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Exploring Support Alternatives Within the European Union Policy Framework for Technological Carbon Dioxide Removal and Biogenic Carbon Sequestration: A Present-Day Assessment

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ABSTRACT
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This thesis studies the landscape of carbon dioxide removal and sequestration (CDRS) support methods within the European Union (EU) with a primary focus on their efficacy in achieving net negative emissions.

The inadequacy of past and current climate action has led to a current situation where the withdrawal of carbon dioxide from the atmosphere is also needed, in addition to emission reductions that remain the primary mitigation tool. The EU too has begun the development of the governance and the tools to incentivise the deployment of CDRS, necessitating a comprehensive analysis of the different support mechanisms, also by the stakeholders, including environmental organisations.

This study uses document analysis as the research methodology, combining a systematic review of the EU’s current CDRS-related policies, the prominent CDRS methods, and support tools. The study identifies key policy instruments, financial incentives, and regulatory frameworks that underpin the EU’s CDRS initiatives. Additionally, it explores the socio-economic and environmental implications of these support systems, considering also the potential benefits and challenges.

Findings indicate that none of the EU's current policy instruments are well suited to efficiently scale up CDRS in a way that would deliver a net benefit. The study discusses the shortcomings of compensation-based support methods and the benefits of activity-based finance for all methods relying on biogenic sequestration.

The implications of this research extend beyond academic discourse, offering current insights for policymakers, environmental advocates, and stakeholders involved in shaping the future of carbon management in the EU. By providing an understanding of CDRS support systems, this thesis contributes to the ongoing discourse on sustainable climate action and the transition towards the EU’s goal of becoming climate-neutral by 2050 and achieving net-negative emissions thereafter.

Keywords: climate change, European Union, climate policy, carbon dioxide removal and sequestration, financing, negative emissions, EU, CDR, CDRS.

CONTENTS

ABBREVIATIONS AND TERMS

AR6	6th Assessment Report
BECCS	Bio-Energy with Carbon Capture and Storage
CCS	Carbon Capture and Storage
DAC	Direct Air Capture
DACS	Direct Air Capture and Storage
CDR	Carbon Dioxide Removal
CDRS	Carbon Dioxide Removal and Sequestration
CO_2	Carbon Dioxide
CRCF	EU Carbon Removal Certification Framework
Eq	Equivalent
ETS	Emissions Trading System
EU	European Union
GT	Gigatonne, billion tonne
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land Use, Land Use Change and Forestry
MRV	Monitoring, Reporting and Verifying
MS	Member State
Mt	Million tonnes
SPM	Summary for Policymakers
SR	Special Report
TLR	Technology Readiness Level
VCM	Voluntary Carbon Market
WG	Working Group

1 INTRODUCTION

1.1 Background of the topic

Halting dangerous climate change requires immediate and deep cuts in global greenhouse gas emissions during this and the coming decades as the primary method for combating climate change. In addition to emissions reductions, to meet the Paris Agreement's temperature goal of limiting global average temperature increase to 1.5° Celsius and the European Union's climate neutrality targets, the withdrawal of carbon dioxide from the atmosphere is also needed in addition to emission reductions. (IPCC AR6, WGIII SPM 2022, 36), (Regulation 2021/1119/EU)

Carbon dioxide removal and biogenic carbon sequestration (CDRS) refer to the processes that remove carbon dioxide from the atmosphere to mitigate the effects of climate change. These methods and systems include a wide range of approaches, such as afforestation and reforestation, direct air capture, ocean fertilisation, and enhanced weathering. CDRS methods vary greatly and have different trade-offs, for example regarding their permanence, costs, negative side effects, and co-befits. All removal and sequestration methods are also limited by their technical, economic, social, and environmental constraints. CDRS may be used in combination with emission reduction strategies to support mitigation, to achieve a balance of emissions and removals (a net-zero target), or to draw down historic legacy emissions from the atmosphere. It is generally acknowledged that carbon dioxide removal and sequestration cannot substitute for reducing greenhouse gas emissions, but they must be employed as an additional measure to mitigation. The International Energy Agency states in its 2023 update of its "Net Zero Roadmap" - report that "*Removing carbon from the atmosphere is costly and uncertain. We must do everything possible to stop putting it there in the first place*". (IPCC AR6, WGI SPM 2021, 10), (Rogelj et al. 2019), (Prütz et al. 2023), (International Energy Agency 2023)

The necessity to remove atmospheric carbon dioxide at scale has been part of the academic debate on climate mitigation for more than a decade, particularly since the adoption of the Paris Agreement which includes the goal of balancing anthropogenic emissions by sources and removals in the second half of this century. In 2018 the Intergovernmental Panel on Climate Change (IPCC) adopted its Special Report on Global Warming of 1.5°C and identified carbon dioxide removal as necessary for all pathways that allow for global surface temperature to rise a maximum of 1.5°C compared to the pre-industrial era. The IPCC in its 6th Assessment report in 2022 identified three distinct roles for CDRS: 1) complementing emission reductions in the near term, 2) neutralising hard-to-abate residual emissions to achieve net-zero CO_2 or greenhouse gas emissions balance, and 3) delivering net negative emissions in the long term. (Paris Agreement 2015, Article 4), (IPCC SR1.5 2918, 14), (IPCC 2018, 14), (IPCC AR6 WGIII 2022)

Although CDRS plays a significant role in the most commonly discussed climate mitigation scenarios until very recently its role has been minimal in the European Union’s (the EU) climate policy deliberations. The European Climate Law provides for the EU to become climate-neutral by 2050 and to achieve net-negative emissions thereafter. Adopting these targets implies that the scale of CDRS the EU intends to employ will be larger than only to counterbalancing of residual emissions. To date the EU climate policy does not include a comprehensive CDRS governance framework nor does it entail significant tools to incentivise its uptake. (EU Regulation 2021/1119), (Tamme & Beck 2021), (Meyer-Ohlendorf 2022)

1.2 Structure and scope of the thesis

To introduce the topic more in-depth the thesis begins by looking into the definition of carbon dioxide removal and sequestration. Chapter 3 also examines the scale of necessary CDRS deployment globally and in the EU in light of physical climate science. This is done by examining the IPCC’s carbon budgets and mitigation scenarios, as well as European Union legislation, initiatives, and analysis.

The following Chapter 4 describes the current state of the EU's CDRS policy, particularly looking into the existing CDRS-relevant legislation as well as the most important current ongoing initiatives. The EU's CDRS policy is currently in an extremely fast-moving phase; carbon removal certification legislation is being debated by the legislators, the European Commission is formulating its 2031-2040 climate targets and governance proposals, the EU Expert Group on Carbon Removals is developing the modalities and the quality criteria of different removal methods, and stakeholders and think tanks are producing reports and proposals on CDRS governance. (European Commission 2022/0394)

Chapter 5 examines six different carbon removal methods and their specific features related to permanence, economic costs, cost structure, accuracy of measuring, harms and risks, and co-benefits. These methods are chosen because of their frequent appearances in the current EU policy discourse as well as the aim to present the wide discrepancy between different CDRS types. The chosen methods are Direct Air Capture and Storage (DAC or DACS), Bioenergy with Carbon Capture and Storage (BECCS), biochar, nature restoration and reforestation, soil carbon enhancement, and peatland rewetting.

Chapter 6 examines different support alternatives within the EU's policy framework for CDRS. These tools include a variety of methods, public and private, voluntary and compliance methods as well as direct support. This is not intended to be a comprehensive overview of all possible support options, but rather an examination of the support tools that either already exist or are being debated and proposed, and exploring the possible advantages and shortcomings of these different methods.

Finally, chapter 7 provides an overview and comparison of CDRS methods and the support and financing tools available or discussed in the EU at the moment. In addition to aiming to answer which CDRS support options allow achieving a net negative emissions balance, several other features are also examined, such as the sources and the type of finance available.

1.3 Purpose, goals, and constraints of the thesis

The purpose of this study is to explore options for supporting different types of carbon removal approaches, and in particular to find alternatives for financing CDRS through emissions compensation that is currently the method most used and discussed, but does not lead to a net negative emissions balance.

CDRS methods' quality criteria are critical in any discussion when aiming to identify which methods can and should be supported. Assessment of different CDRS methods' features is therefore also included in this study.

More concretely this research aims to help the European civil society that engages in the EU CDRS policy-making processes to consider the different support alternatives and their suitability for different types of carbon removal and sequestration approaches.

At the time of writing the European Union's CDRS governance deliberations are in a particularly rapidly moving phase, which sets an important constrain for the longevity of relevance of this study.

2 METHODOLOGY AND RESEARCH QUESTIONS

2.1 Document analysis as the chosen research methodology

The chosen methodology for this master's thesis is document analysis primarily as it allows placing this research within the past and current context of EU climate politics and climate policy development, and it allows the author to utilise her past and current knowledge and experience in working with EU climate policy as well as with the EU's CDRS policy development.

The applied method is a qualitative research method for a systemic review or evaluation of documents. In this analysis method data is examined and interpreted to extract information, meaning, and insights, to gain understanding, and to develop empirical knowledge. Furthermore, in the context of this master's thesis, the chosen method offers the possibility to examine several relevant past and current documents, related to climate science, EU climate policy, and other CDRS initiatives. This method also permits the extraction of nuanced insights and the identification of underlying motivations. The author's familiarity with the subject matter and EU climate policy, in general, aids the author in utilising context to discover substantive meaning. (Bowen 2009), (Roller 2019)

In document analysis, the concept of researcher-as-instrument refers to the researcher as an active participant in the research process, from the design of the research questions, through the document selection, to the presentation. The researcher-as-instrument feature is an intentional part of the chosen research method in this thesis, but when a researcher is considered to be an active respondent in the research process, a risk for bias must be considered and mitigated. The potential for bias may appear for example in pre-existing assumptions or document selection. The author works in a non-governmental environmental advocacy organisation that aims to play a role in the development of the EU's CDRS policy. When conducting this work the risk for bias is mitigated and minimised by awareness, self-reflection, and transparency, and very concretely by referencing, where available, the most authoritative sources such as the reports of the Intergovernmental Panel on Climate Change (the IPCC) and original European Union legislative documents and other documents by the EU institutions. (Pezalla et al 2012), (Hammersley & Atkinson 1995)

2.2 Research questions

The study aims to explore different support alternatives within the EU policy framework that not only support sustainable carbon dioxide removal and sequestration initiatives but also ensure that the removals achieved are in addition to, and not as a substitution for emission reductions.

The overarching research question can be summarised as follows:

> *What are the most viable and effective support mechanisms that can support different types of sustainable carbon dioxide removal and sequestration (CDRS) methods within the EU policy framework, ensuring their additional contribution to emission reduction strategies and resulting in a net negative carbon balance?*

It encompasses four more specific questions:

1. *Which ones of the EU's current climate policy instruments are relevant for policies on governing or incentivising carbon dioxide removal and biogenic sequestration by ecosystems?*

To be able to identify how CRDS can be financed it is necessary to understand where CDRS sits in the EU's current climate policy toolbox.

2. *How the CDRS methods that are currently most prominent in EU policy debates differ from one another on seven key aspects.*

CDRS methods vary greatly and have different trade-offs, for example regarding their permanence, costs, risks, and negative side effects and co-befits.

Understanding these features is necessary to be able to assess which methods can or should be financed, and which finance tools they are suited for.

3. *What are the characteristics of different CDRS support alternatives currently discussed or proposed for financing CDRS in the EU?*

This question explores how the support source or mechanism in question operates, how and what it supports, the scale of possible finance, if the funding comes from a public or private source, and whether is it a short or long-term source. Understanding these features is necessary to be able to assess its suitability for CDRS.

4. *Is it possible to identify and potentially match a CDRS method with a suitable support method that would result in a net negative emissions balance, without risks, and with positive co-benefits?*

The question seeks to determine how to ensure that the carbon removal and sequestration efforts have a positive contribution to climate, the environment, and society as a whole.

