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# Scaling Up Permanent Carbon Dioxide Removal: Can Policies Unlock a Large-Scale Deployment in the EU?

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## Abstract

This thesis investigates the critical role of policies in unlocking a large-scale deployment of permanent Carbon Dioxide Removal (CDR) in the European Union (EU). Employing a qualitative approach, this thesis combines insights from societal, market, and political actors to analyse the political economy of permanent CDR. In the frame of the research, six variables within the political economy that require policy support to ensure favourable dynamics are identified: legitimacy, maturity, public perception, quality assurance, demand, and supply. The research demonstrates that each variable inherently presents unique challenges that ultimately lead to low demand and supply of permanent CDR, effectively hindering large-scale deployment. It also reveals that current demand-inducing, demand-creating, and supply-inducing policies possess significant ambition, implementation, and policy gaps, contributing to today's unfavourable dynamics. Nevertheless, the research shows that policy options, which can theoretically address the challenges of each variable, exist. For instance, an educated public debate resulting in specific targets for permanent CDR, coupled with accelerated efforts to close research gaps and the implementation of transparent quality assurance schemes, could induce demand for permanent CDR. Furthermore, a long-term integration of permanent CDR into greenhouse gas (GHG) pricing frameworks supported by public procurement schemes could create additional sources of demand. Lastly, supply of permanent CDR could be induced through deployment subsidies, alongside measures creating an enabling environment, such as the reduction of regulatory barriers and the availability of $CO_2$ infrastructure, renewable energy, and sustainable biomass. The overarching finding of this thesis is that a large-scale deployment of permanent CDR requires holistic policy support. Hence, the research suggests the development of an overarching permanent CDR policy strategy considering the individual challenges of the variables and the overall dynamics of the political economy to unlock a large-scale deployment of permanent CDR in the EU.

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## List of Abbreviations

- 3-i: ideas-interests-institutions
- AOC: Actor, Objective, Context
- BECCS: Bioenergy with Carbon Capture and Storage
- CATF: Clean Air Task Force
- CCS: Carbon Capture and Storage
- CCU: Carbon Capture and Utilisation
- CCUS: Carbon Capture Utilisation and Storage
- CDR: Carbon Dioxide Removal
- CID: Clean Industrial Deal
- $CO_2e$: Carbon Dioxide Equivalent
- CORSIA: Carbon Offsetting and Reduction Scheme for International Aviation
- CRCF: Carbon Removal and Carbon Farming
- DACCS: Direct Air Carbon Capture and Storage
- DVNE: German Association for Negative Emissions
- ECL: European Climate Law
- EOR: Enhanced Oil Recovery
- EU: European Union
- EU ETS: EU Emissions Trading System
- EUA: EU Allowances
- ESABCC: European Scientific Advisory Board on Climate Change
- FID: Final Investment Decision
- GCD: Green Claims Directive
- GHG: greenhouse gas
- ICMS: Industrial Carbon Management Strategy
- IEA: International Energy Agency
- IEEFA: Institute for Energy Economics and Financial Analysis
- IF: Innovation Fund
- IPCC: Intergovernmental Panel on Climate Change
- LULUCF: Land Use, Land Use Change and Forestry
- MACC: Marginal Abatement Cost Curve

- MRV: Monitoring, Reporting, and Verification
- MRVL: Monitoring, Reporting, Verification, and Liability
- NDC: Nationally Determined Contributions
- NECP: National Energy & Climate Plan
- NECCS: Negative Emission via CCS
- NEP: Negative Emission Platform
- NGOs: Non-Governmental Organisations
- NZI: Net Zero Insights
- NZIA: Net Zero Industry Act
- RD&I: Research, Development, and Innovation
- RE: Renewable Energy
- ROI: Return on Investment
- SBTi: Science Based Targets initiative
- VCM: Voluntary Carbon Market

# Introduction

## Background and Context

The world faces the urgent challenge of climate change, driven by over a century of net greenhouse gas (GHG) emissions resulting from unsustainable energy use, land-use changes, and consumption patterns. The Intergovernmental Panel on Climate Change (IPCC) notes that without “urgent, effective and equitable mitigation actions, climate change increasingly threatens the health and livelihoods of people around the globe, ecosystem health and biodiversity” (IPCC, 2022, p. 40).

In a concerted effort to strengthen the global response to the threat of climate change, the international community reached an agreement on the Paris Agreement in 2015. By adopting the Paris Agreement, each undersigned nation committed to defining and implementing ambitious efforts, known as the Nationally Determined Contribution (NDC), that aim to “hold the increase in the global average temperature to well below 2°C above pre-industrial levels” (Paris Agreement, 2015). This ambition ultimately results in a state where emission sources and sinks are balanced, commonly known as a net-zero scenario.

Despite this target, the latest modelling by the IPCC highlights that policies and pledges are insufficient to meet the goals of the Paris Agreement (IPCC, 2022). The IPCC stresses that achieving and sustaining lower warming targets requires an immediate and substantial acceleration of efforts across all sectors, including a rapid transition away from fossil fuels, significant improvements in energy and material efficiency, and the unavoidable deployment of carbon dioxide removal (CDR) methods.

Whereas GHG reduction and efficiency measures have long been on the political agenda, CDR has recently gained attention in the political arena. The IPCC defines CDR as “anthropogenic activities that remove $CO_2$ from the atmosphere and store it durably” (IPCC, 2022, p. 36). CDR is commonly categorised into temporary and permanent CDR, varying in terms of its removal process, maturity, storage medium, permanence, cost, impacts, risks, and required governance. Temporary CDR refers to “the capture of $CO_2$ from the atmosphere and its storage in carbon pools such as forests, soils, or wood products, where the storage duration is inherently limited and can range from several years to centuries” (ESABCC, 2025, p. 14). Permanent CDR denotes “the capture and long-term storage of $CO_2$ in reservoirs such as geological formations or mineralised carbon, where the storage is designed to be stable and secure for thousands of years" (ESABCC, 2025, p. 14).

In a recent assessment, Direct Air Carbon Capture and Storage (DACCS), Bioenergy with Carbon Capture and Storage (BECCS), and biochar CDR are considered the most mature methods for achieving permanent CDR (ESABCC, 2025). In this report, the different CDR methods are described as follows:

DACCS is a process in which $CO_2$ is captured directly from the ambient air using liquid solvents or solid sorbents and stored permanently in geological formations (Figure 1).

In BECCS, the $CO_2$ produced when biomass is burned for energy or processed to biomethane is captured and subsequently stored durably (Figure 2). Unlike direct atmospheric $CO_2$ removal, BECCS utilises biomass to remove $CO_2$, as biomass initially captures atmospheric $CO_2$ through the process of photosynthesis. Without the BECCS process, this carbon would naturally be released back into the atmosphere, so capturing and storing it results in a net reduction.

Biochar CDR is also based on biomass and refers to the process of pyrolysis in which organic matter is heated up to high temperatures in an oxygen-limited environment, creating a carbon-rich material called biochar (Figure 3). Biochar is a stable product of the pyrolysis process that can store carbon for extended periods, most commonly when applied to soils as a soil amendment.

*Figure 1: DACCS CDR illustration*

*Note. Figure from DVNE (2025)*

*Figure 2: BECCS CDR illustration*

*Note. Figure from DVNE (2025)*

*Figure 3: Biochar CDR illustration*

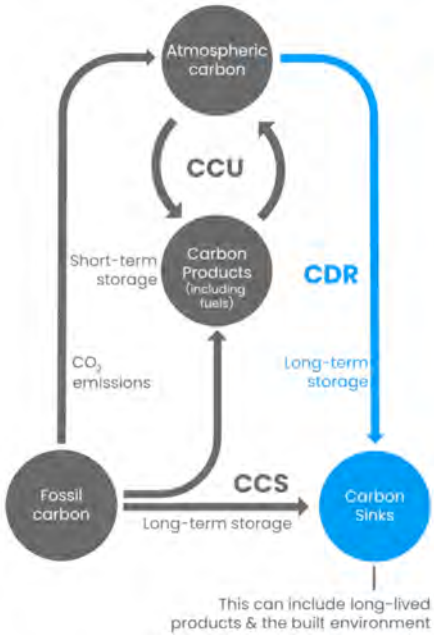
*Note. Figure from DVNE (2025)*

Although the necessity of temporary and permanent CDR to reach net-zero and net-negative scenarios is scientifically recognised, their scale and timing of deployment hinge on their integration into climate policy and the trajectories of gross emission reductions in different sectors (IPCC, 2022).

For instance, the European Union (EU) has gradually integrated CDR into its climate policy framework. In 2021, the EU adopted the European Climate Law (ECL), setting a binding objective of climate neutrality in the Union by 2050 with the aspiration to achieve negative emissions thereafter, which aligns with the temperature goals set out in the Paris Agreement (ESABCC, 2025). This regulation established “a framework for the irreversible and gradual reduction of anthropogenic greenhouse gas emissions by sources and enhancement of removals by sinks” (Regulation (EU) 2021/1119, 2021). Whereas temporary CDR was integrated into the framework with clear targets through the Land Use, Land Use Change and Forestry (LULUCF) Regulation, the role of permanent CDR in the EU climate policy framework remains vague (ESABCC, 2025).

The EU Industrial Carbon Management Strategy (ICMS), published in February 2024, provided one of the first significant policy pushes and recognition for permanent CDR in the EU (European Commission, 2024b). Even though the strategy’s focus was on the significance of Carbon Capture and Storage (CCS) and Carbon Capture and Utilisation (CCU) from industrial processes or fossil fuel emissions for achieving climate goals, which are inherently distinct from CDR, it also called for a strategic framework for all aspects of industrial carbon management, including permanent CDR. As Figure 4 illustrates, CDR captures and stores atmospheric $CO_2$, while CCS and CCU merely prevent new emissions from reaching the atmosphere.

*Figure 4: Differences between CDR, CCS, and CCU*




*Note. Figure from Carbon Gap (2022)*

Additional policy pushes for the deployment of permanent CDR originated from some EU member states (Carbon Gap, 2025a). In Germany, the development of a Long-Term Strategy for Negative Emissions was initiated. Denmark implemented deployment incentives for

CDR through the NECCS Fund, which provides targeted subsidies for CCS and CDR. Sweden introduced a reverse auction scheme for BECCS, a government program designed to provide financial support for the development and implementation of BECCS technologies.

Permanent CDR also gained attraction outside of the EU. For instance, Switzerland has developed a CCS and CDR roadmap, which includes permanent CDR in its national long-term strategy to achieve net-zero GHG emissions by 2050, and has set a target for permanent CDR at 7 Mt $CO_2$ per year by 2050 (Carbon Gap, 2025a). Under the Inflation Reduction Act, the USA incentivised the development of DACCS by enhancing the 45Q tax credit, providing up to $180 per ton of $CO_2$ captured and permanently stored through DACCS (CDR.fyi, 2025a).

