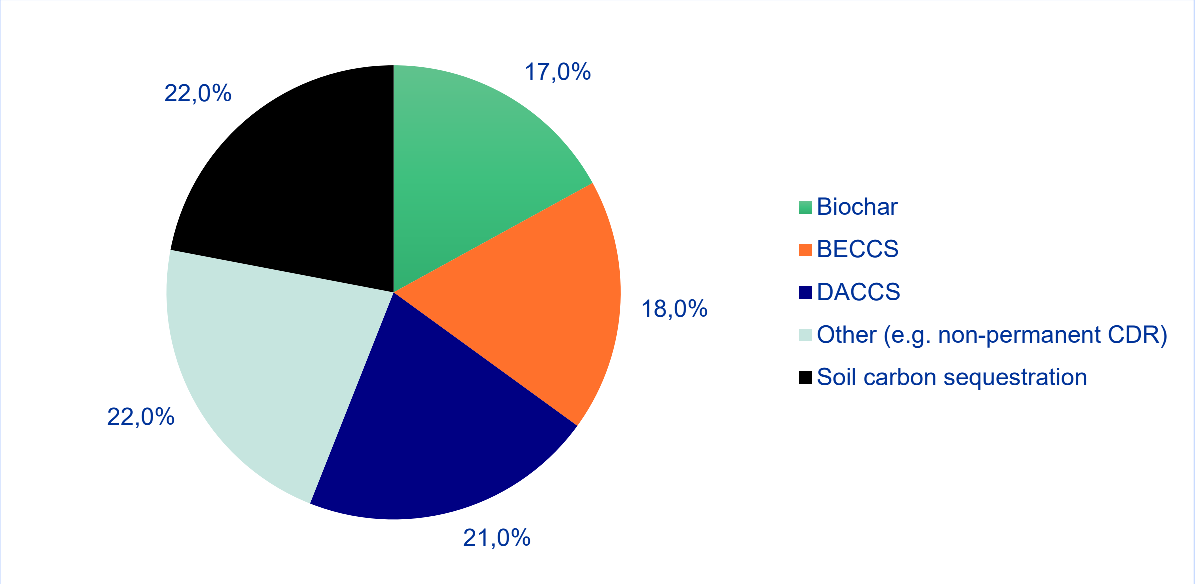
As shown, the current levels of EU funding seem inadequate to meet the investment needs outlined in section 4.4. The following paragraphs provide detailed information on the estimated funding availabilities, incorporating data from external sources as well as calculations conducted within this study.

Global level: Available funding

On the global level the total early-stage investment volumes in CDR startups, from 2009 - 2023, amounts to around €3.6 billion in total (Smith *et al.*, 2024). Of this, around €2.2 billion was raised in 2022 and 2023, showing the rapid increase of CDR investment in recent years. The main funding providers for CDR startups in this period were private, with venture capital (25%), private equity (22%) and corporations (12%), making the largest contributions.

The total estimated value of early-stage R&D support to all CDR (both permanent and non-permanent) was €2.4 billion between 2000-2022 (Smith *et al.*, 2024). In terms of monetary value this R&D support distribution, the CDR method with most funding allocated is soil carbon sequestration (22%), followed DACCS (21%), BECCS (18%) and biochar carbon removal (17%), see Figure 5. Ocean alkalinity enhancement and enhanced rock weathering have received comparatively little early-stage R&D support.