Through addressing these questions, this study aims to provide insights into effective ways of supporting and financing carbon dioxide removal and sequestration initiatives that can contribute to the larger goal of mitigating climate change and its impacts.

2.3 Methodology breakdown into descriptive and analytical phases

The thesis is constructed into descriptive and analytical parts. The thesis begins by defining carbon dioxide removal and sequestration (CDRS) in the introduction and further on explores the likely future scale of needed CDRS deployment globally and in the EU in Chapter 3. The following chapters, 4-6, form the descriptive part of the thesis. Chapter 4 provides an overview of the current state of the EU's CDRS policy. In Chapter 5, the descriptive phase transitions into analysis by examining six CDRS methods, considering features such as permanence, economic costs, and co-benefits. Chapter 6 describes support alternatives within the EU's policy framework for CDRS, exploring the existing instruments and ongoing initiatives.

The final chapter, Chapter 7, offers an analytical overview and comparison of CDRS methods, support tools, and financing options within the EU. It not only analyses achieving a net negative emissions balance but also considers additional features like sources and types of finance.

3 CARBON DIOXIDE REMOVAL AND BIOGENIC CARBON SEQUESTRATION

3.1 Definition of carbon dioxide removal and sequestration (CDRS)

The Intergovernmental Panel on Climate Change (IPCC), in its Special Report on 1.5°C, defines carbon dioxide removal (CDR) as:

> *Anthropogenic* activities removing CO_2 from the *atmosphere* and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage, but excludes natural CO_2 *uptake* not directly caused by human activities. (IPCC 2018, Glossary)

The IPCC definition while not fully comprehensive includes the most important basic requirements of carbon dioxide removal. The word '*anthropogenic'* requires that the removal that takes place needs to be human-induced. While this excludes most carbon removal in our natural biogenic carbon cycle that takes place in soils, vegetation, and oceans it nevertheless leaves much room to be debated of what is human-induced when it comes to managed land or ocean. Good examples of stretching the anthropogenic definition are for example the compensation projects that claim removal units from avoided deforestation. The IPCC definition also states that to qualify as carbon dioxide removal carbon needs to be removed from the '*atmosphere'*. This excludes carbon capture and storage from the burning of fossil fuels. When it comes to the longevity of the storage of captured carbon the IPCC's choice of the term '*durable*' also leaves room for interpretation. The definition does not answer how to consider products that release the captured carbon back into the atmosphere.

When designing governance policies or support schemes for carbon removal, the above definition must be further elaborated to be implementable in a manner that results in desired outcomes. A more concrete definition including principles for carbon dioxide removal can be elaborated based on the work by Tanzer and Ramirez. This implies designating processes as able to deliver carbon removals based on four principles:

1. Carbon dioxide is physically removed from the atmosphere.
2. Upstream and downstream greenhouse gases that are associated with the removal and storage process are accounted for through a broad and comprehensive life cycle assessment.
3. Removed carbon is stored in a manner intended to be permanent.
4. The total quantity of greenhouse gases removed and permanently stored is greater than the emissions associated with the process.

Including the associated emissions into the end balance is important to be able to assess the quantified net benefit of the removal activity. The European Commission has also included a net benefit quantification formula in its proposal for the EU carbon removal certification framework. Tanzer and Ramirez have chosen to use the word ‘permanent’ when discussing the timescales necessary for the removed carbon to qualify as carbon removal.

At the time of writing the definition of permanence is being debated also in the context of EU policy governance and support. As emitted carbon dioxide stays in the atmosphere on average for up to 1000 years, this has been proposed as a straightforward definition of ‘permanence’ in the context of CDR. While 1000 can be considered logical given the relation to the longevity of CO_2 in the atmosphere, it has been criticised for excluding time frames that are also relevant in the short to medium term, as well as excluding practically all nature-based sequestration. (Tanzer & Ramirez 2019), (European Commission 2022/0394), (Meyer-Ohlendorf 2023), (Prado & Mac Dowell 2023)

This research explores methods that are able to produce permanent carbon removals that can be stored for thousands of years, but also the nature-based sequestration methods where storage times may be very short. This distinction is one of the most critical differences between the different methods. Currently permanent and temporary removals are both dealt with together, but also sometimes separately in the EU’s current policy debate. In this research when referring to the wide scale of different methods, from permanent to very temporary, all aimed at the withdrawal of CO_2 from the atmosphere the chosen term aimed at encompassing the full range of methods is carbon dioxide removal and sequestration (CDRS).

3.2 Scale of future carbon dioxide removal and sequestration needs

Future carbon dioxide removal and sequestration deployment needs are largely dependent on how deep and rapid global decarbonisation will be in the near term, and when net-zero greenhouse gas emissions balance will be achieved. There are also important scientific uncertainties on how climate and ecosystems react to the crossing of climate tipping points, such as the collapse of the Arctic winter sea ice or die-off of low latitude coral reefs, nor to so-called ‘overshoot and return scenarios’, where for example the Paris Agreement’s target of 1.5°C is exceeded, and the global average temperature is hoped to be brought back down with net-negative emissions. (Armstrong McKay D. et al. 2022), (Climate Analytics 2021)

Despite these large future uncertainties, science on global carbon budgets, accumulating emissions and global mitigation pathways and scenarios can help in estimating at least the minimum requirements for CDRS.

3.2.1 Global carbon budget and mitigation scenarios

Carbon dioxide (CO_2) accumulates in the atmosphere, and the level of the accumulated emissions defines the level of warming. The global carbon budget is an estimate of the total amount of CO_2 that can be emitted into the atmosphere while limiting global warming to a certain level, such as the 1.5°C target in the Paris Agreement. (IPCC SR 1.5 2018)

The IPCC’s 6th Assessment Report (AR6) confirms that the increase in global mean temperature has a near-linear relationship with cumulative CO_2 emissions and that net zero CO_2 emissions are required to halt CO_2-induced warming. This allows the estimation of carbon budgets consistent with specific temperature goals. (IPCC AR6 WGIII 2022, Chapter 3, Box 3.4) (IPCC AR6 WGI 2021, Chapter 5, Section 5.5, Box 5.3)

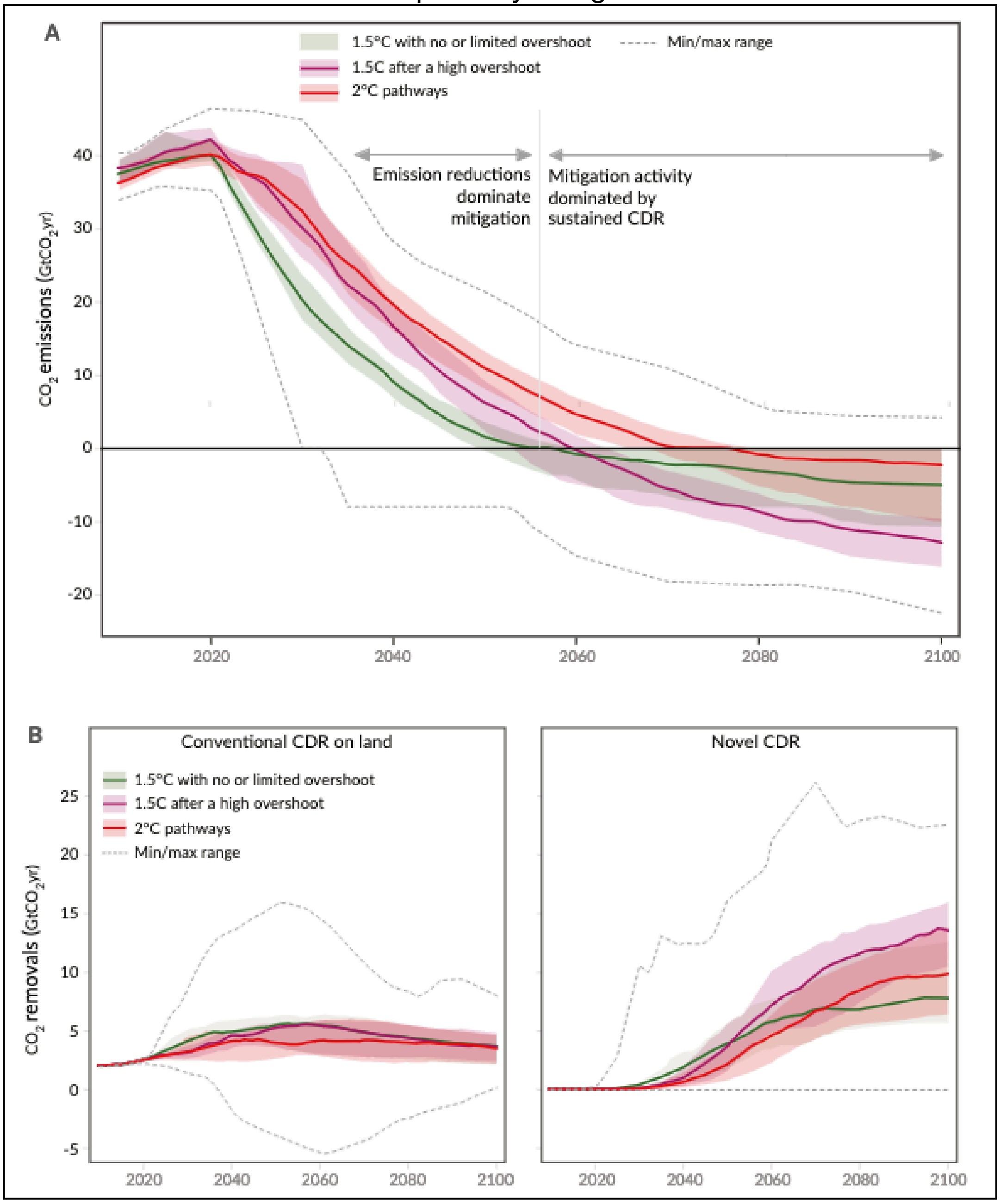
The IPCC also provides estimates of the remaining carbon budget for different levels of warming, with different likelihoods. These budgets are determined by a range of factors, including the amount of carbon stored in natural systems such as forests and oceans, the rate of carbon uptake by these systems, and the cumulative amount of carbon dioxide that has already been emitted into the atmosphere. The IPCC's AR6 Working Group (WG) I assessed the remaining carbon budget from the beginning of 2020 onwards to be 650/500/400 $GtCO_2$ for limiting warming to 1.5°C with a 33%/50%/ 67% likelihood. Since the IPCC AR6 WGI assessment with data up to 2019, the remaining carbon budget has shrunk during years 2020-2022 by 121$GtCO_2$, to 530/380/280 $GTCO_2$ for likelihoods of 33%/50%/ 67% respectively. Furthermore, these estimates of the remaining carbon budget require that non-CO_2 emissions are reduced consistently with the temperature targets for which the budgets are estimated. (IPCC AR6 WGIII 2022, Chapter 3, Box 3.4), (Friedlingstein et al. 2022)

Carbon dioxide removal, including sequestration, has been identified as a necessity, in addition to deep and sustained emissions reductions, in pathways that are compatible with the 1.5 °C climate target. The amount of CDRS deployment during this century varies considerably across the pathways presented in IPCC's Sixth Assessment Report (AR6) that limit warming to 1.5 °C or exceed and return to 1.5 °C in 2100. The assessment on the IPCC AR6 emission pathways conducted in the 2022 report "The State of Carbon Dioxide Removal" concludes that the cumulative amount of CDRS over the 21st century for 1.5°C compatible pathways with no or limited overshoot ranges between 420$GtCO_2$ and 1100 $GtCO_2$, with a median value of 740$GtCO_2$. For higher overshoot of temperature scenarios the cumulative amount needed increases on average by 110$GtCO_2$. (Prütz et al. 2023), (Rogelj et al. 2019) (Smith et al. 2022)

The State of the Carbon Dioxide Removal Report estimates that the current total global CDRS deployment is approximately 2.0 $GtCO_2$ per year, of which

99,9% is conventional sequestration on land, and only a tiny fraction is achieved via novel removal methods. As visualised in Figure 1 (A) below the IPCC AR6 scenarios assume emission reductions dominate mitigation during the first half of this century, with CDRS taking over after 2050. Figure 1 (B) visualises the different development paths for conventional land sequestration removal and novel removal methods, with the former peaking at mid-century and the latter increasing to an annual 5-10GtCO_2 in 2100.