While ambitions increase, the current volumes of permanent CDR remain negligible. In 2023, the global CDR capacity from all permanent methods was estimated to be approximately 1.35 Mt $CO_2$ per year (Smith et al., 2024). For comparison, in their modelled pathways that limit warming to 2°C, the IPCC (2022) estimates global cumulative CDR during 2020-2100 from BECCS and DACCS at 170-650 Gt $CO_2$ and 0-250 Gt $CO_2$ respectively (levels vary depending on assumptions about costs, availability, and constraints). Projected on a linear curve, the IPCC estimates would require DACCS and BECCS removal capacity of 2-11.25 Gt $CO_2$ per year between 2020 and 2100. Thus, current capacities fall short of the projected scenarios by a factor of 1,000 to 8,000.

Titled "Scaling Up Permanent Carbon Dioxide Removal: Can Policies Unlock a Large-Scale Deployment in the EU?", this research investigates the uptake of permanent CDR in the EU, aiming to determine whether policies can facilitate large-scale deployment. Achieving this involves identifying, understanding, and analysing the political economy of permanent CDR, including the dynamics and actors that shape it, and evaluating the impacts of policies on it. While recognising the existence of various promising permanent CDR methods, this research focuses on DACCS, BECCS, and biochar CDR, as their technical readiness level is the most advanced, having passed laboratory validation (ESABCC, 2025).

## Thesis Structure and Methodology

A robust qualitative methodology for gathering, structuring, and processing inputs is essential to identify and understand the actors and dynamics within the political economy of permanent CDR.

A suitable actor-based framework for gathering inputs in a structured manner is the Actor, Objective, Context (AOC) framework developed by Jakob et al. (2020), as it draws on a wide range of theoretical approaches for analysing political economies. This framework considers actors as the primary drivers of policy change or consistency, assuming that these actors pursue specific objectives that shape the political economy. In this context, the authors categorise actors into *societal actors* and *political actors*. While societal actors' objectives matter directly, political actors' objectives represent the interests of the societal actors they serve, as well as their idiosyncratic objectives, such as being re-elected or increasing their political power. The AOC framework also recognises that every actor acts in a general context, which includes institutional, economic, environmental, and discursive aspects, and that this context has an impact on policy development and choices.

As for-profit organisations play an essential role in the political economy of permanent CDR, *market actors* are added to the AOC framework as an additional category of actors. Market actors represent all societal actors with profit-oriented objectives.

The AOC framework is complemented by the ideas-interests-institutions (3-i) framework developed by Gauvin (2014) to gain a more comprehensive understanding of the actors' objectives. The framework holds that "policy development and choices are influenced by actors' interests and ideas, as well as by institutions" (Gauvin, 2014, p. 1). These elements are described by Gauvin as follows.

*Ideas* refer to the definition of the problem that the policy options aim to solve. They address the knowledge of what is, the views about what ought to be, and the effectiveness, feasibility, and acceptance of the policy option to bridge the gap between the current situation as perceived and the desired outcome.

*Interests* refer to the real or perceived agenda of actors and their desire to influence the policy process in order to pursue their own objectives. To analyse the interests of an actor, it is imperative to understand who benefits and who bears the cost from policy decisions, as well as the distribution of benefits and costs among stakeholders.

*Institutions* refer to the formal or informal procedures, routines, conventions, and norms integral to the organisational structure of the political economy. Institutional aspects will complement the understanding of the actors' context, focusing on how past policies create potential path dependencies for future political dynamics.

Implementing the combined AOC-3i framework requires three key steps: first, identifying relevant and diverse societal, political, and market actors; second, understanding their ideas, interests, and objectives within the political economy of permanent CDR; and third, identifying relevant context factors.

Hence, by applying these steps, the following three sub-questions of the research question can be answered:

1. What are the societal, market, and political actors acting in the political economy of permanent CDR?
2. What are the actors' ideas, interests, and objectives?
3. In what context do the actors act?

Assuming actors pursue differing objectives, in alignment with their ideas and interests, to influence the political economy of permanent CDR, key variables of this political economy can be deduced by aggregating common themes from these identified ideas, interests, and objectives. Variables, in this context, refer to dynamic factors influenced by the conflicting and reinforcing ideas, interests, and objectives of the actors. Once identified, each variable will be analysed to understand the challenges affecting its state. This leads to the next sub-questions:

4. What are the key variables influencing the political economy of permanent CDR?
5. What are the challenges within these variables?

Given that a political economy functions as a complex system where elements, in this case identified variables, interact with each other, concepts from Systems Thinking are utilised to structure the variables that were deduced.

Systems Thinking is described as a concept for understanding complex problems by focusing on causal relationships and feedback loops between seemingly isolated variables that reinforce or balance system behaviours (Haraldsson, 2004). According to Haraldsson, it is based on the principle that problems are often non-linear and that one isolated factor cannot be held solely responsible for an outcome caused by the behaviour of the whole system. He describes that due to its holistic, non-discriminatory characteristics, Systems Thinking is often used as a communication tool to help actors understand the impacts of their actions. At its core, System Thinking models consist of multiple dynamic variables within certain boundaries, connections between these variables, and the system's behaviour described by causal loops.

Applying System Thinking to the identified variables will help answer sub-question number six:

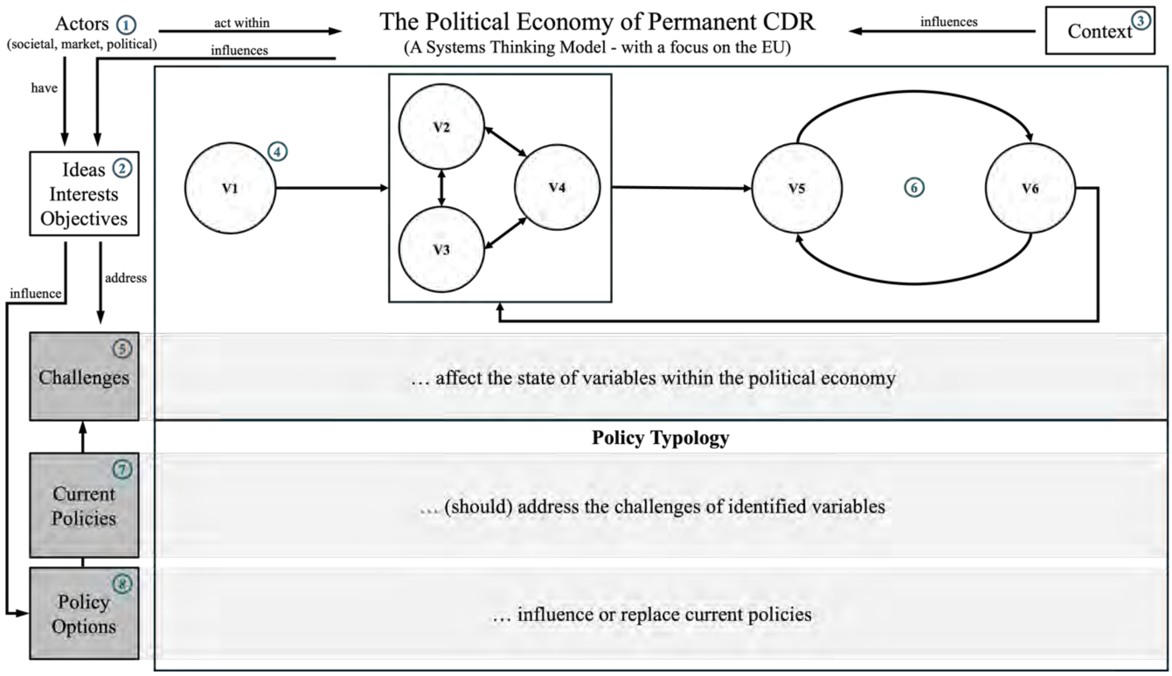
6. How do the identified variables influence each other?

Once the variables of the political economy and their challenges are understood, current policies and potential policy options can be assessed to understand their impact on the political economy of permanent CDR. In this process, the following sub-questions will be addressed:

7. What are the relevant existing policies, and how do they address the challenges of identified variables?
8. What are potential policy options, and how could they address the challenges of identified variables?

Figure 5 illustrates the explained methodology. Applying this process creates the necessary background to discuss whether policies can unlock a large-scale deployment of permanent CDR in the EU.

*Figure 5: Illustration of applied methodology*




*Note. Numbers in blue refer to the sub-questions*

The quality of the analysis and subsequent discussion is directly linked to the quality of the inputs, demanding a comprehensive source base. Data collection for this research involved two key methods: first, 15 semi-structured interviews with key stakeholders within the political economy of permanent CDR, including project developers, CDR purchasers, market facilitators, investors, Non-Governmental Organisations (NGOs), trade and business associations, and the European Commission; and second, an extensive literature review.

This literature review incorporated reports, papers, and articles from scientific advisory committees, academia, NGOs, think tanks, trade and business associations, prominent experts, market actors, and political actors. A detailed introduction to the analysed actors will be provided throughout the thesis. It is noteworthy that the interviews were anonymised to ensure confidentiality and encourage participants to share their honest and unfiltered perspectives. More information about the interview process is available in Appendix A, "Interviews with Societal & Market Actors", and Appendix B, "Interview(s) with Political Actor(s)".

This thesis is structured in two parts. The first part presents a qualitative analysis of the actors, variables, and dynamics shaping the political economy of permanent CDR, addressing sub-questions 1 through 6. The second part discusses how policy can enable large-scale deployment in the EU by answering sub-questions 7 and 8. It draws on insights from the qualitative analysis of the political economy of permanent CDR and discusses the impact of existing policies and potential policy options on the variables and dynamics identified in the first part.

The thesis concludes by summarising the main findings, highlighting the limitations of the research, and suggesting further research topics and recommendations in this field.

The findings of this research represent the independent view formed by the author through his research process. However, it is noteworthy that the author previously worked at Airbus, a market actor in the political economy of permanent CDR, and that this research is conducted in cooperation[1] with the German Association for Negative Emissions (DVNE), the first national CDR association in the EU that serves as a multi-stakeholder, industry-led platform to scale up the temporary and permanent CDR in Germany (DVNE, 2024).

Lastly, the author would like to acknowledge the use of Grammarly for assistance with grammar, spelling, and punctuation checks, as well as for suggestions on refining linguistic expression during the writing and proofreading phases of this thesis. All content, arguments, and interpretations remain those of the author.

[1] The collaboration with DVNE primarily facilitated access to interview partners. It did not influence the research design, the analyses and assessments undertaken, or any conclusions drawn.

# Part 1: Analysing the Political Economy of Permanent CDR

## Key Actors in the Political Economy

Understanding the ideas, interests, and objectives of the actors involved requires a solid comprehension of the roles of the different actors within the political economy. The research is based on selected actor groups and actors deemed as most representative or influential. The following part explains the different groups of actors, their roles, and the reasons for their inclusion in the analysis.

### Societal Actors

*Societal actors* are characterised by their non-profit orientation and represent diverse societal interests. The analysis presented herein includes the perspectives of different societal actor groups, which are listed below.