Figure 5 - Global early-stage R&D support (share of total investments) (developed based on (Smith et al., 2024)



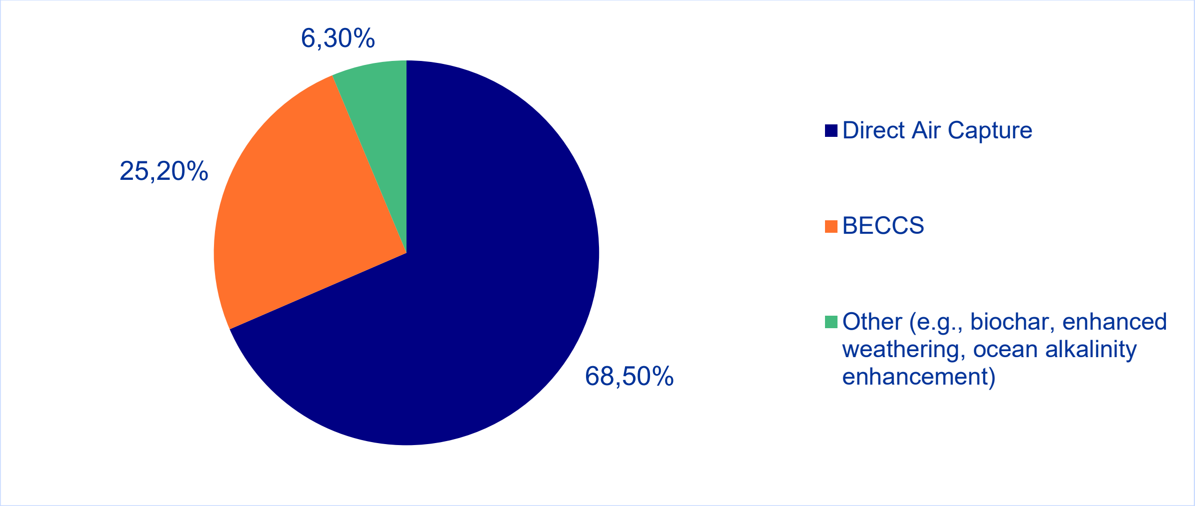
This distribution of early-stage R&D funding likely reflects differences in TRLs, perceived scalability, and number of organisations active in these technologies. While DACCS (21%) has a medium maturity as of now (TRL 4-6), it has attracted substantial funding due to its potential for large-scale deployment through CAPEX reduction, despite its high energy requirements and infrastructure needs. BECCS and biochar also receive significant support, as both leverage biomass-based pathways with existing industrial applications, making them viable for near-term scaling.

In contrast, CDR technologies with lower TRL, such as ocean alkalinity enhancement and enhanced rock weathering, have likely received comparatively little R&D funding as fewer organisations are active in these subsectors and scientific uncertainties on potential pathways remain. These methods are expected to require further research to assess their long-term efficacy, environmental impacts, and scalability before substantial investment is directed towards their development. Potentially, regulatory challenges and limited commercial incentives may also contribute to the slower funding uptake for these approaches.

Focusing on funding beyond R&D, management consultancy firm Oliver Wyman (2024) indicated that CDR projects globally, including both engineered and nature-based removals, have received an estimated total €30 billion in funding to date (until 2024). Of this, €19 billion has targeted engineered CDR, which in this case includes DACCS, BECCS, biochar, enhanced weathering, and ocean alkalinity enhancement, corresponding closely to the technologies covered in this report (i.e., permanent CDR technologies).

Of the funding dedicated to engineered CDR technologies, governments have invested €10.9 billion, compared to private actors who contributed with €8.1 billion (Oliver Wyman, 2024). The majority of the funding has targeted DACCS (€13 billion, 68.5%) and BECCS (€4.8 billion, 25.2%), as also shown in the figure below. Focusing on public funding, DACCS technologies were reported to have received 84.7% of all government spending on engineered CDR (€9.3 billion of the total €10.9 billion in public investment).

Figure 6 - Received capital for engineered solutions (share of total investments), based on work by firm Oliver Wyman (2024)



The distribution of funding beyond R&D suggests a prioritisation of technologies perceived as more scalable and commercially viable in the near term. DACCS has attracted the largest share of investment, particularly from governments, possibly reflecting confidence in its long-term potential for cost reduction and scaling, despite its high energy demand and infrastructure costs. BECCS has also secured substantial funding, potentially due to its integration with bioenergy production and existing industrial applications. Its ability to generate both energy and negative emissions could make it an attractive option for policymakers and investors. For example, in Sweden, the government has earmarked SEK 20 billion (about €1.7 billion) in state aid to support BECCS projects aimed at capturing and storing over 11 million tons of biogenic CO_2 (Swedish Energy Agency, 2025), underscoring growing public-sector commitment to the technology.