FIGURE 1. Figures from The State of Carbon Dioxide Removal 2022 (page 79). Part (A) visualises the global net carbon dioxide emissions in scenarios assessed in the IPCC's Sixth Assessment Report and part (B) the upscaling of CDRS methods under different pathway categories.



3.2.2 Scale of the foreseen CDRS deployment in the European Union

Excluding the Union's legal commitment to climate neutrality by 2050 and the achievement of a net-negative emission balance thereafter that have both been enshrined in the European Climate Law, the overall long-term scale of CDR deployment in the European Union has not been clearly defined. The European Commission's proposal for a Regulation establishing a Union certification framework for carbon removals outlines that "*both natural ecosystems and industrial activities should contribute to removing several hundred million tonnes of CO_2 per year from the atmosphere.*" European Commission's in-depth analysis supporting the "A Clean Planet for All Communication" from 2018 discusses different scenarios that achieve a net zero greenhouse gas balance by 2050. 1.5TECH, 1.5LIFE and 1.5LIFE-LB project a Land Use, Land Use Change and Forestry (LULUCF) sink between -317 and - 472 Mt CO_2eq and carbon captured from biomass and from direct air capture to be between 606 and 385 Mt CO_2eq in 2050. The European Commission's in-depth analysis envisages that approximately half of the captured atmospheric carbon by industrial removal would be stored permanently in geological storage, and the other half would be used for synthetic e-fuels and products. (Regulation 2021/1119/EU), (European Commission 2018, 198, Table 9)

There is more clarity for the near-term 2030 perspective. The revised LULUCF Regulation sets a Union net sink target of -310 Mt of CO_2 eq in 2030 and the European Commission Communication on Sustainable Carbon Cycles outlines that "*5Mt of CO_2 should be annually removed from the atmosphere and permanently stored through frontrunner projects by 2030*" by industrial carbon removals methods. (Regulation 2021/1119/EU), (Regulation 2023/839/EU), (European Commission EU/2021/800)

3.2.3 Ethical considerations related to CDRS use

Ethical concerns associated with CDRS use are numerous, from the theoretical concept to the concerns on the enormous land, water, resource, and energy use and other negative side-effects, to early reversals and the possible eventual failure to reduce overall life-cycle emissions. These are called mitigation deterrence or moral hazard. (McLaren 2020), (Carton et al. 2023)

A primary ethical consideration that is also widely acknowledged is that the reliance on the potential future deployment of CDRS could lead to complacency in reducing greenhouse gas emissions in the near term. This happens when planned or needed emission reductions are substituted with actual or future CDRS, raising the ethical question about the potential for CDRS to undermine essential efforts to address the root causes of climate change. In addition to substitution, mitigation deterrence can happen also with inaccurate accounting of life-cycle emissions, unintended releases of stored carbon, and carbon leakage i.e. increase of emissions elsewhere. Identified solutions to address this moral hazard include setting separate binding targets with specific and dedicated policy tools for emission reductions and carbon removals and sequestration, prohibiting compensation or offsetting, regulating related consumer claims, legislating comprehensive quality criteria for CDRS, and supporting policies that drive rapid decarbonisation. (McLaren 2020), (Höglund et al. 2023)

A second important category of ethical considerations relates to the enormous use of resources, such as land, water, and energy, by some of the CDRS methods. These resources will likely compete with other essential resources and land uses, such as biodiversity or food production. An example can be found in the Land Gap Report 2022 which looked into countries' current climate pledges under the Paris Agreement. The report concluded that the total area of land needed to meet projected biological carbon removal included in the pledges is almost 1.2 billion hectares, which is equivalent to current global cropland. Balancing resource allocation is an ethical consideration that needs to be tackled in an interdisciplinary manner and together with various stakeholders, including local communities. (Dooley et al 2022), (Holz et al. 2018)

Implementation of CDRS methods may have negative and ecological or social consequences that could emerge over time, therefore it is important to set guardrails, conduct comprehensive impacts assessment, and respect the precautionary and do no significant harm principles. Building up robust governance structures with appropriate measuring, reporting, and verification systems that also include provisions on long-term liability, is needed to ensure the use of CDRS has approbate oversight that prevents unauthorised or harmful methods. The risks and trade-offs are further discussed under the following section 3.3 on the characteristics of different CDRS methods. (Holz et al. 2018), (European Commission CRCF Impact Assessment 2022)

4 EUROPEAN UNION’S CARBON REMOVAL AND SEQUESTRATION POLICY

At the time of writing the European Union lacks a dedicated governance framework for carbon removal outside the Land Use, Land Use Change and Forestry Regulation (LULUCF), but CDRS is explicitly and implicitly embedded within the EU’s broader climate policy, and many of the EU’s currently existing climate policy instruments address CDRS where relevant. This chapter describes the current state of the EU’s CDRS policy, including both the existing legislation and the support mechanisms as well as the most important current ongoing and upcoming initiatives. (Regulation 2023/839/EU), (Regulation 2021/1119/EU)

4.1 The European Climate Law

The European Climate Law, a Regulation adopted in 2021, sets a Union-wide, legally binding obligation to reach net zero greenhouse gas emissions by 2050, and a net negative emissions balance thereafter, emphasising the importance of both emissions reductions and removals in achieving this goal. The Climate Law also establishes a binding Union 2030 climate target of domestic reduction of net greenhouse gas emissions (emissions after deduction of removals) by at least 55 % compared to 1990 levels by 2030 and caps the contribution of land-based sequestration via the Land Use, Land Use Change, and Forestry (LULUCF) Regulation to -225 Mt of CO_2eq thereby introducing a distinction between emission reductions and removals. These targets are binding at the Union level, but both the relevant Union institutions as well as the Member States are required to take the necessary measures at the Union and national level, respectively, to enable the collective achievement to meet the targets. While the Climate Law does not as such set separate targets for removals, it nevertheless establishes the necessity to enhance removals domestically within the Union. (Regulation 2021/1119/EU)

4.2 Land Use, Land Use Change and Forestry Regulation (LULUCF)

At the time of writing the only EU legislation particularly designed to govern carbon removals is the EU Regulation for the Land Use, Land Use Change and Forestry (LULUCF) which forms the third column of EU climate policy next to the EU Emission Trading System (EU ETS) and the Effort Sharing Regulation. The LULUCF Regulation sets a net sink target for 2030 and lays down rules for accounting LULUCF sector's carbon fluxes. The aim of the Regulation is both to ensure that emissions and removals from the land sectors are appropriately accounted for and to decrease the emissions and increase the removals from these sectors. (Regulation 2023/839/EU)

The LULUCF Regulation was revised in 2023 as part of the overall revision of the EU's 2021-2030 climate policy and targets, and the revised Regulation sets a separate land-based net carbon removals target of 310 million tonnes (Mt) of CO_2 equivalent (eq) by 2030. This target represents an increase from the current (2020) level of -220 Mt CO_2eq, and from the level (-225 Mt CO_2eq) that the unrevised 2018 LULUCF Regulation would have allowed the sink to be at a minimum in 2030. This Union-wide -310 Mt CO_2eq net target will be implemented through binding national net removal targets for the sector. The LULUCF sector covers the emissions and removals in most land sectors such as managed forest land, cropland, grassland, and settlements, and as well from harvested wood products. Accounting of wetlands emissions and removals will be voluntary until 2025, as of 2026 wetlands accounting becomes mandatory. Emissions and removals from protected land do not fall within the scope of LULUCF, and agriculture emissions from livestock and fertiliser use, most importantly methane and nitrous oxide emissions are regulated under the Effort Sharing Regulation. Most removals come from forest land, whereas the net emitting sectors are croplands, settlements, and wetlands (Figure 3.1). In addition to setting the targets the LULUCF regulation also sets the rules for the accounting of emissions and removals in the sector. (Regulation 2023/839) , (Regulation 2018/841/EU), (European Commission SWD(2021)609 2021, 24)

To increase the size of the net sink in the LULUCF sector, both emission reductions and sink enhancement in the sector are needed. The Union-wide binding -310 Mt CO_2eq target is implemented through nationally binding targets for all EU member states. These national targets are listed in Annex III of the LULUCF Regulation 2023/839. The revised regulation also includes compliance measures similar to the Effort Sharing Regulation; if a member state fails to achieve its annual target an equal amount in tonnes of CO_2 eq, multiplied by a factor of 1,08, will be added to the following year’s figure. (Regulation 2023/839/ EU, Article 13c)

The LULUCF Regulation is kept under review. Within the six months after the first global stocktake of the Paris Agreement (November-December 2023) the Commission is required to submit a report to the European Parliament and the Council on the operation of the LULUCF Regulation. This report will include among other issues a new target for the LULUCF sector for the period 2031-2040. (Regulation of 2023/839/EU, Article 17)

LULUCF Regulation Article 17 also mandates that within the 12 months following the entry into force of the regulatory framework for the certification of carbon removals (the CRCF), the Commission is required to assess the possible benefits and the trade-offs of including carbon storage products into the scope of the LULUCF Regulation. The Commission’s report may include a legislative proposal on the inclusion and needs to consider among other things the direct and indirect land use change and risks of leakage, as well as the EU’s biodiversity objectives. (Regulation of 2023/839/EU, Article 17)

4.3 Directive on the geological storage of CO_2 (CCS directive)

The EU directive on the geological storage of CO_2 (CCS Directive) establishes a legal framework for site selection, permitting, development, and operation as well as the requirements for management and liability throughout the entire lifetime of geological carbon storage in the EU. The CCS Directive also contains provisions on the capture and transport components of the Environmental Impact Assessment Directive and the Industrial Emissions Directive.

The directive also mandates that operators must establish financial security before the injection of CO_2 starts to ensure a cover of potential liabilities. The operators are included in the EU Emissions Trading System, and in case of leakage, the operators are required to surrender a corresponding amount of emission allowances. The Environment Liability directive applies in the case of possible damage to the local environment. The CO_2 emissions that are captured, transported, and stored in compliance with the CCS Directive are considered as not emitted under the Emissions Trading System. (Directive 2009/31/EC) (European Commission website CCS Directive)

The CCS Directive was originally intended to create an enabling framework for carbon capture and storage, its previsions will very likely apply to the geological storage of permanent carbon removals under the Certification Framework for Carbon Removals (CRCF). (European Commission 2022/0394)

4.5 Certification Framework for Carbon Removals (CRCF)

In November 2022 the European Commission launched a proposal for a regulation to establish a carbon removal certification framework (CRCF) for the European Union. This proposal is the EU’s first effort to legislate a variety of different methods from permanent carbon removal to carbon farming and carbon storage in products. At the time of writing this proposal is being treated by the European Parliament and the Council under ordinary legislative procedure. The main objectives of the proposal as outlined in the proposal are both to ensure the high quality of carbon removals in the EU and to establish an EU certification system to avoid greenwashing through applying and enforcing the EU quality framework criteria in a reliable and harmonised way across the Union. These provisions are considered necessary to incentivise and accelerate the deployment of CDRS, and to build future EU policies for these sectors.
(European Commission 2022/0394)

The CRCF proposal aims to create a voluntary certification framework that sets out quality criteria, rules, and procedures for monitoring, reporting, and verifying, as well as rules for the functioning of the certification schemes. The

scope of the proposed regulation is very broad including many different types of CDRS methods from three different categories with different features, side effects, trade-offs, etc. The first category of permanent carbon removals includes those methods that are able to deliver permanent CO_2 storage. The carbon farming category includes biogenic carbon sequestration for example in soils and vegetation, as well as reduction of the release of carbon from the biogenic carbon pool to the atmosphere. The third category includes carbon stored in products, for example in wooden contraction materials.
(European Commission 2022/0394)

The form of the Commission CRCF proposal is a skeleton for the certification governance, with the intention of the many details to be filled in at a later stage through delegated acts. The proposal outlines high-level quality criteria principles, certification process, and governance. The proposal does not discuss any specific CDRS methods or their financing, nor does it specify by whom and how certificates are to be used. The CRCF is intended to be a voluntary framework, and currently, it has no linkages to the EU's compliance legislation, the Emissions Trading System or Effort Sharing Regulation. The draft CRCF Regulation does not specify whether the activities that fall under its carbon farming scope are to be included or to be additional to the current LULUCF target. (European Commission 2022/0394)

At the time of writing it is expected that the Regulation will be adopted early in 2024. Upon its release, the Commission proposal received significant criticism particularly, but not only, from Environmental NGOs. The proposal was criticised e.g. for including some biogenic emissions reductions under its scope, which does not align with the common definition of carbon removal. Other points of concern and criticism were the mixing of permanent and temporary removals, the failure to specify the use, and the shortcomings in the definitions. (Carbon Market Watch 2022), (Bellona 2022)

5 COMMON CARBON DIOXIDE REMOVAL AND SEQUESTRATION METHODS

5.1 Key characteristics of different types of removals

This chapter presents six different carbon removal and sequestration methods that frequently feature in the EU CDRS policy-making debate. These six methods are explored by looking at seven different features: permanence, economic costs, cost structure, technology readiness level, the accuracy of monitoring reporting and verifying, possible harms and risks, and co-benefits.