*Scientific advisory committees* are essential for translating complex scientific knowledge into actionable policy advice. They help governments and institutions to design, implement, and refine strategies to address climate change challenges, ensuring that decisions are informed by the latest and most robust scientific evidence. In the thesis, insights from the European Scientific Advisory Board on Climate Change (ESABCC), the Intergovernmental Panel on Climate Change (IPCC), and the International Energy Agency (IEA) are used as these scientific advisory committees are mandated to advise EU policymakers and have a track record of influence, routinely being cited in policy documents, legislation, and international negotiations.

*Academia* in a political economy provides the evidence, expertise, and critical dialogue necessary for sound policymaking. This thesis draws insights from an extensive literature review published in 2024 and several individual papers published thereafter.

*NGOs and think tanks* are essential actors in the political economy. NGOs amplify the voices of citizens, advocate for marginalised groups, and hold governments accountable, while think tanks provide rigorous research and propose policy innovations. Several NGOs and think tanks that were most prominent in the public debate were considered when developing the thesis.

*Trade and business associations* aggregate and represent the interests of businesses, influence policy and regulation, and facilitate communication between the private sector and policymakers. This research utilised input from EU-level associations representing the DACCS, BECCS, and biochar CDR industry, supplemented by insights from comparable national organisations of EU member states.

*Prominent experts* in a political economy act as knowledge brokers, advisors, and agenda-setters. They advise policy development processes, enhance public debate, and help bridge the gap between complex technical knowledge and practical governance. This thesis incorporates input from prominent experts, identified by their LinkedIn follower count as an indicator of prominence.

Table 1 shows the different societal actors whose views and perspectives were considered in the development of this thesis.

*Table 1: Societal Actors*

| | | |
|---|---|---|
| Societal Actors | Scientific advisory organisation | European Scientific Advisory Board on Climate Change (ESABCC), Intergovernmental Panel on Climate Change (IPCC), International Energy Agency (IEA) |
| | Academia | Represented by the extensive literature review "The State of Carbon Dioxide Removal," published in 2024 and several individual papers published in 2024 or later |
| | NGOs and think tanks | **Greenpeace**, **Carbon Market Watch**, Clean Air Task Force (CATF), CONCITO, **Fern**, Institute for Energy Economics and Financial Analysis (IEEFA), Öko-Institut, Carbon Gap, Bellona Europa, Carbon180 |
| | Trade & business associations | **Negative Emission Platform (NEP)**, Biochar Europe, Deutsche Vereinigung Negativer Emissionen (DVNE), **German Biochar e.V.**, Carbon Capture Coalition |
| | Prominent experts | Sebastian Manhart (41k followers), Robert Höglund (30k followers), Eve Tamme (26k followers) |

*Note. Actors who participated in the interviews are marked in bold.*

<u>Market Actors</u>

*Market actors* pursue profit-oriented objectives and act along the value chain of permanent CDR. The following market actors were considered in the research process.

*Technology providers* develop technologies capable of removing and permanently storing atmospheric $CO_2$.

*Project developers* deploy the technologies and typically operate the DACCS, BECCS, or biochar CDR plants with the goal of generating CDR offset credits.

The IPCC defines an *offset credit* as the "reduction, avoidance or removal of a unit of greenhouse gas (GHG) emissions by one entity, purchased by another entity to counterbalance a unit of GHG emissions by that other entity" (IPCC, 2023, p. 1796). A *permanent CDR offset credit* is commonly denoted as an offset credit that aligns with the defined characteristics of a permanent CDR. Hence, it is a tradable certificate presenting one metric tonne of $CO_2$ removed from the atmosphere and durably stored. Offset credits play an important role as CDR is not a consumer product but a service to society, which can be purchased through these credits[2] (Previte & Swaddle, 2025).

Smith et al. (2024) describe the generation of offset credits as a crucial process involving numerous key market actors. Typically, a credit is issued for trading by a registry after the removal effort has been completed. After removal but before issuance, a third-party auditor certifies the credit, ensuring that the effort is valid and in accordance with a specific methodology. These methodologies are developed by carbon crediting programmes, which are standard-setting organisations that can be either market actors or regulatory bodies.

Another key market actor described by Smith et al. (2024) is the *final user* (e.g. companies) that purchases CDR offset credits directly or through intermediaries (e.g. brokers or traders). Credits are usually retired by final users for either voluntary or compliance purposes, but some may be purchased and stored for later trading. Sellers can also arrange future sales (e.g. offtake agreements) of credits directly with buyers. To avoid double-counting, each credit can only be retired one time and by one organisation.

*Other market actors* facilitate the development of the market or the transaction of offset credits. Other market actors include investors, traders, brokers, quality assurance providers, consultancies, market intelligence providers, and decarbonisation standards providers.

Table 2 presents the various market actors whose views and perspectives were taken into consideration in the development of this thesis. It is noteworthy that as of April 2025, Climeworks and 1PointFive were responsible for 70% of global DACCS CDR offset credit sales, and Stockholm Exergi for 43% of global BECCS CDR offset credit sales (CDR.fyi, 2025b). Additionally, as of April 2025, the CDR credit purchasers consulted in the frame of

[2] To enhance readability, the terms "offset credits" and "credits" will be used interchangeably.

the research purchased 76% of all BECCS, DACCS and biochar CDR offset credits sold globally (CDR.fyi, 2025b). Since the biochar CDR market is less concentrated and scattered across 78 different project developers (CDR.fyi, 2025b), insights from biochar project developers are primarily drawn from the two trade and business associations considered in the societal actors category.

*Table 2: Market Actors*

| | | |
|---|---|---|
| Market Actors | Technology providers and project developers | **Stockholm Exergi**, **1PointFive**, **Climeworks** |
| | Final users | **Airbus**, **Microsoft**, **NextGen CDR** |
| | Other CDR market actors | Carbonfuture (quality assurance service provider and broker), **Removall Carbon** (broker), Boston Consulting Group (consultancy), **Carbon Removal Partners** (investor), SBTi (standard provider), **CDR.fyi** (market intelligence provider), |

*Note. Actors who participated in the interviews are marked in bold.*

Political Actors

*Political actors* directly influence the policymaking process, integrating the interests of societal and market actors they serve into policies and pursuing their idiosyncratic objectives, such as re-election, increasing political power, or enhancing international standing.

The *European Commission* is a central political actor as it plays a key role in shaping the political economy of permanent CDR through policy design and target-setting. As the EU's executive body, it drives the development of frameworks to scale permanent CDR while balancing climate goals with economic interests.

Besides their involvement in national policymaking, *national governments and their ministries* participate in and influence the legislative process of EU policies. Furthermore, they are essential intermediaries between EU-level policy frameworks and local implementation realities. They provide regulatory, financial, and institutional support while ensuring alignment with broader climate and industrial objectives.

*Political parties in the European Union*, both at the EU and national levels, are also key political actors. Their influence is exerted through legislative action, agenda setting, coalition building, and the articulation of public and stakeholder interests.

Table 3 presents the various political actors whose views and perspectives were taken into consideration in the development of this thesis.

*Table 3: Political Actors*

| | | |
|---|---|---|
| Political Actors | European Commission | **DG Clima** |
| | Selected national governments and their ministries | Government and ministries of Germany, Denmark and Sweden |
| | Selected political parties in the EU | EPP, S&D, Renew |

*Note. Actors who participated in the interviews are marked in bold.*

## Analysis of Key Variables within the Political Economy

As described in the introduction, societal, market, and political actors differ in their idea of permanent CDR, which refers to their perception of the current situation, their vision of what an ideal future would look like, and their views of how to transition from the current to a desired situation. Underpinned by each actor's distinct interests and objectives and shaped by prevailing contextual factors, these elements influence numerous variables within the political economy of permanent CDR. Variables, in this context, are understood as dynamic factors within the political economy that could enable or hinder a large-scale deployment.

The following sub-chapters elaborate on these variables, their individual challenges, and their dynamics. Following the methodology outlined in the introduction, the analysis is structured around six variables. These variables are derived from common themes identified during the research and are considered key elements of the political economy of permanent CDR. After analysing each variable individually, a Systems Thinking Model is constructed to provide an overview of the overarching dynamics.

It is noteworthy that another author might have chosen a different constellation of variables or a different Systems Thinking Model. However, according to the principles of Systems Thinking, the arrangement of variables supports the understanding of the complex system at play and does not influence the findings (Haraldsson, 2004).

Legitimacy

Legitimacy emerges as the first key variable. This chapter will examine how actors perceive the legitimacy of permanent CDR deployment, defining legitimacy here as being reasonable and acceptable in the pursuit of societal goals. It contends that while there is a consensus among actors regarding the legitimacy of permanent CDR based on its decarbonising potential and economic opportunity, the scale and timing of its deployment are debated, primarily driven by concerns about mitigation deterrence and potential adverse environmental impacts.

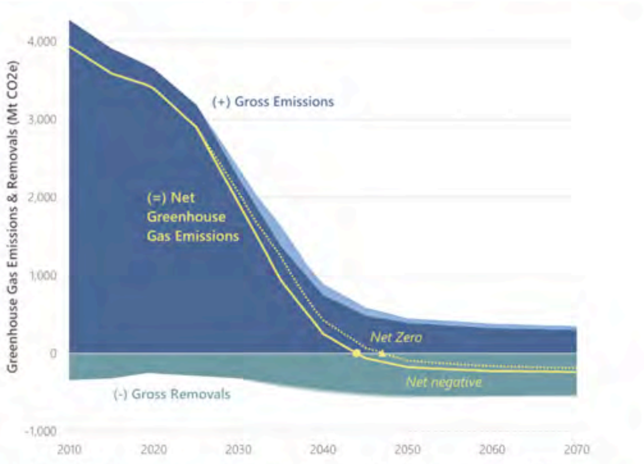
The IPCC (2022) attributes three core functions to CDR:

1. Lowering $CO_2$ emissions in the near term;
2. Counterbalancing hard-to-abate residual emissions to reach net zero; and
3. Achieving net-negative emissions in the long term if deployed at levels exceeding annual emissions.

Throughout the interviews and the literature review, these three core functions were reiterated multiple times, indicating that the core idea of CDR appears to be legitimate.

For instance, the scientific advisory council ESABCC (2025) projects, in its modelled scenarios, that CDR will play a crucial role in the EU's ambition to reach carbon neutrality by 2050 and net-negative emissions thereafter, as shown in Figure 6. Although the ESABCC acknowledges the challenge of estimating the exact level of CDR required due to the unknown availability of mitigation measures and the changing technological and socio-economic landscape, they estimate an annual removal capacity of 544-568 Mt $CO_2$ by 2050, with 119-256 Mt $CO_2$ of this total to be removed by permanent CDR.