Other engineered CDR technologies, such as biochar, enhanced rock weathering, and ocean alkalinity enhancement, have received comparatively less funding. For biochar carbon removal, this might be related to the relative smaller scale of its operational sites, while the attractiveness of investing in enhanced weathering and ocean alkalinity enhancement is likely perceived as lower by both public and private investors due to its low maturity and associated uncertainties. However, recent developments, such as Denmark's substantial state support scheme for biochar (entailing a DKK 10 billion (€1.3 billion) subsidy programme under the Danish biochar strategy (Klima-, Energi- og Forsyningsministeriet, 2024)), indicate growing policy interest.

EU level: Available funding

On EU level, a review of CDR funding conducted by Carbon Gap shows that €0.7 billion of EU funding was allocated to CDR projects between 2020-2023, primarily for purposes of R&D (Carbon Gap, 2024). The EU funding schemes assessed by Carbon Gap were Horizon Europe, the Innovation Fund, the European Innovation Council, and the LIFE programme, and the identified volume represents approximately 0.1% of EU's green transition budget.

Taking a narrow scope and only including funding that has been allocated to permanent CDR projects up until now, EU funding volumes allocated to CDR to date are estimated to €0.3 billion(26). While this amount includes all funding within the current multiannual financial framework (MFF), the majority of funding was allocated from 2020 onwards. For a more detailed breakdown on allocated funding, see section 3.1 of report 1.2 for a detailed breakdown.

For this exercise, it is important to note that the amount of *available* funding can differ significantly from the *allocated* funding volume. For example, DACCS and BECCS projects are eligible under the Innovation Fund application criteria, but in practice only a small share of the total budget is allocated to these CDR technologies.

Of the aforementioned €0.3 billion, €299 million was provided to BECCS and in-situ mineralisation through the Innovation Fund, €24 million to BECCS, DACCS and Ocean-based CDR from Horizon Europe and €4 million to DACCS and biochar carbon removal respectively from the European Innovation Council. Through the LIFE project, no direct allocated funding to permanent CDR was identified (see also report 1.2 section 3.1 for a deeper analysis on these allocated and available funding volumes).

When the scope of CDR funding is widened to include CDR facilitators, such as transport, storage and MRV projects, an additional €1.9 billion from the Innovation Fund and CEF-E can be taken into consideration. When both, directly allocated funding to CDR technologies and CDR facilitators is considered, 90% is provided to projects close to deployment, while 10% is allocated to R&D.

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(26) Includes funding from the Innovation Fund, Horizon Europe, European Innovation Council and the LIFE programme. Funding amounts to Innovation Fund projects invited for grant preparation under the IF23Call have not yet been announced.

4.5.2. Stakeholder perception on availability of funding

Several insights on the qualitative aspects of funding availability can be drawn from the survey data, despite the small number of respondents for certain CDR technologies. The respondents' perception of availability of private and public funding for CDR is shown in Figure 7 and Figure 8, with rating: (1) = very poor, (2) = poor, (3) = neutral, (4) = good, (5) = very good.

General findings on perception of funding availability

The survey findings suggest that when stakeholders are (dis)satisfied with the availability of one of the two funding options, they tend to experience the same with the other funding option. Generally, however, stakeholders appear to be slightly more satisfied with private rather than public funding availability but due to the sample size no conclusions can be drawn from this.