1. **Permanence** answers to how long and how securely the captured CO_2 remains stored. The primary goal of carbon removal activity is its climate impact, therefore permanence is a key consideration. If the captured CO_2 is intentionally or unintentionally released back into the atmosphere it negates the intended impact fully, and most likely results in increased emissions in the atmosphere due to emissions from the initial capturing and storage process Permanence is a key consideration especially when climate impact is the only benefit of the said activity, and when compensating continued emissions with removals as the emitted CO_2 remains in the atmosphere approximately for up to 1000 years. A fossil carbon cycle and a biogenic carbon operate on very different time scales. The former typically lasts millions of years, the latter from a few years to a few decades. (IPCC 2021)

2. **The economic costs** of the carbon removal method are also important to consider because they closely impact the feasibility, scalability, competitiveness, and general affordability of the particular method. Cost-effectiveness impacts both political and financial decisions on which removal methods will be prioritised. Economic costs need to be balanced against the benefits, including possible additional social or environmental benefits.

3. **The cost structure** of CDRS methods varies significantly. Some methods might require significant upfront investment and/or constant upkeep, or resource and energy inputs. Looking at the cost structure is equally needed to inform

decision-making about the economic feasibility, long long-term viability and identify appropriate financing options.

4. **Technology readiness level (TRL).** Assessing the (technology) readiness level (TRL) of different CDRS methods is necessary in the first place to assess whether the method in question is feasible within relevant timeframes. When it comes to financial support, understanding the TRL is necessary for determining if the financing needs are for research and development, for a pilot project, or for scaling up or for maintaining the activity.

5. **Ease of Accounting and accuracy of Monitoring, Reporting, and Verifying (MRV)** is essential to ensure that the intended removal is real. Soil or nature-based carbon sequestration is particularly challenging to measure accurately because ecosystems and the variables that impact the biogenic carbon cycle are complex. There is natural and spatial variation as well as gaps in knowledge, technology, and common accounting rules. Modelling natural carbon fluxes includes assumptions and uncertainties that can affect the accuracy of measurements. (IPCC 2021)

6. **Harms and risks.** Carbon removal methods may have negative side effects, even significant enough to negate or undermine the initial intended benefits. Therefore regulation and proper assessment of removal methods are crucial. Harms and risks vary greatly depending on the removal activity. Negative impacts may relate for example to loss of biodiversity, competition for land, resource use, albedo changes, or removal activities may also have negative social consequences.

7. **Co-benefits.** Some of the currently discussed removal methods can come, if done well, with significant co-benefits that can overlap with other societal goals, such as biodiversity conservation, ecosystem resilience, adaptation, job creation, and food security. Identifying co-benefits can help to maximise positive impacts for society, and contribute to the decision-making on which removal methods are to be favoured.

5.2 Common CDRS methods

The availability of accurate data on different CDRS methods is currently still very limited. Even though 99,9% of the current CDRS is conventional biogenic sequestration on land, the complexities of the biogenic carbon cycle prevent accuracy on quantification, permanence, and costs. The novel removal methods currently only contribute 0.1% of the current CDRS deployment, but the early development phase of these methods is the main reason behind the lack of up-to-date data and significant variation in cost estimates.
(Smith et al. 2023), (IPCC 2021)

CDRS methods vary greatly and have different trade-offs, among others regarding the features listed above. Therefore comparing these methods to one another is not comparing apples to oranges, but rather comparing apple trees to Apple AirPods. Taking into account these challenges, such as the lack of accurate data and the broad differences between methods, the six tables presented in chapters 3.4.1 to 3.4.6 provide an overview of features, but are not necessarily comparable to one another.

Assessing the potential scales of what different CDRS methods could deliver would be an important and interesting additional feature to include in the analysis for a more comprehensive overview. However, there is an important number of related uncertainties that prevent including a meaningful assessment. These constraints and uncertainties stem from a combination of technological, economic, regulatory, environmental, and societal challenges. For example, the technological removal methods are at an early stage of development, and assessing reliably their future potential and effectiveness is challenging. Some methods that rely on natural sequestration or biomass availability are fully dependent on future land use availability and prioritisation. Political choices as well as public perception and acceptance are also likely to impact largely on what methods are to be invested in in the future.

5.2.1 Direct Air Capture and Storage (DACS)

Direct Air Capture and Storage (DACS) is a chemical process in which CO_2 is captured directly from the ambient air and subsequently stored. Typically direct air capture (DAC) is done with large fans that draw in ambient air that then passes through a chemical sorbent absorbing or adsorbing the CO_2 molecules. This CO_2-rich material is then processed further, often with heat, to separate the CO_2. The captured CO_2 is then stored to prevent its release into the atmosphere. DAC is still today a very expensive and energy-intensive technology, and to achieve a net-negative emissions balance DACS needs to be powered with renewable energy sources.
(IPCC 2018, Glossary), (Wilcox et al. 2021), (International Energy Agency 2022)

TABLE 1. Direct Air Capture and Storage

Direct Air Capture (and Storage)	
Permanence	0 - 1000s years. Can be permanent with geological storage, or very temporary if used in fuels and short lived products..
Cost	1000€-1300€/tCO2.
Cost structure	High upfront investment, continuous renewable energy supply needs.
Technology Readiness Level (TRL)	Pilots projects are concluded, in scaling up phase.
Ease of Accounting (MRV)	Relatively easy, common standards do not exist.
Harms & Risks	Renewable energy intensive, technologically challenging.
Co-benefits	Very few: job creation, innovation

(International Energy Agency 2022) (Tanzer and Ramirez 2019), (Smith at al. 2023), (Climeworks web-shop)

5.2.2 Bioenergy with Carbon Capture and Storage (BECCS)

Bioenergy with Carbon Capture and Storage (BECCS) is a hybrid method combining biomass growth with engineered applications for producing energy and capturing the CO_2 from the waste stream. The captured CO_2 is then stored underground to prevent its release into the atmosphere. The net climate benefit of BECCS depends on the magnitude of bioenergy supply chain emissions and land and climate interactions. (Wilcox et al. 2021), (IPCC 2018, Glossary), (IPCC SRCCL 2019, Chapter 6)

TABLE 2. Bioenergy with Carbon Capture and Storage

Bioenergy with Carbon Capture and Storage (BECCS)	
Permanence	0 - 1000s years. Can be permanent with geological storage, or very temporary if used in fuels and short lived products..
Cost	15-400€/tCO2. However, the sequestration happens outside BECCS installations and the net gain may be offset due to land-use change.
Cost structure	High upfront investment, continuous renewable energy and biomass feedstock needs.
Technology Readiness Level (TRL)	Pilots projects are concluded, in scaling up phase.
Ease of Accounting (MRV)	Difficult and contain many uncertainties.
Harms & Risks	Competition of biomass, land and water resources, risks for land degradation, food insecurity, increased GHG emissions and other environmental goals such as biodiversity.
Co-benefits	Waste utilisation, (energy production)

(IPCC SRCCL 2019), (Tanzer & Ramirez 2019), (Soimakallio et al. 2016), (Smith et al. 2023), (Harper et al. 2018)

5.2.3 Biochar (biological charcoal)

Biochar is a carbon-rich material, a type of charcoal, produced from biomass through pyrolysis, a burning process without oxygen supply. Pyrolysis results in a form of carbon that breaks down slowly and can be added to soils to enhance soil fertility, water retention, and carbon sequestration. (IPCC 2018, Glossary), (Lehman et al. 2021)

TABLE 3. Biochar

Biochar	
Permanence	10 - 100s years. Depends on use and soil type.
Cost	10-345€/tCO_2 Considered to be one of the most economic. Can be profitable if biochar products are sold, heat is used/sold, and waste biomass is available.
Cost structure	Upfront costs depend on the scale of the installation. Significant labour costs, constant feedstock needs that may vary.
Technology Readiness Level (TRL)	Pilots projects are concluded. In scaling up phase.
Ease of Accounting (MRV)	Difficult and contains many uncertainties.
Harms & Risks	Competition of biomass use, darker soils (negative albedo impact), possible air quality impacts from pyrolysis, and uncertainty about long-term impacts on soil ecosystems.
Co-benefits	Increased soil health and crop yields, water retention, reduction of pesticide needs, waste biomass utilisation, avoided emissions (e.g. peat replacement) - if done well.

(Biochar durability statement 2023), (Griscom et al. 2017), (Azzi et al. 2021), (Fuss et al. 2018), (Wilcox at al. 2021), (Smith et al. 2023)

5.2.4 Nature restoration and reforestation

Nature restoration and reforestation include restoring degraded or damaged ecosystems to enhance carbon sequestration capabilities and overall ecological health. Reforestation is the planting of forests on lands that have, historically, previously contained forests but which have been converted to some other use. In Reforestation requires decades, even more than 100 years, to have an impact, while preventing deforestation contributes to climate protection immediately maintaining the co-benefits, such as biodiversity. Avoided deforestation is not a CDRS method while it deserves to be mentioned in this context. (Wilcox et al. 2021), (IPCC 2000, 2.2.3.2)

TABLE 4. Nature restoration and reforestation

Nature restoration and reforestation	
Permanence	0 - 100s of years. May be long-term, but high risk for reversals.
Cost	0-250€/tCO2
Cost structure	Upfront costs include land acquisition, seedling and labour, excluding passive restoration. Established ecosystems are relatively self-sustaining.
Technology Readiness Level (TRL)	Ready to be implemented in large scale
Ease of Accounting (MRV)	Difficult and contains many uncertainties.
Harms & Risks	Very limited if done well, albeido impacts (darker land cover)
Co-benefits	Numerous. Improves ecosystems resilience, biodiversity, water regulation and adaptability to climate change.

(Smith et al. 2023), (Wilcox et al. 2021), (Harper et al. 2018), (Fuss et al. 2018)

5.2.5 Soil carbon enhancement

Soil carbon enhancement involves improving land management practices in ways that increase the carbon content of soil. This is achieved through methods like no-till agriculture and planting cover crops. Some methods such as agroforestry improve both below and above-ground sequestration.
(Wilcox et al. 2021)

TABLE 5. Soil carbon enhancement

Soil carbon enhancement	
Permanence	0 - 100s of years. May be long-term, but high risk for reversals, by both biochemical and socio-economic factors.
Cost	0-100€/tCO_2, costs may even be considered negative due to increased soil fertility and reduced fertiliser needs.
Cost structure	Upfront costs include training and education, possible technical investments.
Technology Readiness Level (TRL)	Ready to be implemented in large scale.
Ease of Accounting (MRV)	Difficult as with all land based, as well as assessing additionality.
Harms & Risks	Limited if done well, may result in lower harvests during transition period.
Co-benefits	Improved soil quality, resilience and agricultural productivity.