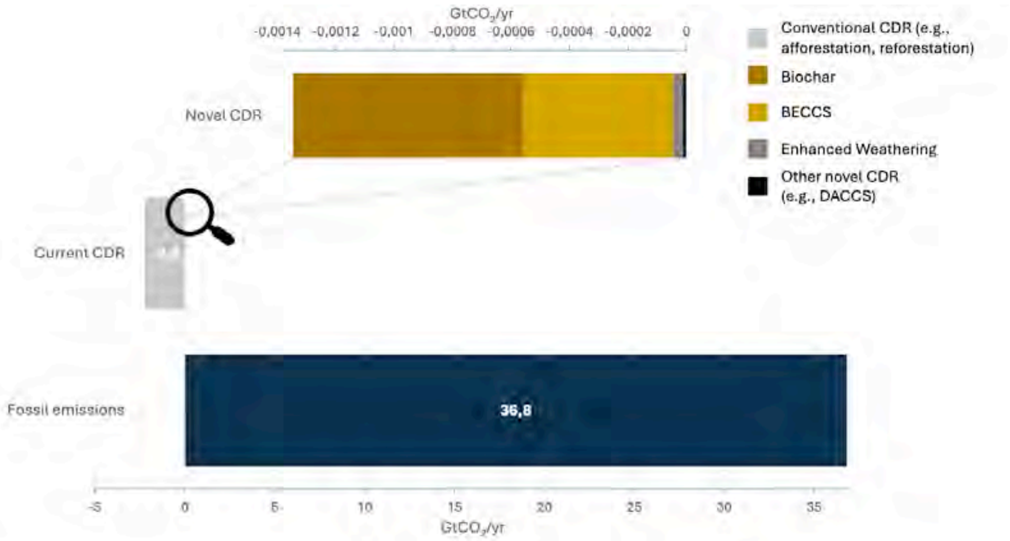
*Figure 6: Role of removals towards EU climate neutrality*




*Note. Figure from ESABCC (2025, p. 31)*

Nevertheless, the current level of permanent CDR is significantly below projected future needs. Figure 7 illustrates this discrepancy on a global scale. In 2023, permanent CDR (sometimes referred to as novel CDR) represented only 0.06% of total CDR and a mere 0.004% of total emissions (Edenhofer et al., 2024).

*Figure 7: Fossil emissions and total amount of CDR in 2023*




*Note. Figure from Edenhofer et al. (2024, p. 2)*

This significant gap between today's and projected levels leads to two diverging conclusions, which form the basis for subsequent interests and objectives of actors and were evident throughout the interviews. On the one hand, various actors, especially market actors, advocate for accelerated action to increase the uptake of permanent CDR in order to leverage the functions attributed to CDR by scientists. They view permanent CDR as an innovative, scalable product that complements $CO_2$ reduction and natural sink enhancement in climate change mitigation. On the other hand, societal actors, particularly NGOs concerned about insufficient $CO_2$ reduction efforts, see a potential for mitigation deterrence, giving emitters "the license to emit" in exchange for future removal efforts.[3]

Mitigation deterrence, sometimes referred to as the moral hazard effect, is "the idea that CDR might negatively impact emission reduction efforts or intentions" (Smith et al., 2024, p. 111). Mitigation deterrence can occur in different ways. In the conventional sense, it refers to the economic decisions taken by emitting companies. If permanent CDR is seen as equivalent to emission reduction measures, emitting companies might first delay implementing abatement measures until sufficient information for cost-optimal decision-

[3] See Appendix A, "Interviews with Societal & Market Actors"

making is gathered, a situation commonly known as the "hold-up problem" (Sultani et al., 2024). Driven by budget or time pressure, they might then decide to opt for the potentially cheaper CDR pathway (Stolz & Probst, 2024), which could prevent learning cycles and cost reductions in abatement technologies (Edenhofer et al., 2024).

Another form of perceived mitigation deterrence relates to one of the very core functions of permanent CDR, the ability to decouple the time and place of $CO_2$ removal from the original emission point. Edenhofer et al. (2024) describe this function of decoupling as the enabler for *temperature overshoot management* (the ability to exceed temperature limits temporarily by removing $CO_2$ later). Nevertheless, societal actors view this as a potential incentive for emitting companies to rely on the availability and effectiveness of future technology, thereby delaying or even halting mitigation efforts pursued today[4].

Furthermore, mitigation deterrence can occur in the context of resource availability. BECCS and biochar CDR sequester carbon from the biosphere, not directly from the atmosphere. Societal actors are concerned that the expansion of these technologies, if they rely on non-sustainable biomass, could lead to biosphere depletion (Pigeon, 2024). This concern is especially pertinent as the EU's LULUCF carbon sink has diminished by approximately one-third over the last decade, a decline largely attributable to reduced forest sequestration due to increased harvesting and decreasing soil carbon stocks from agricultural and peatland management (ESABCC, 2025). Additionally, some societal actors expressed concerns in the interviews that the land-use needs for additional biomass could compete with the expansion of renewable energy sources[5], another form of mitigation deterrence.

DACCS is also associated with concerns regarding resource availability, even though it does not rely on the availability of sustainable biomass. For its operation, DACCS requires significant amounts of low-carbon electricity. Studies estimate future electricity needs for DACCS at 0.8 MWh per ton of $CO_2$ captured[6] in 2050 (Mühlbauer et al., 2025). Taking the projection from the ESABCC and assuming a high permanent CDR scenario using only DACCS (256 Mt $CO_2$ removal in 2050), an annual low-carbon electricity demand of 205 TWh would be required for DACCS operation in 2050. This represents 14% of the low-carbon electricity produced in the EU in 2022 (Eurostat, 2024) or 3.4% of the EU's estimated low-carbon electricity production in 2050 under the IEA's Announced Pledges Scenario

[4] See Appendix A
[5] See Appendix A
[6] Energy optimised conditions: low temperature operation, fully electrified process, and onshore storage

(IEA, 2024). Societal actors are concerned that the substantial electricity demand from DACCS could compete with other needs for low-carbon electricity, potentially delaying the phase-out of fossil fuels in electricity production[7].

So far, the legitimacy of permanent CDR has been analysed from a climate change perspective, showing that it can be, at the same time, supportive and detrimental in mitigating global warming. Another perspective that legitimises the deployment of permanent CDR in the EU relates to its potential to increase the cost-effectiveness of decarbonisation and the creation of a new industry, thereby contributing to economic growth.

In response to global pressure to align economic activities with the targets outlined in the Paris Agreement, approximately half of the Forbes Global 2000 companies have established voluntary net-zero targets (Stolz & Probst, 2024). Furthermore, many high-emitting economic activities became subject to carbon pricing schemes or carbon taxes. For instance, the EU Emissions Trading System (EU ETS) places a price on every tonne of $CO_2$ emitted by more than 15,000 stationary installations and 1,500 aircraft operators (European Environment Agency, 2025), governing approximately 40% of total GHG emissions in the EU (European Commission, 2024a).

These voluntary commitments and compliance obligations drive economic actors to invest in $CO_2$ reduction measures. In this context, economists refer to the Marginal Abatement Cost Curve (MACC), which essentially represents the additional cost incurred to achieve one more unit of emissions reduction (Edenhofer et al., 2024). Economists describe that while different economic actors have distinct MACCs, the nature of the curve shows that each additional effort of abatement is more costly than the previous one. Hence, as an economic actor (or the collective under schemes like the EU ETS) approaches net zero, abatement becomes increasingly expensive.

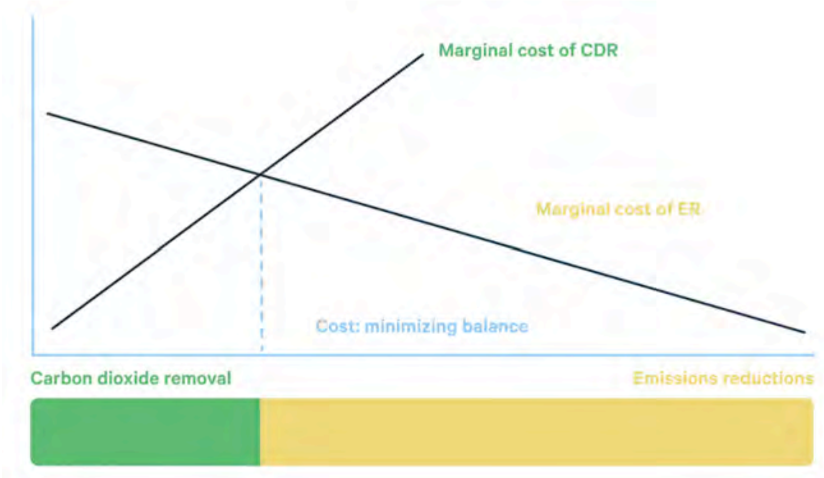
The effects of increasing the cost of decarbonisation efforts are already visible. A recent study found that, out of a sample of 1,041 firms, 9% failed, and 33% quietly abandoned their voluntary net-zero goals (Jiang et al., 2025). Interviewed market and societal actors assume this shift is related to the additional costs associated with decarbonising economic activities and the subsequent change in the international focus from decarbonisation to competitiveness[8]. Recent policy developments underscore this trend, such as the European

[7] See Appendix A
[8] See Appendix A

Commission's Clean Industrial Deal (CID), published in February 2025, which serves as a clear signal to boost the competitiveness of the European economy (European Commission, 2025c).

Against this background, interviewed market, societal, and political actors see an opportunity in permanent CDR. If integrated into net-zero standards such as those offered by the Science Based Targets initiative (SBTi) or compliance schemes like the EU ETS, permanent CDR could curb the MACC, thereby reducing decarbonisation costs while remaining on track towards decarbonisation targets[9]. The MACC would essentially be capped by the marginal cost curve of permanent CDR (Figure 8), which represents the additional cost incurred to achieve one more unit of carbon removal.

*Figure 8: Marginal cost of abatement capped by the marginal cost of permanent CDR*




*Note. Figure from Boyd et al. (2024, p. 38)*

For instance, a study on integrating permanent CDR into the EU ETS demonstrates a potential reduction in the cost of EU Allowances (EUA) from a projected €650 to €343 by 2050, where one EUA denotes the right to emit one tonne of Carbon Dioxide Equivalent ($CO_2$e) within the system (Sultani et al., 2024).