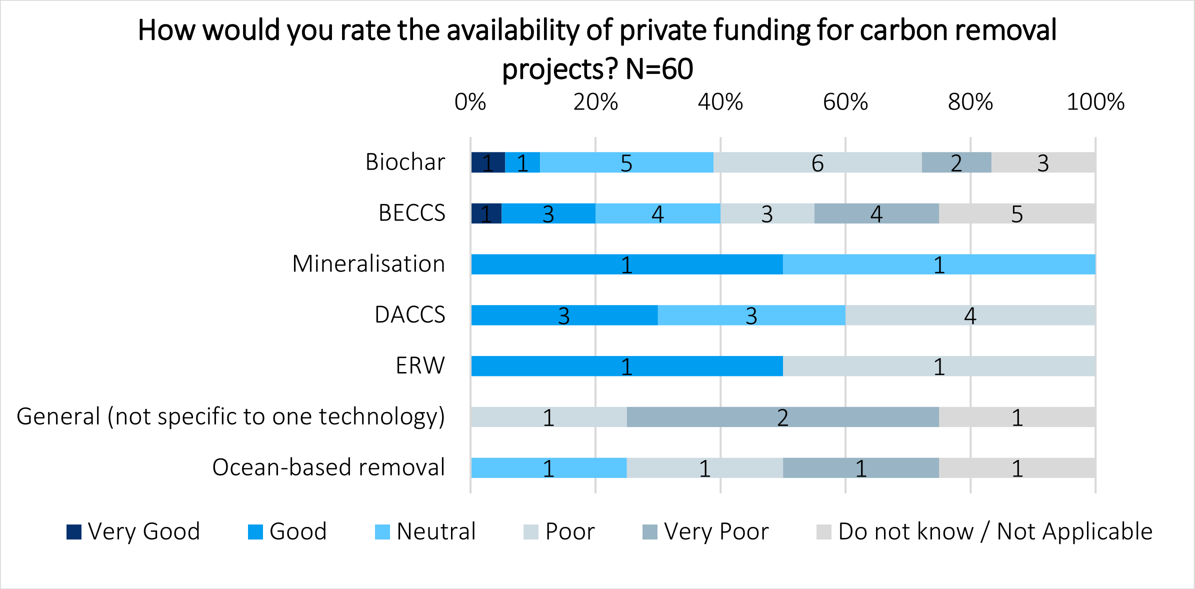
The findings suggest that CDR technologies with medium to high maturity (TRL > 4), such as biochar carbon removal, BECCS, and DACCS, are seen as having more funding available than less mature CDR technologies. This is likely due to their larger potential for scaling up in the short-term, even when high current high CAPEX and OPEX needs. As mineralisation (both in-situ and ex-situ) and ocean-based CDR have relatively low technological maturity, this appears to have a negative effect on the available funding. This is likely also the result of the limited number of actors currently operating within these technologies.

Private funding availability

Specifically on the availability of private funding for CDR, the stakeholder perception varies considerably across technologies, as also shown in the figure below. DACCS operators indicated the most overall positive feedback, with several respondents (3) rating funding availability as "good" suggesting stronger private sector interest, potentially due to its scalability and commercial appeal.

Biochar and BECCS also received one (1) "very good" rating each, but the overall responses were more mixed, with a notable share of neutral or negative ratings. This may indicate that while some private investment exists for these technologies, it remains inconsistent or insufficient for large-scale deployment. Additionally, a significant number of respondents selected "do not know / not applicable," particularly for ocean-based removal, highlighting uncertainty or a lack of awareness regarding private funding opportunities in certain CDR sectors. As such, these findings offer useful insights, they should be interpreted with caution, as the limited sample size and sectoral focus of respondents may not fully capture broader trends in private sector investment.