(Wilcox et al. 2021), (Smith et al. 2023), (Varney et al. 2022)

5.2.6 Peatland Rewetting

Many peatlands have been drained for agriculture, forestry, or other land uses. This has lowered the water table and exposed the peat to oxygen, which has led to decomposition and carbon release. Peatland rewetting entails restoring drained peatlands by raising the water table. This prevents peat decomposition, reduces emissions, and in the long term also sequesters carbon. At the time of writing the European Union policymakers are debating whether peatland rewetting should or should be categorised as a CDRS method, given that the impact of rewetting on carbon flows comes in the form of emission reductions. (Smith et al 2023), (European Commission 2022/0394)

TABLE 6. Peatland rewetting

Peatland rewetting	
Permanence	Not enough data: peatland forming as carbon sink takes multiple decades to several centuries, and has several variabilities that further increase uncertainty.
Cost	Not enough data to assess the costs of removal units. Restoring peatlands is often relatively expensive (costs range from 5.000 to 150.000€/ha).
Cost structure	Peatland rewetting requires, after initial investment, ongoing management to maintain water levels. It is resource-intensive and requires long-term commitment and planning.
Technology Readiness Level (TRL)	Ready to be implemented in large scale.
Ease of Accounting (MRV)	Difficult, inaccurate, and laborious.
Harms & Risks	Increased methane emissions, land competition.
Co-benefits	Emission reductions, habitat restoration, improved biodiversity and water quality, flood prevention.

(Smith et al 2023), (Mathias 2022), (Scheid et al 2023), (European Commission 2022/0195),(European Commission 2022/377)

6 METHODS TO SUPPORT CARBON DIOXIDE REMOVAL AND SEQUESTRATION DEPLOYMENT IN THE EUROPEAN UNION

This chapter presents eight different policy measures, instruments or other types of finance tools for supporting carbon dioxide removal and biogenic sequestration that are in use or are currently being legislated or debated in the European Union. Methods presented are diverse, they may be public or private, voluntary or compliance methods or direct support tools. This is not intended to be a comprehensive overview of all possible support options, but rather an examination of the support tools that either already exist or are being debated and proposed, and exploring the possible advantages and shortcomings of these different methods.

6.1 Compensation claims (offsets) via voluntary carbon markets

Compensation claims currently are the most common tool to finance CDRS globally and in the EU. Compensation claims in the context of climate policy refer to when an organisation, a company or individuals address their greenhouse gas emissions by purchasing carbon credits to fund emission reductions or CDRS activities. While the majority of carbon credits traded currently come from emission reductions and not from carbon removal and sequestration activities, compensation claims have been the first financial tool for CDRS activities. The most common method to purchase compensation claims is via carbon offset programs from the voluntary carbon markets. These programs aim to calculate the amount of CO_2 emissions generated from various activities (travel, energy consumption) and offer corresponding CDRS carbon claims to "neutralise" or "offset" those emissions. (Atmosfair), (Compensate)

A voluntary carbon market (VCM), is a collection of decentralised markets for buying and selling carbon credits with the aim to compensate or offset the occurred emissions. As the name refers, participation in VCM is voluntary unlike in cap and trade compliance markets, such as the EU ETS, that are mandatory for certain emitters. Reasons for participation in VCM vary, for credit providers and intermediaries the aim is to generate finance, and for buyers to reduce their carbon footprint, to improve the company's image, or to otherwise support mitigation efforts. (Streck et al. 2021), (Carbon Market Watch 101 2020) , (Carbon Market Watch Above and Beyond 2020)

Voluntary carbon markets for CDRS activities do not have commonly agreed rules, accounting, baselines, definitions, or standards. There are thousands of operators on the voluntary carbon market and it operates on agreements between the seller and the buyer. For these reasons, the VCM has been heavily criticised for failing to deliver actual removals, and recently VCM has been shadowed by several scandals revealing cheating, false claims, environmental destruction, and human rights violations. Other identified social and environmental concerns around VCM and compensation credits include over-crediting, non-additionality, poor accounting and MRV, negative side effects, very short storage times, and the lack of liability provisions. Additional structural problem with the VCM is related to the large amounts of middlemen that are needed for the operation of offsetting programs, and the fact that everyone in the business benefits from more amounts over credits. Past experience with carbon offset markets, such as the Kyoto Protocol's Clean Development Mechanism or the existing VCM, indicates that unless quality standards are continuously improved and rigorously enforced, serious environmental and social problems are bound to remain. (Guardian 2023), (Streck et al. 2021), (Carbon Market Watch 101 2020), (Fankhauser et al. 2022)

Out of the three different roles identified by the IPCC for CDRS as outlined in Chapter 1.1. on page 7 VCM compensation claims may only, (under ideal conditions when excluding all the problems of which some are listed above), address the second function identified by the IPCC, neutralising hard-to-abate sectors. The use of compensation claims does not complement emissions reductions but may delay them, as it is done instead of reducing emissions. Compensation claims can neither deliver net-negative emissions. When it comes to the second function of neutralising hard-to-abate emissions, there is no common understanding of what those emissions are. Defining hard-to-abate emissions is difficult, also given that it needs to be a constantly shrinking category. (IPCC AR6 WGIII 2022), (Buck et al. 2023), (Allen et al. 2020)

Finance for CDRS from voluntary carbon markets comes from private sources, and its duration is uncertain as it is based on voluntary action. An important risk for VCM as a predictable funding source includes buyers reprioritising voluntary offsetting that may be for example a result of either too high costs or lack of credibility due to poor quality results. Currently, the price of one tonne of CDRS on voluntary carbon markets varies considerably, the cheapest offsets are priced at a few cents, whereas direct air capture company Climeworks sells their permanent removals1300€/tonne. (Fiekowsky & Douglis 2023), (Climeworks webshop)

The complications of integrating CDRS into the EU ETS are numerous. ETS integration also only serves for emissions compensation, thus not being able to deliver additional removals. Furthermore, CDRS methods are very different when it comes to their costs, readiness, impacts, and permanence. All methods relying on sequestration can only provide temporary storage and therefore are not suitable for compensating fossil emissions, whereas the permanent solutions that are available are extremely scarce and very expensive, and unlikely to be financed for by the ETS operators in the near term. In 2023 EU ETS carbon price has fluctuated between 80€-100€/tonne of CO_2, and is expected to double from current by the end of this decade. (Edenhofer at al. 2023), (La Hoz Theuer et al. 2021), (Meyer-Ohlendorf 2023), (Sandbag, Carbon Price Viewer)

The European Union is currently developing its own carbon removal certification legislation that is intended to create carbon removal certificates with improved quality criteria and centralised control. At the time of writing it remains unclear if these certificates can be used for offsetting or other types of CDRS finance. (European Commission 2022/0394)

6.2 Integrating CDR into the EU Emissions Trading System

The question of integrating carbon removals into the EU Emissions Trading System is currently a widely discussed and popular topic in policy briefings and debates among EU climate policymakers.

The EU Emissions Trading System (ETS) is a cap-and-trade system that aims to reduce greenhouse gas emissions through a decreasing cap and putting a price on emissions. At the same time, it aims to incentivise investments in emission reductions by increasing the cost of energy-intensive business-as-usual practices.

As the emissions cap is gradually tightened, the emission allowances available for the ETS sectors (energy, industry, and domestic aviation) will decrease to zero in 2039. The concern that some residual emissions will remain at that point and will need to be offset has prompted several studies exploring options to include removals into the EU ETS. Integration of removals into the ETS could also be seen as a means to promote their deployment. The revised ETS Directive from 2023 mandates the European Commission in 2026 to report and possibly propose legislation, to the European Parliament and to the Council on if and how permanently stored removals could be included in the EU ETS without compromising emission reductions. (Directive EU/2023/959), (Edenhofer at al. 2023), (La Hoz Theuer et al. 2021)

6.3 Innovation Fund

The Innovation Fund (IF) is the EU’s funding programme particularly designed to finance innovative projects with the potential to reduce greenhouse gas emissions. It is financed from the auctioning revenue from the EU Emissions Trading System (EU ETS), and its overall budget depends on the ETS carbon price. The European Commission estimates its budget to be 40 billion € for the period of 2020 - 2030, with a moderate carbon price of 75€/tonne of CO_2. (European Commission, Innovation Fund website)

Novel technical carbon removal projects fit within the Innovation Fund awarding criteria, and carbon capture and storage projects have already been selected in the earlier calls. So far, during the years 2020-2023, the IF has run six calls and intends to run regular calls throughout this decade. The IF provides up to 60% of funding in its regular grants and up to 100% in case of reverse actions. As the IF project funding for possible carbon removal projects would come from public finance sources it is additional to emission reductions.
(European Commission, Innovation Fund website)

6.4 Reverse auctioning (competitive bidding)

Reverse auctioning is a procurement method in which the seller of goods or services competes to win by offering increasingly lower prices. It is the opposite of a traditional auction where buyers bid higher prices. Bidding for government contracts is a typical example of reverse auctioning. The difference with traditional grants is that auctions will provide payments only based on certified and verified outcomes. Many EU member states have used auctions for example to support renewable energy. In the EU, a recent example of such a procurement method is the Union's renewable energy financing mechanism and its tenders for renewable energy projects. The EU Innovation Fund is currently also developing a new reverse auctioning tool called “competitive bidding”. The terms and conditions of the first pilot competitive bidding on non-biological renewable hydrogen were published in August 2023. The fixed price will be paid up to ten years per kilogram of produced hydrogen. (Investopedia website), (Regulation EU/2018/1999, Article 33), (Innovation Fund Auction ToR 2023)

Following the logic of the above-mentioned examples, reverse auctioning could be a suitable tool to incentivise and support quantifiable permanent removals that meet the required quality criteria and can deliver the largest amounts of removals most cost-efficiently. The Swedish government in its 2020 report “Vägen till en klimatpositiv framtid” recommends reversed auctioning as the most cost-effective tool to support Bio Energy Carbon Capture and Storage (BECCS). The Swedish Energy Agency has been preparing the auction for solutions that can deliver removals that meet the quality criteria with the lowest cost per tonne of removed and stored CO_2. Swedish Energy Agency has estimated the price per BECCS removed tonne to be between 1100 and 2000 Swedish Krona, and the government's commitment to be 15 years. (Swedish Government 2020), (Lundberg & Fridahl 2022)

Reverse auctions can be designed to be broad or very specific. They can both be designed to deliver large amounts of any type of removal at the lowest possible cost, or they can be designed to scale up specific expensive novel methods that are considered important. For CDRS methods that are less quantifiable, in particular, land-based sequestration, "per tonne" -type of public support is less suitable. As reverse auctions are typically funded from public budgets, they do deliver additional removals to emissions reductions. In the case of the European Union when auctions are financed from the EU Innovation Fund that is financed by the EU ETS revenue the polluter would indirectly pay for the removals.

6.5 Horizon Europe

Horizon Europe is the European Union's research and innovation program for the period 2021-2027 with a budget of 95.5 billion euros. It is aimed at advancing and strengthening research, science, technology, and innovation across the EU in various domains. An important goal of Horizon Europe is to tackle societal challenges, such as climate change.
(European Commission, Horizon Europe website)

As carbon dioxide removal and sequestration efforts align with Horizon Europe's focus on addressing climate change, research and innovation related to CDRS can be supported through its different funding mechanisms and programs, as well as through various dedicated calls, missions, and initiatives that focus on climate. Horizon Europe provides only partial funding, and eligibility criteria vary from one call and program to another. For example, Horizon Europe's Work Programme 2023-2024 on Climate, Energy and Mobility includes several relevant calls both for novel technical carbon removal methods and for sequestration on soils and ecosystems.

(European Commission Horizon Europe website), (European Commission, Horizon Europe work programme 2023-2024)

Horizon Europe is likely to offer important finance for the development of new and innovative CDRS methods in the EU, but as it provides finance for innovative research, and therefore cannot be used for scaling up activities or to provide continuous funding for CDRS.