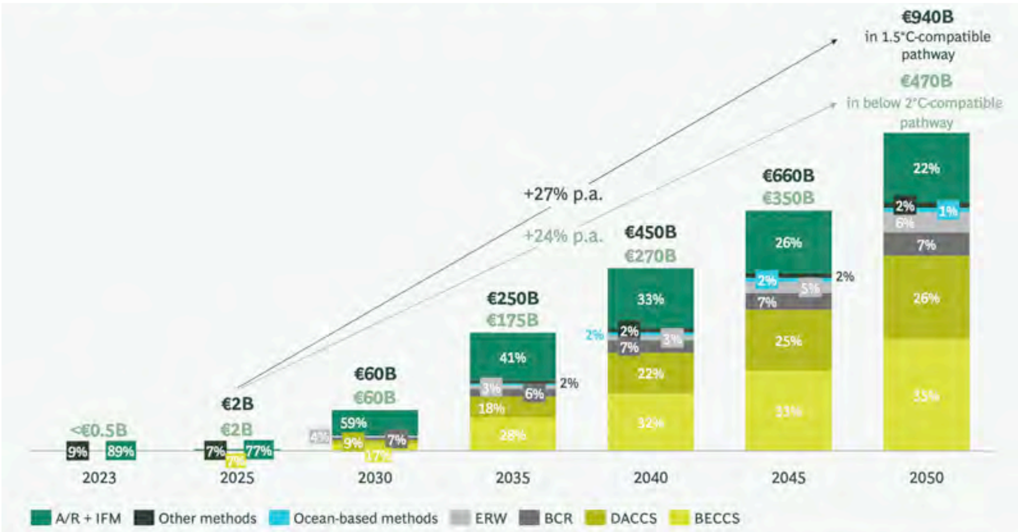
However, as pointed out by a Policy Officer in the European Commission, convergence between EUAs and permanent CDR credit prices may occur only in the mid- to long-term. This is evident when comparing recent prices and volumes. Whereas EUAs traded around €70 in the first quarter of 2025 (EEX, 2025), with approximately 1.3B EUAs available on the market for the year (European Commission, 2025d), the weighted average prices for BECCS, DACCS, and biochar CDR on the voluntary market in 2023 were significantly

[9] See Appendix A and Appendix B, "Interview(s) with Political Actor(s)"

higher at €300, €715, and €131 respectively, with a total volume of approximately 4 million CDR credits traded (Smith et al., 2024).

Although the effects of curbing the MACC may not be immediately apparent in the short term, a large-scale deployment of permanent CDR can bring other short-term economic benefits, such as job creation and GDP growth. A recent study estimates that deploying permanent CDR in accordance with a 1.5°C-compatible or below 2°C-compatible pathway can generate economic potential in the EU of €25 billion by 2030 and up to €733 billion by 2050. Most of this potential stems from BECCS, DACCS, and biochar CDR (see Figure 9; temporary CDR was deducted from the total) (BCG & DVNE, 2024).

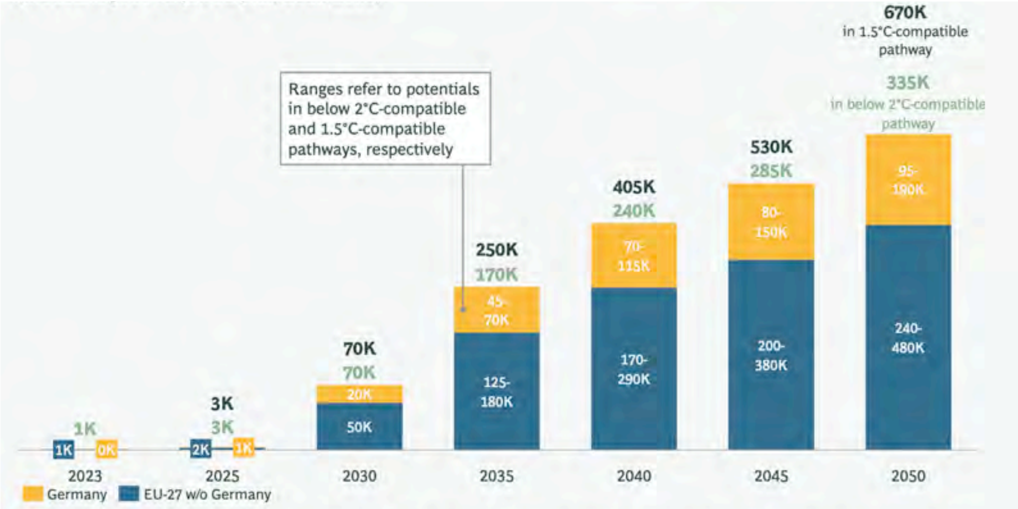
*Figure 9: CDR-induced economic potential by method*




*Note. Figure from BCG & DVNE (2024, p. 42)*

The study highlights that this economic potential is mainly driven by activities in plant technology and equipment, operations and maintenance, and $CO_2$ transport and storage infrastructure (BCG & DVNE, 2024). Additionally, it is stated that Europe, and especially Germany, is well-positioned to perform these activities due to a strong competitive advantage in mechanical and plant engineering. Translated into jobs, the study estimates a CDR-induced potential of up to 670k jobs in Europe in a 1.5°C-compatible pathway and 335k jobs in a below 2°C-compatible pathway, where most of the jobs would be in the permanent CDR sector (Figure 10).

*Figure 10: CDR-induced job potential by region*




*Note. Figure from BCG & DVNE (2024, p. 52)*

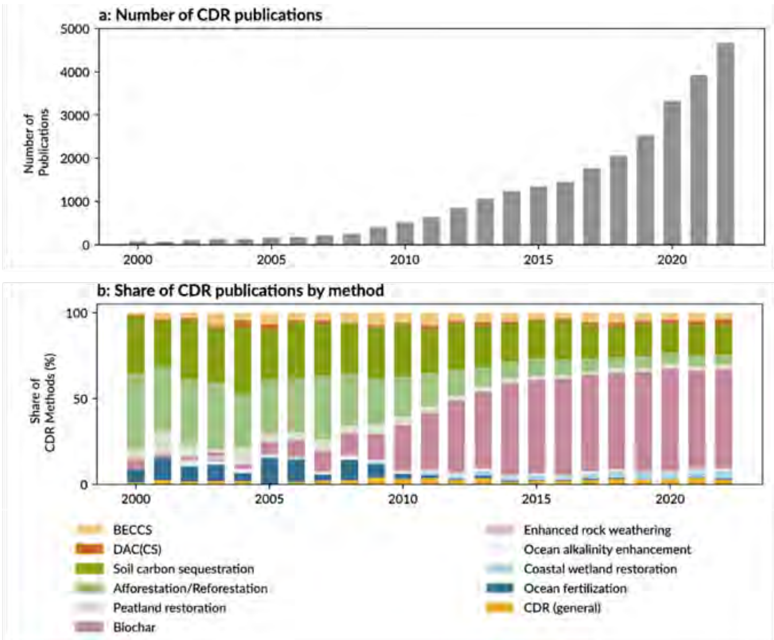
The legitimacy of permanent CDR lies primarily in its mid- to long-term potential. If deployed at a large scale, it is an important tool to counterbalance residual emissions and increase cost-effectiveness on the journey to net zero. It also offers humanity the possibility to manage overshoot scenarios and "clean up" historic emissions. Furthermore, deployment can lead to significant economic benefits for the EU by creating a new clean tech industry, offering GDP growth and job creation. However, short-term mitigation deterrence and adverse environmental impacts weigh on the other side of the balance, questioning its short-term legitimacy. Ultimately, today's main challenge is to reduce emissions as quickly as possible while avoiding any mitigation deterrence. This creates a dilemma: neglecting permanent CDR deployment today due to mitigation deterrence concerns risks foregoing its decarbonisation and economic mid- and long-term benefits. The key challenge for current and future policies is to reduce the perceived and actual risk of mitigation deterrence associated with permanent CDR, thereby ensuring its legitimacy. The second part of this thesis will investigate how existing policies and potential policy options address this challenge.

Maturity

The second variable identified in the research process is the maturity of technology and governance of large-scale permanent CDR deployment. This chapter examines the varying perceptions of actors regarding this level of maturity and the interests and objectives derived from these perceptions. A central observation is that, despite the rapid increase in knowledge, some actors perceive the maturity as being prohibitively insufficient for safe large-scale deployment. This creates another dilemma, as deployment and learning cycles are necessary to gain further maturity and alleviate concerns.

Although the number of scientific papers published cannot directly measure the level of maturity, its growth serves as an indicator of interest in a field and its potential for knowledge expansion (Smith et al., 2024). Figure 11 shows a significant increase in the global number of CDR publications over the last decade, now reaching approximately 5,000 publications per year. It also demonstrates that since 2013, over 50% of these publications have focused on permanent CDR, with papers on biochar accounting for the largest share and the number of papers on DACCS increasing rapidly.

*Figure 11: Number of publications and share of CDR publications by method*




*Note. Figure from Smith et al. (2024, p. 38)*

Despite this significant increase in scientific publications, many research gaps persist. The NGO Carbon Gap has established a database tracking 350 open research gaps, addressing, among others, the impact of permanent CDR on society and the environment, optimisation and cost reduction of removal technologies, quality assurance and governance issues, and $CO_2$ transport and storage capabilities (Carbon Gap, 2025e).

Within the framework of the interviews, a few perceived research gaps were repeatedly mentioned, namely the effectiveness of carbon capture technologies, the permanence of $CO_2$ storage, and the capacity to assess the quality of permanent CDR. Here, quality refers to the extent to which a CDR activity represents a tonne of $CO_2$ that has been truly removed (considering all lifecycle emissions of the process) and the co-benefits generated by the activity.[10]

A case in point illustrating the differing perceptions of maturity is the reaction of NGOs to Stockholm Exergi's BECCS project in Sweden.

In March 2025, Stockholm Exergi's project to build the first large-scale BECCS facility in Europe, designed to remove 0.8 Mt $CO_2$ yearly, reached its Final Investment Decision (FID). Following the FID, construction has commenced for this €2.7 billion project, with the intention of starting operations in 2028 (Stockholm Exergi, 2025b). NGOs criticise this project for several reasons. Firstly, they are concerned that the project may not reach its planned 90% capture rate, citing that carbon capture rates have significantly underperformed in other projects and have barely reached 80% (Pigeon, 2024). Secondly, they contest that the risk of using non-sustainable biomass is high, claiming that definitions for sustainability criteria are loose, not reflecting true emissions in harvesting and logging and that control capabilities are missing (Pigeon, 2024). In short, they perceive that the current effectiveness of carbon capture technology and today's governance of biomass are insufficient to ensure true $CO_2$ removal from BECCS.

Another point of contention concerns the differing perceptions of the maturity of $CO_2$ storage. Whereas most interviewed actors considered $CO_2$ storage well-researched, a few highlighted that debates regarding its technical and commercial viability remain[11]. They referred to research analysing the geological $CO_2$ storage locations Sleipner and Snøhvit in Norway. In this research, the author emphasises that $CO_2$ storage carries high uncertainties given the very limited practical, long-term experience of permanently keeping $CO_2$ in the ground (Grant Hauber, 2023).

The aforementioned concerns lead to diverging interests and objectives among actors. Some societal actors perceive the research gaps as prohibitive for the deployment of permanent CDR, arguing that, given the current level of maturity, the legitimacy of permanent CDR deployment is not apparent (Jäger et al., 2024). In contrast, other actors, particularly market actors, argue that a more exploratory approach must be taken to gather the necessary

[10] See Appendix A
[11] See Appendix A

knowledge for large-scale deployment, as the industry must undergo several cycles of learning to ensure effectiveness in delivering the benefits that permanent CDR offers[12].