Figure 7 - Survey responses on availability of private funding for CDR projects



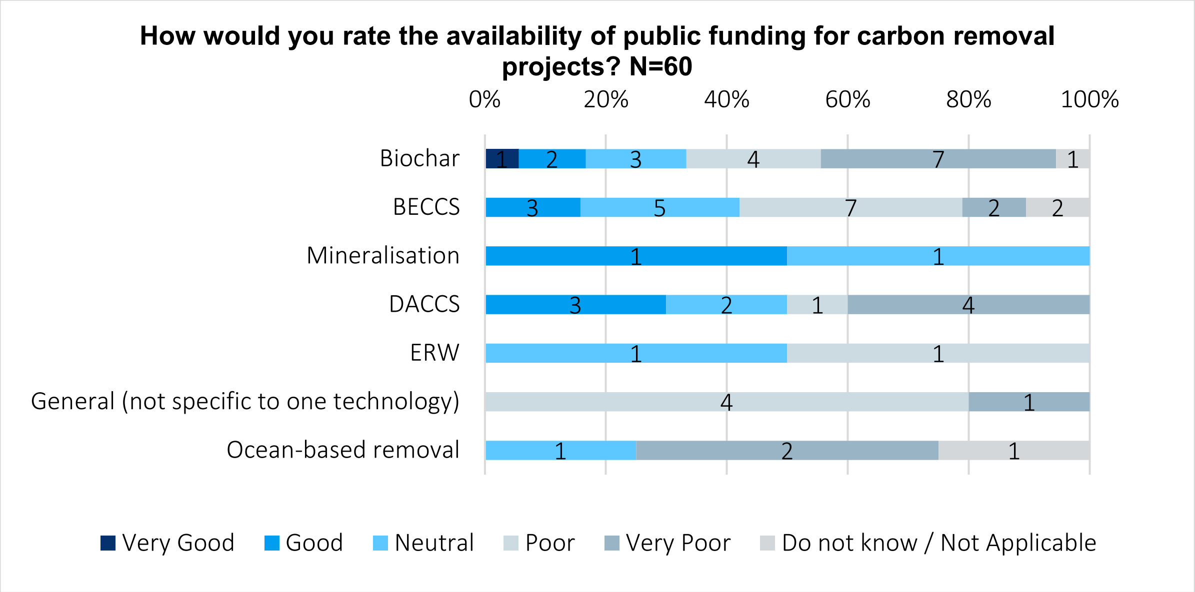
Public funding availability

Compared to private funding perceptions, public funding appears to be viewed ‘very poor’ more often for several technologies, such as DACCS, biochar carbon removal and ocean-based CDR. Specifically, while DACCS was rated relatively well for private funding, its public funding availability received more negative responses (4 respondents indicated very poor availability of public funding, while private funding was rated ‘poor’ as lowest instead). This suggests that stakeholders of these technologies are more dissatisfied with public funding availability compared to private funding availability. The exception is the stakeholder perception among BECCS organisations, which received three (3) ratings of "good" on the perceived availability of public funding.

From this perception analysis it can be inferred that public funding is inadequate for several of the CDR technology, forming a barrier to further scaling, development and deployment. While further explored in report 1.2, this dissatisfaction largely due to limited amount of funding amounts, awareness among stakeholders and calls specifically on CDR.

For mineralisation, enhanced rock weathering, and general CDR funding, limited responses on perceived funding availability make it difficult to draw strong conclusions. The small sample size introduces uncertainty, suggesting that perceptions of public funding for these technologies are either unclear or vary significantly between stakeholders.

Figure 8 - Survey responses on availability of public funding for CDR projects



4.6. Barriers to scaling CDRs

Specific barriers to scaling up, outlined per CDR technology are highlighted in the Table below. These barriers are identified through the analysis of the survey data, desktop research and interviews.

Common barriers across all CDR technologies

The industrial-scale deployment of CDR technologies in the EU faces several significant barriers, including long-term economic feasibility, regulatory clarity, and MRV uncertainty. In the EU, current demand-pull policies remain weak, with limited initiatives in countries' climate strategies to drive substantial demand. Furthermore, while standardisation is ongoing in the EU under the CRCF, the current lack of robust Monitoring, Reporting, and Verification (MRV) protocols undermines market trust and the effectiveness of CDR efforts. Public awareness of novel CDR methods is low, which, coupled with financial bottlenecks and challenges in converting leads to sales, limits growth for startups.