6.6 Common Agriculture Policy

The EU's Common Agricultural Policy (CAP) is a set of laws aiming to ensure European food security, support EU's farmers and rural development and promote climate mitigation and environmentally friendly agriculture. It is the EU's oldest policy policy still in operation covering approximately one third of the EU's budget. The CAP is regularly reformed and renegotiated. The current cycle 2023-2027 has an overall budget of 386.6 billion Euros that is dispersed and implemented through EU member states' own CAP Strategic Plans that the member states have designed based on the commonly agreed CAP objectives. (European Commission CAP website), (European Council CAP website)

The CAP finance is dispersed through two Pillars. Pillar 1 provides direct support for farmers for the general activity that fulfils the mandatory baseline, and Pillar 2 is particularly designed for supporting rural development. Both Pillars include options for dispersing finance for agricultural practices that support carbon mitigation and sequestration in soils and vegetation, such as nature restoration and agroforestry. The EU member states should spend at least 25% of the Pillar 1 payments and 35% of the Pillar 2 for activities that support environment and climate protection, which over the current CAP cycle of 2023-2027 amounts to approximately 72 billion Euros. The European Commission has also in its Sustainable Carbon Cycles Communication identified CAP as an important finance tool for providing public finance for the so-called carbon farming activities.
(European Commission CAP website), (European Council CAP website), (EEB 2023), (European Commission EU/2021/800)

Even while the CAP has a very large budget and the necessary policy means to upscale climate and environmental objectives in agriculture it has been widely criticised for failing to do so. The CAP's measures that aim to reduce emissions or increase sequestration are dwarfed by the other measures that support intensive farming practices that increase soil emissions and degrade ecosystems. The European Court of Auditors critiqued the CAP heavily in their 2021 Special Report on '*Common Agricultural Policy and climate: Half of EU climate spending but farm emissions are not decreasing*'. As the next seven-year cycle of the CAP needs to be in place to be implemented from the beginning of 2028 the negations for the new round are expected to start before long. (European Court of Auditors 2021)

6.7 Separate targets for carbon removals and biogenic sequestration

In 2024 the European Commission (EC) will present a proposal for a new 2040 climate target for the European Union, as mandated in the European Climate Law. As part of the preparatory process to set the target, the European Commission conducted a public consultation collecting feedback and stakeholders' views on the level of ambition, sectoral transformations, and the overall policy architecture of the 2031-2040 EU climate policy. The majority of the respondents (54%) who provided feedback advocated for three separate targets to be set for the upcoming policy cycle. A separate target for greenhouse gas emissions reductions, a second separate target for land-based biogenic sequestration, and a third target for permanent carbon removals. (Regulation 2021/1119/EU), (European Commission Ares 5698212 2023)

Legally binding EU-wide or national member state level targets for permanent removals and biogenic sequestration are not direct financing mechanisms per se, but can incentivise CDRS in several ways. Legally binding targets require governments to take adequate action and develop policies to meet the targets. They also provide a long-term perspective and financial security that can help mobilise private investments and funding. The EU's current climate policy framework is already divided into separate legally binding targets. Emission reductions are governed by the Effort Sharing Regulation and the EU Emissions Trading System Directive, and biogenic sequestration targets and accounting rules are set in the Land Use, Land Use Change and Forestry Regulation. This approach calls for a new separate target to be set for industrial removals that are currently not included in the EU policy framework.

6.8 Nature Restoration Law

The European Commission's proposal on the EU Regulation on Nature Restoration (the Nature Restoration Law, NRL) seeks to set binding targets for member states to restore degraded ecosystems. The proposal prioritises the restoration of ecosystems with a high potential to sequester and store carbon, such as peatlands and forests. Referring to the EU Climate Law’s binding objectives of 2050 climate neutrality and net negative greenhouse gas emissions thereafter, the Commission’s NRL proposal states: “*The restoration of ecosystems can make an important contribution to maintaining, managing and enhancing natural sinks and to increasing biodiversity while fighting climate change.*” (European Commission 2022/0195, Recital 16)

While all healthy ecosystems sequester and store carbon better than the degraded ones, Article 9 of the NRL proposal provides particular measures on rewetting peatlands that are often considered as a CDRS method. Member states are to put in place binding restoration and rewetting measures on drained peatlands that are in agricultural use. For example by 2040 restoration measures need to be in place at least in 50% of such areas, of which at least half must be rewetted. The NRL proposal also addresses soil carbon enhancement by requiring member states to achieve a trend of increasing organic carbon stocks in mineral soils. (European Commission 2022/0195, Article 9)

The Commission’s NRL proposal did not include detailed proposals on how the restoration measures described are to be financed, but the Council as a co-legislator wants to mandate the European Commission to report and propose new funding to fill the gaps within 12 months after the NRL’s entry into force.

(European Council 10867/23/Article 18)

At the time of writing the negotiations between the co-legislators on the final outcome of the Nature Restoration Law are still ongoing.

7 ANALYSIS OF THE CURRENT EU CDRS POLICY LANDSCAPE

This chapter analyses the current landscape of carbon dioxide removal and sequestration (CDRS) policies and their support options within the European Union. This is done by looking at the expected deployment needs, the four key EU laws that currently are the most relevant for CDRS governance and support in the Union, and the eight support tools available for supporting CDRS initiatives within the EU. Additionally, to provide for context and practicability, six distinct CDRS methods we studied.

Throughout this analysis, the aim is to provide a comprehensive understanding of the EU's CDRS landscape, its policies, methods, and support mechanisms, contributing to informed decision-making and policy development in the EU.

7.1 Scale of future CDRS deployment

Chapter 3 of the literature review discusses the scale of CDRS deployment needs globally and in the EU. Research into the latest science, such as the 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), confirms that significant amounts of CDRS will be necessary to reach net-zero emissions, even while the CDRS needs are closely related to emission reductions and the timeline for reaching a global net zero emissions balance. While the IPCC does not provide any specific amounts, the assessment on the IPCC AR6 emission pathways conducted in the 2022 report "The State of Carbon Dioxide Removal" concludes that the cumulative amount of CDRS over the 21st century for 1.5°C compatible pathways with no or limited overshoot ranges between 420GtCO_2 and 1100 GtCO_2, with a median value of 740GtCO_2.

For the European Union, the needed long-term scale of CDRS deployment is still undefined, but the European Climate Law provides a clear direction of travel and a long-term perspective for CDRS needs and development in the EU. The Climate Law sets a legally binding commitment to climate neutrality by 2050 and the achievement of a net-negative emission balance thereafter. Excluding the EU-wide net -310Mt CO_2eq 2030 target for Land Use, land Use Change and Forestry (LULUCF) sector, the EU does not have clearly defined targets for technical removals. The European Commission's proposal for a Regulation establishing a Union certification framework for carbon removals outlines that " *both natural ecosystems and industrial activities should contribute to removing several hundred million tonnes of CO_2 per year from the atmosphere.*"

In light of this data as well as trends observed it becomes evident that scaling up CDRS will be imperative in the coming decades, both in the EU and globally. These findings align with the prevailing consensus in the literature.

7.2 Existing CDRS legislation in the EU

Chapter 4 of the literature review explores the European Union's existing climate policy legislative acts that are relevant to carbon dioxide removal and sequestration. This analysis focuses on acts that either regulate these processes or have the potential to influence the CDRS landscape within the EU.

The research conducted identified four key legislative acts with important implications:

- **European Climate Law:** The European Climate Law provides the binding target for climate neutrality in 2050 and for reaching net negative emissions thereafter.
- **Land Use, Land Use Change and Forestry Regulation (LULUCF):** The LULUCF Regulation provides for the accounting rules and a separate binding net target of -310 MtCO_2eq for 2030 for biogenic emissions and sequestration in the sectors covered. The EU-wide target is further divided into national binding targets for member states.
- **CCS Directive:** The role of the CCS directive is limited to providing rules for geological carbon storage.
- **Carbon Removal Certification Framework (CRCF):** The CRCF is the EU's first effort to legislate particularly for the different types of CDRS methods. The CRCF proposal aims to create a voluntary certification framework that sets

out quality criteria, rules, and procedures for monitoring, reporting, and verifying, as well as rules for the functioning of the certification schemes. At the time of writing, the deliberations on the final form of the CRCF are still ongoing.

The analysis of the EU's current carbon dioxide removal and sequestration policy framework reveals important gaps for effective regulation and support of CDRS, even while the Carbon Removal Certification Framework aims to tackle some of them, such as definitions and quality criteria. The most noteworthy gaps that remain are the lack of clarity on the scale of future CDRS deployment including the targets, and the lack of support mechanisms.

These findings underline the need for further examination and policy development to address the existing gaps and to create a more robust regulatory framework for effective CDRS governance within the EU.

7.3 CDRS methods

To provide practical context for the analysis, Chapter 5 of the literature review presented and studied six different CDRS methods that feature frequently in the EU CDRS policy-making debate. These methods were explored by looking at their specific features, namely permanence, economic costs and cost structure, technology readiness level, accuracy of monitoring, reporting and verifying, possible harms and risks, and co-benefits. The analysis revealed significant variations across all evaluated criteria, making direct comparisons between these methods unfeasible.

To provide a summarised overview of the different CDRS methods and to visualise their distinct features, a simplified compilation of Table 7 is presented. It is essential to note that nuances are simplified in this representation, and for a more detailed analysis, readers are encouraged to refer to Chapter 5, pages 30-35.

Below is an explanation for the columns of the table 7:

1. **CDRS method:** The six methods studied in Chapter 5.
2. **Storage length**: Methods are categorised as ‘Permanent’ if they can provide for geologic storage for more than 1000. ‘Temporary’ is used for biogenic sequestration methods in soils and vegetation that are easily reversible, and cannot guarantee 1000 years of storage.
3. **Cost in € per tonne:** This column indicates the price per CDRS tonne. The wide ranges are explained with the variety of sources in the literature review.
4. **Cost structure, upfront and running:** Upfront and running costs are categorised as ‘High’, ‘Medium’, and ‘Low’.
5. **Technology readiness level (TRL):** Instead of the more common TRL scale of 1-9, methods in the below table are assessed with a simplified scale of 1-3, with 1 indicating the conceptual research and development phase, 2 representing the demonstration and validation phase, and 3 representing mature and viable implementation.
6. **Ease of accounting/ accuracy for Measuring, Reporting and Verification (MRV):** Methods are rated as ‘Easy’ or ‘Difficult’. 'Easy' is assigned to methods with relatively straightforward MRV, while 'Difficult' is assigned to methods relying on soil and vegetation for sequestration and as a storage medium, due to the complexities in biogenic carbon cycle measurement and baseline establishment.
7. **Risks:** Methods rated as ‘High’ are considered to have relatively high risks that relate to possible increases in emissions, loss of biodiversity, and ecosystem degradation. ‘Medium’ represents lower, but still considerable risks, and ’Low' is assigned to methods with no significant identified risks to ecosystems.
8. **Co-benefits** are rated from 1-3. Methods scored with a 1 are methods where no significant co-benefits have been identified, methods rated with a 2 have limited co-benefits, and a score of 3 is given to methods that have been identified to come with important co-benefits, particularly for ecosystems.

TABLE 7. Presenting a summarised and simplified overview of the different CDRS methods and their distinct features. Please see above a clarification of different columns.

CDRS method	Storage lenght	Cost in €/ tonne of CO2	Cost structure upfront & running	TRL	MRV	Risks	Co-benefits
Direct Air Capture and Storage (DACS)	Permanent	1300€	Upfront: High Running: Medium	2	Easy	Low	1
Bioenergy with Carbon Capture and Storage (BECCS)	Permanent	15-400€	Upfront: High Running: Medium	2	Difficult	High	1
Biochar	Temporary	10-345€	Upfront: Medium Running: Medium	2	Difficult	Medium	2
Restoration and reforestation	Temporary	0-250€	Upfront: Low-Medium Running: Medium	3	Difficult	Low	3
Soil carbon enhancement	Temporary	0-100€	Upfront: Low Running: Low	3	Difficult	Low	3
Peatland rewetting	Temporary	No data	Upfront: Low Running: Medium	3	Difficult	Low	3

The leading CDRS methods under consideration in the EU's policy discussions differ significantly across all assessed criteria. These substantial differences render both direct value assessments and comparisons between these methods impractical.