Despite these differing views on immediate deployment, most actors conclude that more research is required to address uncertainties, clarify the risk-benefit balance, and develop approaches for managing risks and enhancing benefits associated with permanent CDR[13]. In the second part of the thesis, the discussion will focus on how policies can cater to these needs.

Public Perception

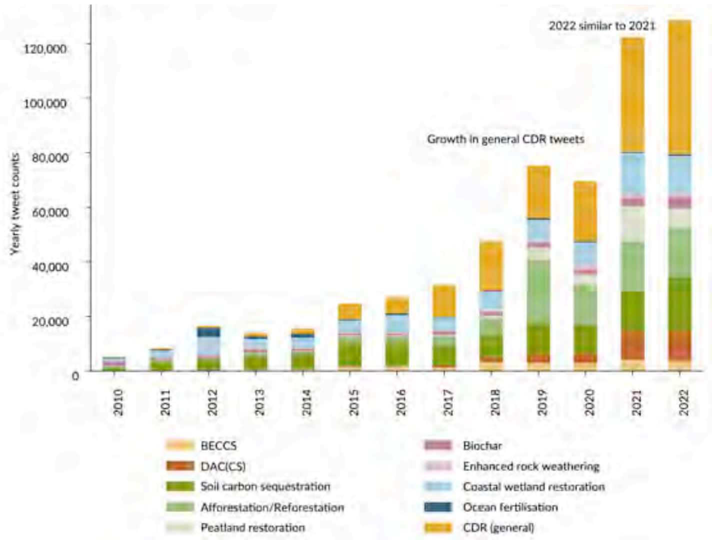
Closely related to the level of maturity is the public perception of permanent CDR, the third identified variable within the political economy of permanent CDR. The main observation in this chapter is that, despite growing attention on social media, existing knowledge primarily circulates among a few actors, resulting in limited widespread awareness and contributing to misperceptions.

In almost all interviews with societal, market, and political actors, it was stated that the general public lacks awareness of permanent CDR and does not fully understand its risks and benefits, leading to fears and concerns[14].

This observation was made against the background that CDR, in general, has received growing attention over the last decade, as shown in Figure 12, which illustrates the increase in tweets on X (formerly Twitter) (Smith et al., 2024). Besides the perceived low general awareness, interviewed actors noted that knowledge on permanent CDR mainly circulates in academia, certain industries dealing with decarbonising hard-to-abate emissions (such as aviation), or specific companies with ambitious net-zero targets, such as Microsoft[15]. As one interviewee pointed out, this is particularly problematic as it prevents potential beneficiaries from accessing the decarbonisation and economic benefits offered by permanent CDR[16].

[12] See Appendix A
[13] See Appendix A
[14] See Appendix A and B
[15] See Appendix A and B
[16] See Appendix A

*Figure 12: Growing attention to CDR on X (former Twitter)*




*Note. Figure from Smith et al. (2024, p. 114)*

Many interviewed actors stated that if aware of permanent CDR, the general public tends to perceive it with scepticism and fear, largely due to its association with Enhanced Oil Recovery (EOR), fossil fuel-based CCS, and controversies surrounding low-quality offsets[17].

The association with EOR is significantly damaging as it contradicts the very purpose of CDR. EOR is a process driven by economic factors involving the injection of $CO_2$ into mature oil and gas wells to enhance the extraction of remaining reserves; historically, 73% of captured $CO_2$ has been used for this purpose (Pigeon, 2024). In stark contrast, CDR is fundamentally different from EOR as its objective is to remove $CO_2$ from the atmosphere and store it permanently, thereby contributing to decarbonisation rather than fuelling fossil fuel exploitation.

According to interviewed actors, associations between permanent CDR and fossil-fuel CCS are primarily driven by ongoing public debates. These debates concern the optimal use of captured $CO_2$ and the deployment of $CO_2$ infrastructure. Distinguishing between atmospheric and fossil fuel sources of captured $CO_2$ using shared infrastructure, such as pipelines and geological storage, is complex, and the potential for valorising $CO_2$ into products like e-fuels further complicates this issue.[18]

Confusing permanent CDR with fossil-fuel CCS is not necessarily beneficial for the public perception of permanent CDR. For instance, Götze (2024) describes that, a few years ago,

[17] See Appendix A

[18] See Appendix A and B

fossil-fuel CCS was widely publicly debated in Germany as a potential option for extending the lifetime of coal power plants. Many societal actors and citizens successfully demonstrated against the use of fossil-fuel CCS, resulting in its widespread prohibition in Germany.

Failing to differentiate between permanent CDR and fossil-fuel CCS not only evokes old debates but also undermines several crucial functions of permanent CDR, including counterbalancing hard-to-abate emissions, enabling overshoot management, and compensating historical emissions.

Lastly, public perception of permanent CDR is particularly influenced by historical and recent controversies regarding low-quality offset credits. Although permanent CDR is distinct from emission reduction and emission avoidance certificates, discussions surrounding CDR may evoke memories of the failures of the Kyoto Protocol's Clean Development Mechanism and the acceptance of its certificates in the EU ETS, which began in 2008 (Sultani et al., 2024). By integrating low-quality emission reduction credits into the EU ETS, the EUA price became diluted by certificates that were found to fail to deliver genuine emission reduction, thereby undermining the EU ETS's core function of providing financial pressure to accelerate decarbonisation (Sultani et al., 2024). Scepticism towards offset credits was further exacerbated by the findings of a widely discussed study from 2023, which, based on a sample covering one-fifth of the total credit volume issued up to that time, found that less than 16% of the carbon credits represented real emission reductions (Probst et al., 2024).

Although permanent CDR credits neither contributed to the dilution of the EU ETS nor were they included in the study sample, interviewees often cited these events as having negatively impacted public perception of permanent CDR[19].

Public perception plays an important role in the development and deployment of new technologies. The public influences policy mandates, determines a project's "social license to operate", and provides demand pull for innovation (Smith et al., 2024).

If growing attention leads to misperceptions and knowledge remains inaccessible to the wider public, the very individuals who stand to benefit from the technologies could block their large-scale deployment. It is worth noting that public scepticism is not inherently

[19] See Appendix A

negative. For instance, public protests against coal power plants with CCS contributed to the uptake of renewable energy, which ultimately proved to be the superior option.

The second part of this thesis will analyse how current and potential future policies can enhance awareness, correct misperceptions, and address concerns regarding the appropriate use of offset credits. These elements are seen as indispensable for fostering a well-informed public debate on the merits of permanent CDR and its governance, a prerequisite for positive public perception.

Quality Assurance

Operationalising and governing permanent CDR requires quality assurance. Without quality assurance, meaning the ability to ensure that a tonne of $CO_2$ was truly removed, permanent CDR would be hardly legitimate, and public perception would be largely negative. This chapter explores the pillars of quality assurance. It argues that while most actors agree on the need for quality assurance, its implementation remains challenging, largely due to technical complexity and conflicting actors' interests.

The Monitoring, Reporting, and Verification (MRV) process is central to all quality assurance schemes for permanent CDR and sometimes extended by Liability as a fourth pillar. Two leading NGOs, namely Carbon Market Watch and Bellona Europa (2024), define the pillars as follows:

*Monitoring* refers to the measurement and quantification of baseline carbon flows, the additional carbon removed through the CDR activity, and the amounts of carbon released in the value chain, both before the activity and during the storage period. Monitoring frameworks must be tailored to each activity and location to ensure accuracy and account for statistical uncertainty.

*Reporting* involves the detailed and transparent communication of how data was gathered, including quality control procedures, data sources, and underlying assumptions.

*Verification* ensures the accuracy and reliability of the reported data, thereby maintaining the integrity of the CDR activity. It should be conducted by an independent verifier who belongs to either a private or a public scheme. Once verified, the operator receives certification, and the project is eligible to generate permanent CDR credits.

*Liability* guarantees responsibility for a particular CDR effort, primarily ensuring a clear allocation of accountability in the event of a carbon reversal (re-release of stored $CO_2$).

Figure 13 illustrates how the MRVL process is integrated into the permanent CDR environment.

*Figure 13: A robust framework for the certification of high-quality CDR*


*Note. Figure from Carbon Market Watch & Bellona Europa (2024, p. 32)*

A recent study surrounding the lifecycle assessment for biochar CDR serves as an example showcasing the importance of MRVL. In this study, it was found that the "emission intensity of energy inputs to the pyrolysis process and whether the bio-oil co-product is used as a chemical feedstock or combusted are critical factors impacting the net carbon dioxide emissions of biochar production" (Kane et al., 2025, p. 1). By comparing best-practice with poor-practice scenarios, the study shows that in a best-case scenario, carbon removal is highly certain (>99.99%), with a median removal of 1.4 kg $CO_2$e/kg biomass. In contrast, in a poor-practice scenario, removal is highly uncertain. Specifically, the likelihood of net emissions in a poor-practice scenario is 66%, with a median net emission of 0.090 kg $CO_2$e/kg biomass. Hence, the methodologies and protocols enshrined in the MRV framework determine whether biochar CDR truly results in a high-quality CDR.

As Smith et al. (2024) explain, it is essential to recognise that although MRV frameworks are designed to ensure the quality of CDR, the quality of the MRV framework itself can also vary. This means that credits issued based on a specific MRV framework only attest to the adherence to the methodologies and protocols of that framework but do not necessarily guarantee the intended atmospheric outcome. This variability in framework quality and its impact on the credibility of credits leads to several practical questions and challenges.

Firstly, it raises the question of who should establish these MRV frameworks. As Smith et al. (2024) point out, such frameworks are typically developed by carbon crediting programs, which can be either private organisations or regulatory bodies. Their analysis found that market actors on the voluntary market, who also issue credits, currently develop the majority of MRV frameworks. Consequently, this raises questions about oversight and impartiality when the same actors are responsible for both development and issuance. Additionally, the authors observe a proliferation of overlapping MRV frameworks for the same technology on the voluntary market due to rapid development and a lack of regulated guidelines, while other CDR methods receive less attention. This asymmetric development risks technological lock-ins, potentially reducing openness to alternative CDR methods.

Secondly, the variability in framework quality raises concerns about establishing a robust MRV framework. Interviewed actors advocated for science-backed methodologies[20]. However, the precise details of what this entails and whether the technical capacities exist to execute sophisticated methodologies in a commercially viable manner remain unclear. Eventually, every additional requirement to ensure quality comes at a cost. Biomass-based CDR serves as a relevant example again. As discussed, many actors perceive knowledge gaps in the lifecycle assessment of biomass due to various emitting effects associated with harvesting, logging, or processing (Pigeon, 2024). Nevertheless, calculating the exact lifecycle emissions in an open system is challenging, as one interviewee pointed out[21]. Another factor complicating the establishment of robust and comparable MRV frameworks relates to intellectual property rights. Many permanent CDR methods depend on protected technology, which restricts access to underlying MRV protocols (Smith et al., 2024).