Across all CDR technologies, the identified barriers complicate the securing of financing, hindering scale-up and commercialisation of the technologies. CDR startups often face significant challenges in securing public funding, such as grants, which do not necessitate relinquishing equity, while private funding, including venture capital, is more accessible. The difficulty with public funding lies primarily in the lengthy acquisition process rather than its availability or terms. Additionally, obtaining grants typically requires dedicating a full-time employee to the application process, which can strain the limited financial resources. During this period, the evolving needs and priorities of the startup can complicate the allocation of funds, particularly when they must be utilized as initially proposed (Smith *et al.*, 2024).

Specifically, widespread lack of awareness of CDR technologies among policymakers and finance providers further inhibits investment and widespread adoption. Without a clear understanding of the technologies' potential and impact, decision-making is delayed, and funding remains insufficient, thus slowing the scaling-up of CDR efforts.

Furthermore, despite ongoing efforts under the CRCF to standardise MRV, continued uncertainty surrounding MRV protocols remains a persistent challenge for all CDR technologies. The complexity and technical demands of developing standardised MRV systems add significant risks to the investment and operational feasibility of CDR initiatives. As such, companies face the challenge of navigating a landscape where MRV requirements are not only uncertain but also expected to be difficult and resource-intensive to meet, further hindering large-scale deployment.

Table 30 - Barriers to industry scale-up of CDR technologies in the EU

CDR tech	Technical	Financial	Regulatory	Cultural/social	Other
BioCCS	• Technical challenges with scaling up. • Limited feedstock availability due to increasing demand for biomass and land. • Insufficient infrastructure: Lack of CO_2 transport and storage (T&S) infrastructure, and fragmented global supply chains.	• Lack of reliable investment incentives: No compensation available for biogenic carbon services. • High CAPEX and infrastructure costs, reducing economic feasibility. • Uncertain revenue opportunities (VCM and Compliance regimes). • No reliable financing mechanisms with a long-term perspective. • Limited demand: Lack of sustained demand for high-quality CDR, reducing access to necessary growth finance.	• Lack of coordinated strategy for building and financing CO_2 transport networks. • No back-stop risk models where government intervention is necessary to mitigate financial risks	• Public acceptance challenges for CO_2 transport and storage projects. • Limited support for scaling up carbon removal projects. • Difficulty in building trust and transparency in voluntary carbon markets. •	• Inconsistent carbon accounting: Discrepancy in carbon accounting standards between private and public sectors hampers market clarity. • Risk of exceeding sustainable biomass feedstock availability, if scaling up of biomass sourcing occurs outside of existing agricultural areas. •

CDR tech	Technical	Financial	Regulatory	Cultural/social	Other
Biochar carbon removal	• Uncertainty on MRV requirements, with the expectation that these will be complex. • Limited feedstock availability.	• High production costs and perceived expense by consumers. • Complex funding schemes. • Lack of investment due to uncertain long-term market stability.	• Regulatory uncertainty for long-term CO_2 reduction recognition. • Difficulty obtaining permits for innovative pyrolysis plants.	• Low consumer awareness and acceptance of biochar products. • Misunderstanding of pyrolysis and biochar benefits (e.g., carbon capture potential): Policymakers, investors, and the public have limited understanding of CDR methods, their benefits, and risks, slowing adoption and investment.	• Potential contamination concerns from low-quality or misapplied biochar.