7.4 Assessment of support tools for CDRS in the EU

In chapter 6 of the literature review, research was conducted into support tools available for supporting CDRS development within the EU. Eight different funding mechanisms were identified that currently support CDRS or part of the current CDRS-policy deliberations in the EU:

1. **Compensation claims (offsets) via voluntary carbon markets (VCM):** Decentralised voluntary markets for emission compensation without commonly agreed rules, accounting, baselines, definitions, or standards.
2. **Integrating CDR into the EU Emissions Trading System:**

Still only conceptual, but widely debated. The inclusion of carbon removals into the EU ETS would offer operators the possibility to compensate for emission reductions with removals.

3. **Innovation Fund:**
   Small and large project funding for demonstration installations.
4. **Reverse auctioning (competitive bidding)**:
   A procurement method in which the sellers of for example carbon removals compete to win by offering increasingly lower prices.
5. **Horizon Europe**:
   EU's research and innovation programme that can provide finance for CDRS research.
6. **Common Agriculture Policy:**
   EU's largest budget, with goals also to enhance carbon sequestration via activity-based finance.
7. **Separate targets for carbon removals and biogenic sequestration:**
   In the current EU policy framework land use land use change and forestry are under a separate target. The widely discussed proposal is to maintain the separation from emission reductions and add a new target for permanent technological removals. Guarantees additional removals, but does not provide finance as such.
8. **Nature Restoration Law:**
   Legislation to set binding nature restoration targets with an important focus on ecosystems that would also enhance carbon sequestration. Final legislation is still being negotiated, but it will include provisions for activity-based finance.

For an overview, the above-listed finance tools and other support policies are assessed in Table 8 by looking into four different features presented below.

1. **What type of financing is the instrument or policy designed for?**
   Research conducted in the literature review found four different types of finance. Two one-off types of finance that are meant either for research and development or pilot or demonstration projects. These finance tools are not designed for financing continuous removals or sequestration. Two other types of finance are quantified results-based finance and finance that is

provided for conducting a specific activity. These two can support continuous CDRS. In the case of quantified finance, a price range of € per tonne of CDRS is also included in the table.

2. **What sources the funding is derived from?**
   The research identified that finance comes from either taxpayers or polluters. In some cases, as the tools and policies researched are yet to be fully defined or implemented, both options are possible, depending on the eventual design.

3. **Does the instrument in question support the Polluter Pays Principle?**
   This is an important environmental policy approach, also enshrined in the EU Treaty, implying that the party responsible for pollution is financially responsible for the associated costs of environmental damage. It promotes accountability and encourages polluters to bear the costs of their environmental impact, fostering responsible behaviour.

4. **Is the tool designed for emission compensation or can it deliver additional CDRS to emission reductions?**
   This is an important feature to look into as the CDRS through emissions compensation does not lead to a net negative emissions balance. This is a central question considering the aims of the overall research.

TABLE 8. Support methods analysed on four different features: 1) type of finance, 2) source of finance, 3) whether it supports polluter pays principle, and 4) is the net benefit additional or an emission offset.

	Type of finance	Sources funding is derived	Supports PPP	Net benefit
VCM offsets	Quantified 1-1300€/tonne CO2	Private companies' etc voluntary purchases	No Voluntary	Offsets
ETS integration	Quantified 80-100€/tonne CO2	Industry and energy installations included in the EU ETS	Yes	Offsets
Innovation Fund	Demonstration projects	EU ETS revenues Public funds	Yes	n/a
Reverse auctioning	Quantified TBC€/tonne CO@	In the EU's case from the IF (ETS revenue). Tool for public or private purchases	Yes	Additional
Horizon Europe	Research and Development	Public funds	No	n/a
Common Agri-cultural Policy	Activity based finance	Public funds	No	Additional
Separate targets	Quantified TBC€/tonne CO2	TBC	Yes	Additional
Nature Resto-raton Law	Activity based finance	Public funds	No	Additional

Some of the analysed options are yet to be implemented or even fully designed. Currently, the only ones in real operation are the voluntary carbon markets (VCM), the Common Agricultural Policy (CAP) and member states' LULUCF targets. The literature review identified important shortcomings in particular with the compensation claims under the VCM and the CAP to deliver real CDRS.

7.5 Compatibility analysis of the support options with different types of CDRS methods

Considering the overarching goal of the thesis to contribute to informed CDRS decision-making and policy development in the EU, it is important to conduct the matching exercise with the broader implications of CDRS policies in mind. Therefore the first step should be to exclude those CDRS methods with important negative side effects or risks. The analysis above guides us to exclude Bioenergy with Carbon Capture and Storage (BECCS). This is due to the many identified negative side effects, such as competition for biomass, land and water resources, risks for land degradation, food insecurity, possible increased greenhouse gas emissions and other environmental hazards such as the risk of loss of biodiversity, as well as lack of important co-benefits. The other five studied CDRS methods also come with their own set of risks and co-benefits but with a more nuanced overall picture. Therefore the rest are included in the matching analysis below.

Furthermore, with the overarching goal of the thesis in mind, understanding the broader policy implications of matching CDRS methods with support tools involves typically an aspect of interpretation. Therefore a more in-depth matching exercise is included in the Discussion Chapter 8. Having said that, it is nevertheless possible to draw the analysis further when considering the suitability of certain CDRS methods with the particular support tool or policy.

An answer to the overarching research question of the thesis about identifying the CDRS support mechanisms that can ensure additional contribution to mitigation efforts and help in achieving net negative carbon balance can be drawn relatively straightforward from the above analysis. Out of the eight support methods analysed, only four tools are potentially able to provide for additional CDRS. These are Common Agricultural Policy (CAP), Nature Restoration Law, reverse auctioning and separate targets (Table 9).

TABLE 9. Four of the analysed eight support methods that can potentially deliver additional CDRS to mitigation action.

Net benefit: ADDITIONAL	
Separate targets	Nature Restoration Law
Common Agricultural Policy	Reverse austioning

Analysing these four tools deeper reveals however significant differences. The Common Agricultural Policy and Nature Restoration Law are designed for activity-based finance, whereas reverse auctioning and separate CDRS targets are designed for quantified results-based finance as presented in Table 10.

TABLE 10. Dividing the four CDRS support methods that can provide for additional CRDS to results- and activity-based categories.

Results-based finance	Activity-based finance
ETS integration	Common Agricultural Policy
Separate targets	Nature Restoration Law

When aiming to match suitable CDRS methods with these four support methods two qualities appear particularly important: the length of storage times (permanent or temporary) (table 11) and ease of accounting/measuring, reporting and verifying (table 12). Those CDRS methods that can only provide temporary storage and are relatively difficult to account for and MRV are more suitable for activity-based finance. Methods that provide permanent storage and are relatively easy to account for and MRV are more suitable for quantified results-based support. The hard-to-quantify methods typically involve the biogenic carbon cycle and the relatively easy-to-quantify typically include industrial/technical solutions.

TABLE 11. Division of CDRS methods to permanent and temporary.

Permanent CDRS	Temporary CDRS
DACS	Soil carbon
	Biochar
	Nature Restoration
	Peatland rewetting

TABLE 12. Division of CDRS methods to those relatively easy to account and those relatively difficult to account.

Relatively easy to account & MRV	Relatively difficult to account & MRV
DACS	Soil carbon
	Biochar
	Nature Restoration
	Peatland rewetting

The analysis concludes that nature restoration and reforestation, soil carbon enhancement, peatland rewetting and biochar are more suited to be supported by activity-based finance that could be provided by the Common Agricultural Policy and Nature Restoration Law finance provisions. Direct Air Capture and Storage (DACS) is relatively easy to quantify and at the same time able to provide permanent storage could be supported with instruments that are designed for results-based finance.

Another important metric is to look at CDRS methods that come with significant co-benefits for nature and ecosystems and that benefit the society beyond climate impact, for instance, nature restoration, and prioritise those over those without significant co-benefits.

TABLE 13. Division of CDRS methods to those with important co-benefits and those without significant co-benefits.

Important co-benefits	No significant co-benefits
Soil carbon	DACS
Biochar	
Nature Restoration	
Peatland rewetting	

Adding the co-benefits to the analysis further confirms the importance of supporting soil carbon enhancement, nature restoration and reforestation, peatland rewetting and biochar with activity-based finance.

Another interesting dimension is to see which of the support methods sustains the polluter pays principle. This is an important environmental policy approach, also enshrined in the EU Treaty, implying that the party responsible for pollution is financially responsible for the associated costs of environmental damage. It promotes accountability and encourages polluters to bear the costs of their environmental impact. Only two methods of the eight analysed support the principle, presented in Table 8 below. It is to be noted that 'ETS integration' does not provide for additional net benefit, but is however the only additional to the separate targets -approach that entails this important principle. This point of view gives more prominence to the separate targets -approach. It is further debated in the following Discussion Chapter 8.

TABLE 14. Only two CDRS support tools entail the polluter pays principle.

Compliance tools that support polluter pays -principle	
Separate targets	ETS integration

The cost and the cost structure of different CDRS methods are included in the literature review in Chapter 5. Comparing the estimated price of a tonne of CO_2 removed or sequestered with a particular CDRS method to the price provided with a particular finance tool, significant incompatibilities may be identified. For example, the current price of CO_2 removed and stored with direct air capture and storage is around 1200€/per tonne, while emission allowances on EU ETS are currently around 80€per tonne. This type of matching can be conducted to eliminate unsuitable options.

The research instrument Horizon Europe and Innovation Fund provides finance from public sources but are intended for early development phases and not for the longer-term running cost. Reverse auctioning (competitive bidding) is not a source of finance as such, but a tool that can be used for quantified public or private purchases.

Finally, the answer to the question of whether it is possible to identify and potentially match a CDRS method with a suitable support method that would result in a net negative emissions balance, without risks, and with positive co-benefits is yes. The analysis conducted brings out two particularly interesting conclusions. Firstly, it confirms the importance of supporting soil carbon enhancement, nature restoration and reforestation, peatland rewetting and biochar with activity-based finance. Secondly, none of the activity-based finance tools is designed to support the polluter pays principle. Only the separate targets -approach and the integration of CDR(S) to EU emissions trading appear to entail this feature, of which the ETS integration, being an offset method, does not provide additional CDRS.

8 DISCUSSION

8.1 Interpretation of findings and policy implications and recommendations

While the features of different methods are crucial in any CDRS discussion, the particular aim of this study was to explore options for supporting different types of CDRS approaches, and if possible to identify alternatives for supporting CDRS deployment through emissions compensation. The overarching research questions on identifying alternative finance options for offsetting were explored through a) identifying the EU's current climate policy instruments that are relevant for CDRS, b) identifying key aspects of different CDRS methods, c) assessing different characteristics of the supporting alternatives, and d) is it possible to match a CDRS method with a suitable support source that would result in a net negative emissions balance, without risks and with positive co-benefits.

Expanding upon the analysis presented earlier, this chapter delves deeper into these questions by building on the identified findings, providing interpretations, and considering their policy implications and recommendations.

CDRS methods' risk assessment remains insufficient.