Furthermore, another ongoing debate addressing quality assurance schemes concerns the accounting of co-benefits. For instance, biochar CDR is associated with improved soil health and crop yields and can potentially mitigate the effects of drought; however, the methods for quantifying and incorporating these benefits into the MRV remain debated (Smith et al., 2024).

As mentioned earlier, liability is a crucial pillar of quality assurance for permanent CDR. Smith et al. (2024) stress that governance schemes should prevent the unfair and premature transfer of risks and benefits from private to public actors, specifically by avoiding the privatisation of financial gains from $CO_2$ removal while socialising long-term liabilities. While agreeing with this, other authors point out that establishing durable liability is challenging, particularly with cross-border transport of $CO_2$ or retrospective claims of

[20] See Appendix A
[21] See Appendix A

insufficient quality, as permanent $CO_2$ storage exceeds the usual lifetime of a company (Carbon Market Watch & Bellona Europa, 2024).

Policies aimed at resolving this dilemma are frequently criticised. For instance, Greenpeace has expressed concerns about the German policy that transfers liability from the storage site operator to the state 40 years after the site is no longer in active management (Jäger et al., 2024). Carbon Market Watch also criticises this practice, arguing that countries and the public should not bear the risk of $CO_2$ reversal when private entities have received financial rewards from storing the carbon (De Simone, 2023).

While the MRVL pillars are essential for ensuring the quality of permanent CDR, their implementation presents significant challenges. There is a balance to be found between the requirements for generating high-quality and reliable permanent CDR with guaranteed long-term liability and the practical technical and commercial viability of deploying the required methodologies and protocols. The second part of this thesis will examine how policies can contribute to achieving this balance.

Demand

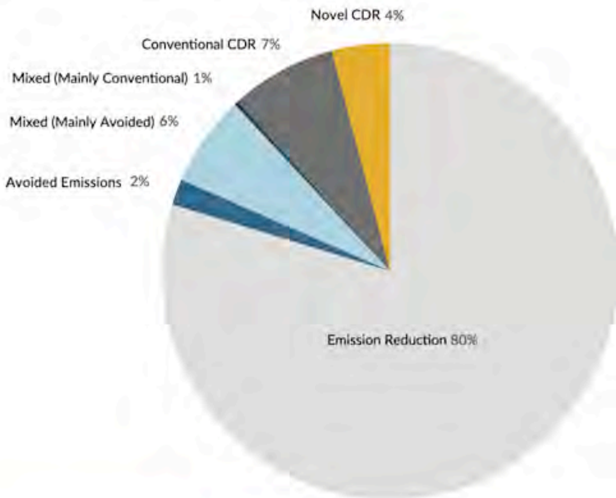
The most frequently mentioned factor during the research is demand. Demand for permanent CDR can be loosely defined as the quantity of permanent CDR offset credits that market participants are willing and able to purchase at a given price over a specific period. This chapter examines the various markets, market participants, their motivations, and the dynamics that influence the demand for permanent CDR.

The main observation is that most of the current demand stems from the voluntary market. However, the demand from the voluntary market remains at scales insufficient for large-scale deployment, primarily because market participants do not perceive the recognised value of permanent CDR credits to exceed their costs and risks. Although this perception is likely to change over time, many uncertainties persist, keeping demand low.

According to Smith et al. (2024), demand for permanent CDR offset credits is crucial for compensating the cost of generating permanent CDR. They state that these credits are currently primarily traded on the Voluntary Carbon Market (VCM), which serves as a platform where actors voluntarily finance projects that reduce or remove $CO_2$ emissions, encompassing transactions through marketplaces and direct procurement from suppliers. While Smith et al. estimate that the VCM accounts for only 2% of the total carbon trade globally, with compliance markets such as the EU ETS covering the remaining 98%, they highlight its crucial role in enabling actors to exceed mandatory decarbonisation efforts and in developing the market for permanent CDR.

Although the VCM has been instrumental in developing permanent CDR, its uptake of permanent CDR credits has been limited. Figure 14, for instance, reveals that these credits currently represent just 4% of all VCM-traded credits (Smith et al., 2024).

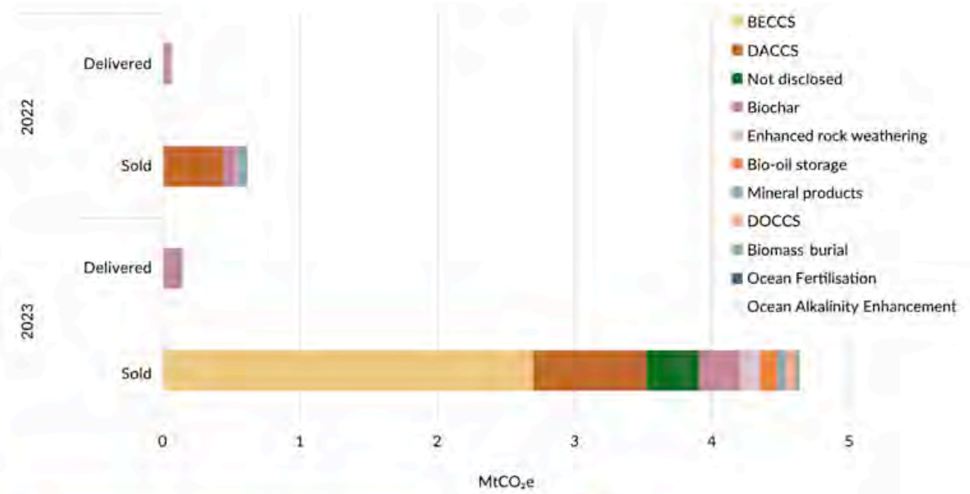
*Figure 14: Proportion of projects within the VCM (2022-2023)*




*Note. Novel CDR=permanent CDR. Figure from Smith et al. (2024, p. 76)*

However, recent developments suggest that this trend may be shifting. For instance, Figure 15 illustrates a sevenfold increase in purchases of future permanent CDR credits from 2022 to 2023, rising from 600,000 to 4.6 million, with most credits originating from BECCS, DACCS, and biochar CDR (Smith et al., 2024). This fast-growing trend continues, and as of May 2025, more than 26 million permanent CDR credits have been sold, representing an estimated $6.2 billion spent in this nascent market (CDR.fyi, 2025b).

*Figure 15: Breakdown of the volume of CDR in the VCM by CDR method (2022-2023)*




*Note. Figure from Smith et al. (2024, p. 79)*

This changing trend might reflect an underlying shift in the motivation to buy these credits. Interviewed actors explained that in the past, climate action primarily focused on emission reduction and the enhancement of natural sinks[22]. Consequently, many market actors who set net-zero or net-negative goals primarily invested in reduction measures and compensated for remaining emissions with cheaper emission reduction and temporary CDR credits.

Two main forces supported this development. Firstly, permanent CDR credits were significantly more expensive, exceeding the price of emission reduction credits by at least a factor of 100 and temporary credits by at least a factor of 10 (Smith et al., 2024). Secondly, as highlighted by many interviewed actors, most guiding standards, such as the SBTi Corporate Net-Zero Standard, did not recognise the usage of permanent CDR[23]. Indeed, in 2023, less than 1% of companies with a science-based target had purchased permanent CDR (Smith et al., 2024). Buyers who engaged in purchasing permanent CDR despite these circumstances were predominantly motivated by their desire to support its early development (Smith et al., 2024). Interviewed actors frequently stated that the primary reason for purchasing permanent CDR credits was related to the outlook of compensating hard-to-abate emissions and achieving net-negative scenarios in the mid- and long-term in an economically viable manner[24].

Today, different, overlapping shifts in motivation influence the demand for permanent CDR credits. On the one hand, internationally recognised standards and policymakers are starting to consider incorporating permanent CDR into their guidance. For instance, the SBTi launched a public consultation in March 2025 addressing how CDR could be an option for companies to manage residual emissions (SBTi, 2025). Proposed options include mandatory and optional near- and long-term targets for CDR, as well as different approaches for transitioning from temporary to permanent CDR over time (SBTi, 2025). Another example refers to the European Commission's recently initiated public consultation that, among other topics, examines the potential usage of permanent CDR within the EU ETS (European Commission, 2025a).

[22] See Appendix A
[23] See Appendix A
[24] See Appendix A

Interviewed actors describe these developments as the beginning of a demand-inducing pre-compliance market where actors seek to either secure future access to credits or commence exploring permanent CDR options[25].

On the other hand, as many interviewees noted, market actors remain cautious about purchasing permanent CDR credits. Their reluctance is fuelled by concerns such as the potential for public backlash, reminiscent of recent controversies surrounding low-quality carbon credits and the perception of buying a "license to emit". Moreover, interviewed actors noted that the limited inclusion of permanent CDR in public climate mitigation frameworks, the ongoing debate surrounding its legitimacy, and the absence of widely recognised quality assurance schemes contribute to this hesitation.[26]

Furthermore, a recent market survey indicated that even if net-zero target-setting frameworks induce demand, the price of CDR is the most significant factor in corporate decision-making, and current prices are considered prohibitively high (CDR.fyi, 2025c). Adding to this challenge, interviewees noted that despite market actors recognising permanent CDR's potential for mid- to long-term cost reduction in decarbonisation, recent international policy shifts (e.g. the USA withdrawing from the Paris Agreement) and short-term economic pressure are prompting corporations to delay purchases, waiting for prices to fall[27]. This tendency to wait for others to drive market development and benefit from future lower prices is known as the Free Rider Effect, a dilemma that often prevents the anticipated progress (O'Gorman, 2010).

Demand appears to be a central variable in the political economy of permanent CDR, with most consulted sources agreeing that current demand is insufficient for large-scale deployment. The second part of the thesis will examine how policy can induce or create sufficient demand and overcome the Free Rider Effect to facilitate the large-scale deployment of permanent CDR.

<u>Supply</u>

The last identified variable influencing the political economy of permanent CDR is supply, which denotes the current and future availability of permanent CDR offset credits for voluntary and compliance markets, reflecting the growth of permanent CDR capacity. A key

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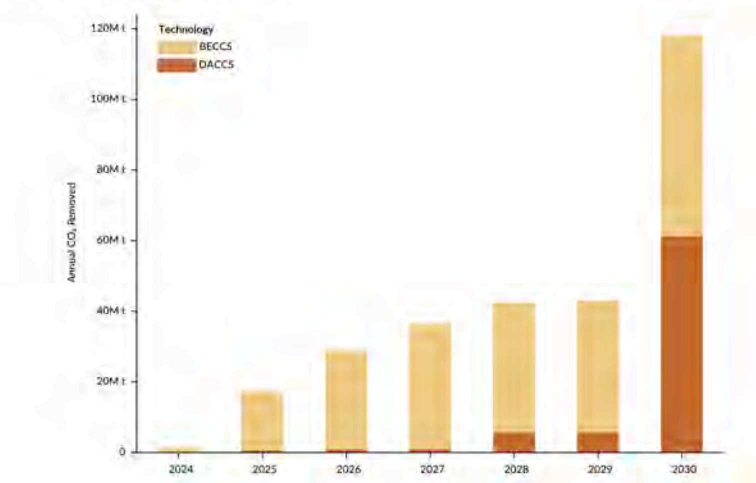
[25] See Appendix A
[26] See Appendix A
[27] See Appendix A

observation in this chapter is that despite high ambitions and rapid technological advancement, securing financing for permanent CDR projects presents a significant challenge. Furthermore, as demonstration projects are developed, regional challenges influencing the uptake of supply emerge.