CDR tech	Technical	Financial	Regulatory	Cultural/social	Other
DACCS	• **Low TRL**: Many DACCS companies are still in early stages and not yet proven at scale. • **High energy costs**: Energy-intensive methods like DAC face affordability challenges, especially in regions with high energy prices. • **Insufficient infrastructure**: Lack of CO_2 transport and storage (T&S) infrastructure, and fragmented global supply chains.	• **High CAPEX needs**: Limited access to financing for First-of-a-Kind (FOAK) and Next-of-a-Kind (NOAK) facilities. • **DEVEX funding shortage**: Lack of targeted development expenditure funding to drive projects forward. • **Limited demand**: Lack of sustained demand for high-quality CDR, reducing access to necessary growth finance.	• **Unclear policies**: Absence of clear policy mechanisms and compliance markets to incentivize DACCS at scale. • **Slow permitting**: Delays in obtaining permits for renewable energy and storage projects, particularly in Europe. • **Lack of coordinated strategy** for building and financing CO_2 transport networks.	• **Industry risk aversion**: Early DACCS projects face hesitation from conservative industry players reluctant to take risks on unproven technologies. • **Low awareness and knowledge gaps**: Policymakers, investors, and the public have limited understanding of DACCS, their benefits, and risks, slowing adoption and investment.	• **Political uncertainty**: Lack of long-term policy certainty discourages investments and strategic planning. • **Land limitations**: Insufficient physical space for renewable energy projects, slowing the scale-up process. • **Energy limitations**: Insufficient renewable energy availability for DACCS projects, slowing the scale-up process.

CDR tech	Technical	Financial	Regulatory	Cultural/social	Other
Mineralisation (in-situ, ex-situ), ERW	• **Uncertainty on MRV requirements**, with the expectation that these will be complex. • **Methodological standardisation** of ERW processes.	• **Securing financing**: Limited availability of funding for ERW projects, making large-scale deployment difficult. • **High upfront costs:** Initial capital requirements for mining, processing, and spreading rock materials are significant.	• **Missing regulatory guidance** from EU level. • **Unclear classification** of mineralisation and ERW under carbon removal frameworks	• **Low awareness and knowledge gaps**: Policymakers, investors, and the public have limited understanding of mineralisation, their benefits, and risks, slowing adoption and investment. • **Land use conflicts:** Competing interests for land use (e.g., agriculture, conservation) can hinder large-scale deployment.	• **Logistical challenges:** Transporting and spreading rock materials over large areas requires significant infrastructure.
Ocean-based CDR (Direct Ocean capture, ocean alkalinity enhancement)	• **Uncertainty on MRV requirements**, with the expectation that these will be complex and technically challenging.	• **Finance for First-of-a-Kind Projects**: often lack of clear and reliable funding mechanisms. • **Currently, carbon removal credits cannot be easily monetized or financed**, leaving project developers in a precarious financial position. • **Lack of investment** due to uncertainty and risks due to immaturity of technology.	• **Regulatory clarity**: A lack of clear and consistent regulations around carbon removals (especially for ocean-based methods) impedes development and adoption. • **Exclusion of ocean-based CDR in CRCF methodologies,** creating a regulatory gap.	• **Lack of demand**: The voluntary market for carbon removal credits is insufficiently mature or widespread, leading to a lack of incentives for developers. • **Low awareness and knowledge gaps**: Policymakers, investors, and the public have limited understanding of ocean-based CDR, their benefits, and risks, slowing adoption and investment.	• **Unknown environmental impact**: Some CDR methods, particularly ocean-based ones, may have unknown long-term environmental consequences, adding uncertainty and risk to their deployment.

5. Conclusions

The relevance of permanent CDR technologies cannot be overstated within the spectrum of solutions aimed at addressing EU climate targets, especially when considering the ambitious goal of climate neutrality by mid-century. For this purpose, this report provides an overview of the current state and future supply of CDR in Europe. It evaluates CDR technologies, including their expected removal capacity, costs, and barriers, and maps existing and planned projects to assess the region's capabilities and future needs.

The findings underscore the potential and diversity of permanent CDR technologies, but also highlights pressing challenges in deployment. The TRLs vary widely across CDR technologies, with biochar carbon removal and BioCCS showing relatively high maturity levels, while (ex-situ) mineralisation (including enhanced rock weathering) and ocean-based CDR (direct ocean capture and ocean alkalinity enhancement) still being in early stages of development. Investment requirements and funding availability, too, differ by technology and stage of deployment.