The decisions regarding whether or not to support certain carbon dioxide removal and sequestration (CDRS) options require first and foremost a comprehensive evaluation of trade-offs, potential negative side effects, and positive co-benefits, as well as considering variables such as availability, scalability, readiness level, and time lags, among others. The research conducted in Chapter 5 on pages 30-35 on the different features of the six (DACS, BECCS, biochar, soil carbon enhancement, nature restoration, peatland rewetting) commonly discussed CDRS methods highlighted issues that raise questions on their overall feasibility as CDRS methods. For example, peatland rewetting cannot be considered a CDRS method as there are important uncertainties if the rewetted peatlands eventually turn into sinks (European Commission, SWD/2022/377). This is in any case likely to take hundreds of years. However, rewetting peatlands looks to be beneficial as it reduces emissions and, if done well, comes with important biodiversity and ecosystem resilience benefits. Also, reforestation takes several decades and often longer than that before the reforested area turns into a significant sink, whereas uncut forest provides both sequestration and biodiversity benefits immediately (Wilcox et al. 2021). Another example is BECCS, bioenergy with carbon capture and storage. The literature suggests that the CO_2 emission balance is likely positive with a full accounting of associated emissions (Soimakallio et al. 2016). Furthermore, BECCS employment appears to be associated with important negative side effects and risks (IPCC SRCCL 2019). Before extending further political and policy support for BECCS, it is important to ensure that potential risks, such as impacts on biodiversity, as well as a comprehensive assessment of biomass feedstock availability, including direct and indirect land-use change emissions, are thoroughly considered.

Compensation-based support models have crucial shortcomings.

The premise of this study was to look for options to finance CDRS deployment that can deliver a net negative emissions balance. As emission compensation with CDRS, even under optimal conditions, results in a neutral outcome, delivering zero advantage, this study aimed to identify alternative ways to finance and support the development and scale-up of CDRS. Given that offsetting currently is used for providing CDRS finance, the research touched upon it on several occasions. The research revealed other negatives of offsetting emissions, such as incomplete accounting of all associated emissions, flawed baselines, double claiming of units, short storage times with quick rereleases of carbon back to the atmosphere, damage to ecosystems, and human rights violations (Guardian 2023). These problems are not restricted to CDRS in connection to offsetting, but for example, inaccurate accounting is less problematic when CDRS is additional to emission reductions.

The IPCC has identified three different roles for CDRS: 1) complementing emission reductions in the near term, 2) neutralising hard-to-abate residual emissions to achieve net-zero CO_2 or greenhouse gas emissions balance, and 3) delivering net negative emissions in the long term (IPCC AR6 WGIII 2022).

Out of these three functions compensation-based CDRS finance models are only able to, under ideal conditions, address the second function identified by the IPCC, neutralising hard-to-abate sectors. Many of the recent CDRS policy design proposals put forward by think tanks and policymakers, including the European Commission (e.g. the CRCF, ETS integration), focus fully only on the 2nd role identified by the IPCC, on ways to compensate hard-to-abate emissions. One could argue that the two other roles identified by the IPCC to deliver additional CDRS to emission reductions and deliver net negative emissions deserve at least equal consideration.

The research conducted in the literature review also highlighted the incompatibility of compensating fossil emissions with methods based on biogenic carbon sequestration, such as reforestation or soil carbon enhancement. The biogenic carbon cycle is only able to provide for short storage times and CO_2 stored in ecosystems is easily reversibly and vulnerable to natural hazards, and therefore is not fungible with fossils either in the ground or with the length that emitted CO_2 remains in the atmosphere (IPCC 2021).

Comparing prices of different CDRS methods also revealed that some, particularly the poor quality sequestration credits offered on voluntary offsetting markets, are extremely cheap (a few cents per tonne of CO_2), and allowing emission compensation with those would lead to important mitigation deterrence (McLaren 2020). Then again methods that can be relatively accurately accounted for and that can offer permanent removal storage, such as direct air capture (DACS), are extremely expensive (1200€ per tonne of CO_2). Inclusion of DACS credits to the EU ETS for example for offsetting purposes would unlikely cause mitigation deterrence as the current EU ETS carbon price is at around 80€/per tonne CO_2, but equally unlikely to result in direct investment in DAC deployment via ETS. Another argument that speaks against focusing on emission compensation as a tool to finance CDR(S) is that offsetting becomes less relevant as emissions decrease the demand for offset credits should decrease as well, as there are fewer emissions to offset.

In light of the above indications, it would seem appropriate for the European Union to abstain from designing policy instruments that are based on offsetting emissions, and instead evaluate whether engaging in offsetting efforts is a worthwhile endeavour. This assessment should involve careful strategic consideration, weighing the potential benefits against the associated challenges and implications.

Public finance has a particular role in financing sequestration.

Public finance can be a stable and flexible source of funding for different types and stages of CDRS. The European Union Common Agricultural Policy currently, and potentially the Nature Restoration Law in the future, are examples of public finance instruments that can provide funding for sequestration enhancement activities. Both the Horizon Europe and the Innovation Fund provide research, development and demonstration finance for early development phases and not for the longer-term running cost. They are interesting for new CDRS research and pilot- and scale-up projects such as direct air capture. Reverse auctioning (competitive bidding) does not provide finance as such, but it is a tool that can be used for quantified public or private purchases.

Public finance could be considered suitable for activity-based funding for nature-based sequestration for several reasons. Very importantly nature provides a multitude of essential other services beyond carbon sequestration, such as biodiversity enhancement and ecosystem resilience that are aligned with the EU's broader environmental objectives (Scheid et al. 2023). These are easier to encompass with activity-based finance, in contrast to quantified per tonne CO_2 payments. Given the temporary nature of the biogenic carbon cycle combined with difficulties with accounting and baseline setting and the high of reversals, activity-based finance seems appropriate for enhancing sequestration and carbon storage in ecosystems.

Public finance also may be uncertain in the long term due to changes in government and shifting priorities. Government funding for projects can be subject to political changes and budgetary shifts.

Separate distinct targets offer numerous advantages.

Legally binding EU-wide or national member state level targets for permanent removals and biogenic sequestration are not direct financing mechanisms per se, but can incentivise CDRS in several ways. They create a regulatory framework that ensures that the targets are met. Government accountability drives action and ensures that governments implement policies to deliver CDRS. These can be in the form of carrots or sticks, such as subsidies, public procurement or taxes. Legally binding targets provide long-term certainty for the private sector to voluntarily increase investments towards CDRS.

Separate removal and reduction targets are necessary for avoiding mitigation deterrence, meaning that the current or potential future deployment of CDRS could lead to complacency in reducing greenhouse gas emissions in the near term. This happens when planned or needed emission reductions are substituted with actual or future CDRS. Therefore active balancing of the role of CDRS is essential as over-reliance on sequestration and removals for future climate targets diverts focus from necessary emissions reductions, and will escalate the cost of achieving net zero targets and net-negative emissions balance. This applies to both land-based sequestration and the technical CDRS methods, which face uncertainties in feasibility, scalability, and impacts.

Furthermore, considering the fundamental differences between land-based sequestration and the technological removal methods separating those from one another under dedicated targets and instruments becomes necessary. Ideally, the EU’s upcoming 2031-2040 policy framework should entail three separate targets, for emission reductions, land-based sequestration and novel technological carbon removal solutions. This would create clarity and transparency and allow more optimised support policies for different methods. Looking at the price ranges of different CDRS methods in Chapter 5 of the literature review, it becomes evident that sequestration is considerably cheaper whereas direct air capture for example is priced well above 1000 euros per tonne of removed CO_2, making it hard to apply fitting support tools for both under the same instrument, as the price directs the support to the cheapest options only.

8.2 Shortcomings and limitations of the research

The topic of carbon dioxide removal and sequestration is very new for the European Union policy development. Even basic definitions are not yet commonly agreed or set. At the time of writing the EU’s deliberations on CDRS governance and support instruments have been in a particularly rapidly moving phase which brings in certain inherent limitations and poses a challenge to the study's long-term relevance. However, it reflects a snapshot of discussions in the second half of 2023.

The chosen breadth of the topic, aimed at practical applicability in ongoing policy debates, necessitated a balance between depth and comprehensiveness. While the initial intent did not encompass an exhaustive analysis of various CDRS methods, their significance in the discussion became apparent in the course of writing. The research focuses on methods frequently featured in the EU's CDRS policy debates, recognising the impossibility of covering all existing methods. This study does not encompass the entirety of existing CDRS support tools, policies, and instruments explored outside the EU, which could potentially also be considered for the EU policy framework but were not included due to constraints.

This work is a document analysis, and the insights are derived from existing research and other material. The absence of direct perspectives from CDRS developers, obtained through interviews or similar means, represents a limitation. While such insights on CDRS developers’ thoughts on finance and other support tools would have delivered another layer of practicability into this work, the current focus was on synthesising information from available sources.

8.3 Potential future research

The European Union’s policy development on carbon dioxide removal and sequestration is set to continue and even further increase in the coming years. The European Commission will soon table its first proposals for the next climate policy cycle 2031-2040 on the targets and the governance architecture. Other upcoming near-term topics include the implementation of the EU certification framework for carbon removals (CRCF) and CDRS methods’ quality criteria.

Given the novelty of the topic, there is no shortage of avenues for potential future research. Some of the particularly interesting and related to this study include financing nature protection and protection of the EU's LULUCF sink, identifying safeguards of CDRS deployment for biodiversity and ecosystems, and implementing the polluter pays principle in the EU while avoiding offsetting.

9 CONCLUSIONS

This thesis explored carbon dioxide removal and sequestration (CDRS) support methods within the European Union policy framework with the particular aim of identifying those support methods that are suitable for achieving net negative emissions.

The conclusions of this study suggest that none of the EU's current governance and support instruments are suited for effective CDRS support. The EU policy is still underdeveloped when it comes to CDRS governance, definitions, quality criteria and support mechanisms. This calls first and foremost for a careful and thorough evaluation of different trade-offs, feasibility, and risks associated with different CDRS methods before any widespread implementation and policy decisions in the EU.

Following from this, there are four additional key takeaways from this research.

The first key conclusion drawn from this study is that given the fundamental differences between the CDRS methods associated with biogenic sequestration and the technical methods, it is paramount to govern and incentivise them with separate and different types of instruments.

Biogenic sequestration is coupled with the short carbon cycle that can provide only temporary storage and has a high risk of reversals. Furthermore, CO_2 sequestration and storage are only one of the many crucial functions of nature. Ecosystem resilience, food production, and water and air purification are a few examples of nature's functions that cannot be ignored when dealing with nature and land use. Any EU policy instrument aiming at nature-based sequestration and storage needs to give at least equal consideration to the other functions, making results-based quantified support models unsuitable for incentivising biogenic sequestration. Activity-based support instruments are more suited to capture the other crucial nature's functions, for example, biodiversity protection. The unsuitability of quantified results-based support tools for biogenic sequestration is further reinforced by the apparent difficulties in accurate accounting of the biogenic carbon flows.

The second key conclusion asserts that the European Union should abstain from designing policy instruments that are reliant on offsetting emissions. Emission compensation as a means to finance CDRS deployment is not effective, as even under ideal circumstances it fails to achieve a net negative emissions balance. The EU's first policy instrument proposal that was particularly designed for CDRS, the certification framework for carbon removals (CRCF), builds on the idea of emissions compensation. Integration of CDR(S) into EU ETS would equally be based on compensation. Instead, the EU should develop policy instruments that can ensure that CDRS functions as an additional measure to emission reductions. These instruments should ultimately facilitate the EU in achieving its post-2050 climate target of removing more CO_2 from the atmosphere than emitting into it.

The third key conclusion suggests that legally binding separate targets for technical removals and biogenic sequestration play a crucial role in incentivising CDRS in a way that can ensure additionality and provide a framework in which the EU's post-2050 climate goals can be achieved. The critical differences between emission reductions, land-based sequestration and technological removal methods call for three dedicated targets in the EU's future policy framework. A regulatory framework with three distinct targets ensures accountability and allows clarity, transparency, and optimisation of support policies for different methods. Importantly separation of CDRS from emissions reduction targets prevents mitigation deterrence and allows the defining of an appropriate role for CDRS.

The fourth and final key conclusion is that while carbon dioxide removal and sequestration is needed, it is very difficult, expensive, it takes time and it is challenging to do in a way that benefits the society as a whole. In the context of biogenic sequestration, the immediate benefits are realised only through the preservation of standing forests and resilient ecosystems. In conclusion, preventing emissions and protecting nature we have now proves simpler than capturing CO_2 from a 420 parts per million mixture.

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