The lack of a broad, robust demand for CDR and coherent policy mechanisms, combined with industry risk aversion towards emergent technologies, further hinders industry scale-up. While public and private funding flows into the CDR domain have picked up pace in recent years, especially for technologies such as DACCS and BECCS, financing for the development and scale-up of these technologies remains a key barrier. This is underscored by stakeholder perception analysis conducted through the survey analysis on the perceived availability of both, public and private funds across and within CDR technologies.

Potential CDR capacity by 2030 and 2035

According to the mapping review, Europe’s landscape is home to 176 CDR organisations (e.g., project developers, technology providers) and 150 projects. While some CDR technologies are distributed more evenly across the continent (e.g., biochar), others are only found in specific countries (e.g. DACCS activities are largely based in Iceland, while technology providers are often from Germany).

Based on the project mapping and literature review, current European CDR supply is estimated to be between 0-0.6 $MtCO_2$/year, with an estimated future supply of around 7 $MtCO_2$/year by 2030 and between 22-37 $MtCO_2$/year by 2035. These estimates are provided under the assumption that CDR is able to scale up substantially in the coming years. By 2035, BECCS, DACCS, and biochar are anticipated to contribute the largest annual removal capacity in Europe, with BECCS accounting for more than half of all European removals by 2035.

Despite the strong projected growth in European CDR supply between today and 2035, permanent removal capacity would need to increase by a factor of three to four by 2050 to align with the levels identified in the European Commission's impact assessment for the EU's 2040 climate target (2024). This highlights the scale of effort required to meet long-term climate objectives and the critical role of sustained investment and policy support for permanent carbon removal solutions.

Expected costs by 2030 and 2035

Projections based on literature and cost data analysis suggest that optimisation and scaling-up will lead to reductions with a converging trend towards 2030 and 2035. For most technologies, costs are expected to go down as they mature, and operations scale up. Especially the removal cost of DACCS is expected to decrease substantially, from €462-1,256/tCO_2 to €201-402/tCO_2 by 2035.

However, these estimates remain uncertain, as several factors (change in biomass feedstock, energy prices, technological breakthroughs etc.) are bound to have effect on cost reductions. Additionally, the amount of data available on both current and future costs was limited, only adding to the uncertainty of the estimated future removal costs of these CDR technologies. As such, the cost estimates provided as part of this study should be treated with caution.

Financing needs

CDR requires a large amount of financing, with both private and public funding needing to increase significantly to support its growth and development. To date, both private and public sources have contributed to funding, with government investments being particularly significant for engineered CDR technologies such as DACCS and BECCS. However, there remains a disparity in funding availability, with the more mature technologies generally seeing more significant investment compared to less mature ones (TRL < 4), like ocean-based CDR technologies.

Barriers to scale up

Common barriers across (most) CDR technologies include high initial investment needs (CAPEX), regulatory uncertainties, and the uncertainty over what may be anticipated to be complex Monitoring, Reporting, and

Verification (MRV) requirements (e.g. under CRCF). Even though CRCF aims to provide certainty by streamlining and harmonising MRV requirements, today uncertainty remains. Due to the limited demand and supporting policy mechanisms, together with the risk-aversive industry approach, these barriers hinder further industry scale-up.

Furthermore, each technology faces OPEX related challenges; for instance, DACCS projects suffer from high energy demands, biochar and BioCCS are constrained by feedstock availability, while (ex-situ) mineralisation (and enhanced rock weathering) face logistical challenges and a gap in public awareness. CDR also faces challenges to attract finance relative to emission reduction measures within existing regulated activities and operations (e.g. under the EU ETS).

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Appendix 1. Collected data and supporting analysis

See separate excel file for Appendix 1

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