Smith et al. (2024) argue that while a permanent CDR capacity of 1.35 Mt $CO_2$ in 2023 may appear negligible, it is essential to consider the high growth rates, which are expected to continue. Just two years prior, permanent CDR capacity stood at 0.66 Mt $CO_2$, and according to public announcements from project developers, DACCS and BECCS capacity is set to reach an annual removal capacity of 120 Mt $CO_2$ in 2030, as Figure 16 shows[28].

*Figure 16: Near-term permanent CDR company plans*




*Note. Figure from Smith et al. (2024, p. 61)*

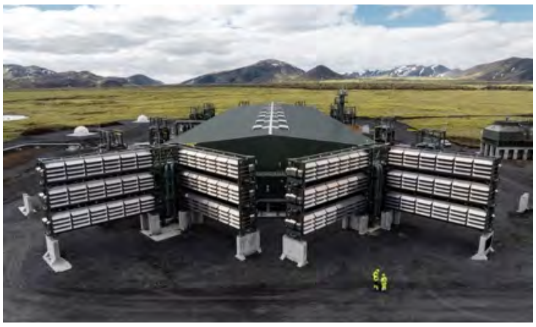
The rapid development of DACCS plant capacities underscores the high growth rates. Climeworks' Orca, the first large-scale DACCS demonstration plant, began operating in 2021 with a capture capacity of 500 tonnes per year (Climeworks, 2025). Two years later, their second plant, Mammoth, started operations with a significantly higher targeted removal capacity of 36 kt $CO_2$ annually (Climeworks, 2025). This upward trend continues with 1PointFive's STRATOS plant, scheduled for commercial operation by mid-2025, with a targeted annual removal capacity of 500 kt $CO_2$ (1PointFive, 2025). Within just four years, the DACCS plant capacity of the two leading DACCS project developers increased by a factor of 1000. Figures 17 to 19 illustrate the evolution of the dimensions of these DACCS plants.

[28] It should be noted that company plans are not binding commitments and do not automatically lead to a FID.

*Figure 17: Orca DACCS plant*

*Note. Figure from Climeworks (2025)*

*Figure 18: Mammoth DACCS plant*



*Note. Figure from Climeworks (2025)*

*Figure 19: STRATOS DACCS plant*

*Note. Figure from 1PointFive (2025)*

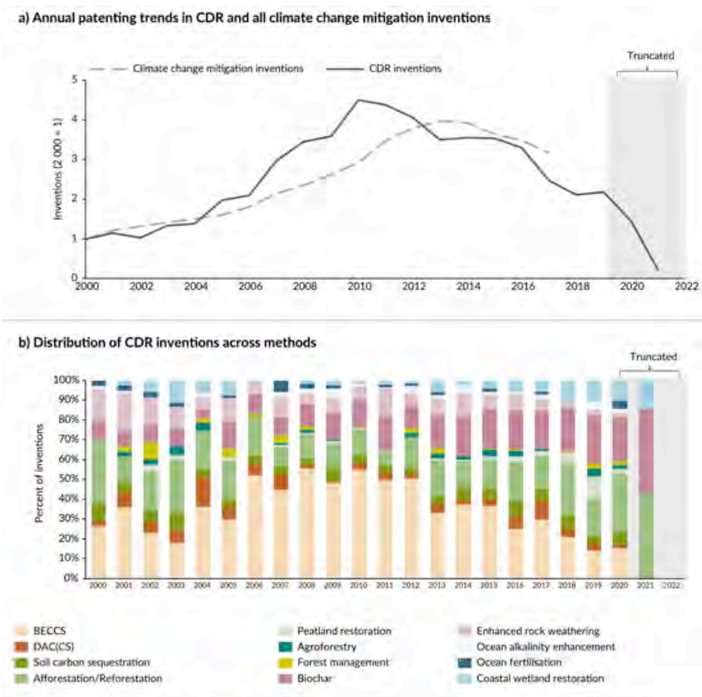
Not only are plant capacities increasing rapidly, but technology efficiency is also improving at a high rate. Climeworks, for instance, announced that their latest technology, intended for deployment in a new facility called Cypress, has the potential to reduce costs by up to 50% relative to their Mammoth plant technology, with a target of achieving $400-600 per ton net removal by 2030 (Climeworks, 2024).

Similar to DACCS, Smith et al. (2024) observe a rapid increase in capacities for biochar CDR, highlighting that biochar CDR deployment rates are expected to increase sevenfold from 2023 to 2025. This observation is shared by interviewed actors, who also anticipate steep growth rates for biochar CDR, citing its less centralised nature and potential for local, smaller-scale deployment as its main drivers[29].

Further insights into the potential development of supply capacities can be gained from the evolution of annual patenting trends. As Figure 20 illustrates, the number of patents issued annually for temporary and permanent CDR has increased over time, with a peak in 2010.

[29] See Appendix A

*Figure 20: Annual patenting trends across CDR methods*



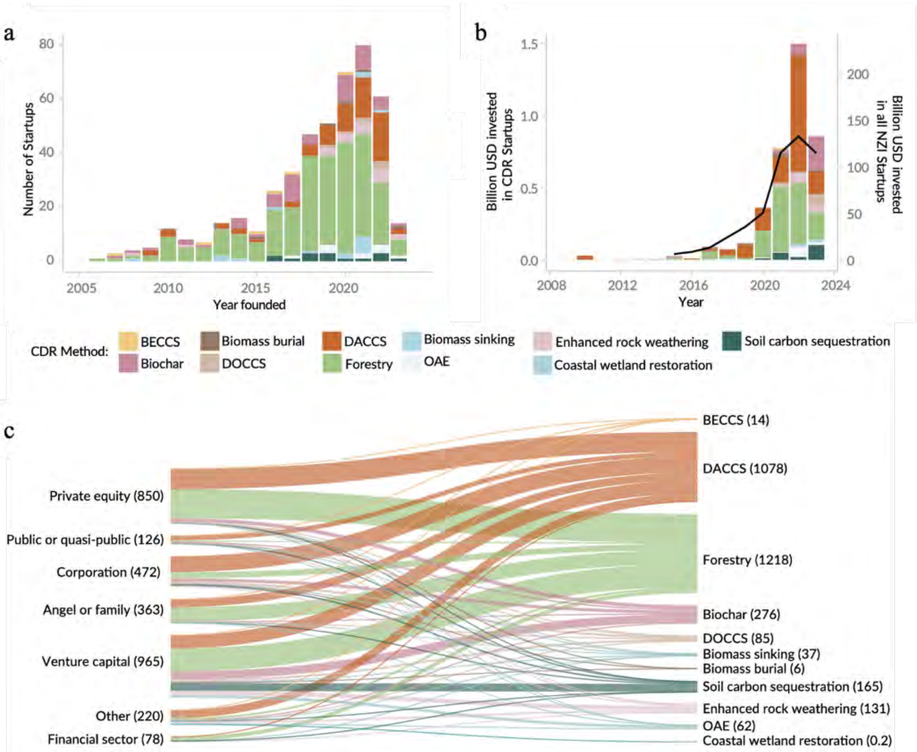

*Note. Figure from Smith et al. (2024, p. 41)*

Notably, the trend for annual BECCS invention continues to decline, whereas biochar CDR continues to increase. This pattern aligns with the observations of interviewed actors who perceived BECCS and biochar CDR as mature technologies ready for deployment but allocated higher innovative potential to biochar CDR[30].

The increasing number of CDR startups and investment in these startups represent another positive trend. As Figure 21 illustrates, the global number of CDR startups increased from 2005 to 2023, reaching a total of 509, and these startups successfully secured significant funding. Figure 21 also shows that DACCS startups received some of the highest investments from various sources, particularly private equity, corporations, and venture capital.

[30] See Appendix A

*Figure 21: Global investment trends in CDR startups*




*Note. Adapted from "Investment trends in carbon dioxide removal (CDR) startups from 2009 to 2023" by Smith et al. (2024, p. 57). (a) Number of startups founded in each year; (b) US dollar value of investments in each year and total investment for climate-tech startups tracked by the Net Zero Insights (NIZ) database (black line); (c) Flow of investments by investor type to CDR method in millions of dollars*

Interviewed actors confirmed that while venture capital is amply available for solid business cases in the permanent CDR sector, the primary challenge lies in accessing non-dilutive capital and securing funding for first-of-a-kind projects. They emphasised that predictable Return on Investment (ROI) is essential for securing investment and reaching the FID of large-scale removal plants. However, ROI for these Capital Expenditures-intensive projects heavily depends on stable, increasing demand and early offtake agreements with low counterparty risk. This applies to BECCS and DACCS projects, which require investments in the order of billions of euros, as well as to local biochar CDR projects with expenditures in the range of €3-5 million.[31]

As previous chapters have shown, stable and increasing demand for permanent CDR is currently absent. Demand is considered insufficient, and the existing demand originates from the volatile voluntary market. One interviewee highlighted that given that investments in permanent CDR are based on timeframes exceeding 20 years (typically surpassing the duration of standard offtake agreements), today's investors are essentially betting on a

[31] See Appendix A

sustained and steep increase in voluntary market demand and the integration of permanent CDR into compliance markets[32].

Beyond demand, regional factors such as resource and infrastructure availability, as well as permitting and regulation within a given jurisdiction, significantly influence supply. For instance, DACCS is heavily dependent on the availability of and access to low-carbon electricity. A case in point is CarbonCapture's project in Wyoming, USA, which was intended to remove 5 million tons of $CO_2$ annually by 2030 but failed due to its inability to secure access to sufficient renewable energy supply (Hiar, 2024).

$CO_2$ infrastructure and storage are also scarce resources currently. A decisive factor in Stockholm Exergi's decision to secure FID for its BECCS project was the FID for the extension of the Northern Lights $CO_2$ storage location in Norway, which aims to increase its transport and storage capacity from 1.5 Mt $CO_2$ to 5 Mt $CO_2$ per year starting from 2028 (TotalEnergies, 2025). The availability of $CO_2$ storage sites is further constrained by the critical need for operators with low execution risk, as one interviewee highlighted[33]. He explained that while $CO_2$ storage constitutes a small portion of total BECCS and DACCS costs, its failure could jeopardise the entire project.

National or local permitting and regulations can further complicate the deployment of permanent CDR facilities. According to another interviewee, pyrolysis, the process leveraged to create biochar CDR, is not clearly categorised in German regulation, leading to uncertainty in emission control regulation and the accounting of climate benefits[34].

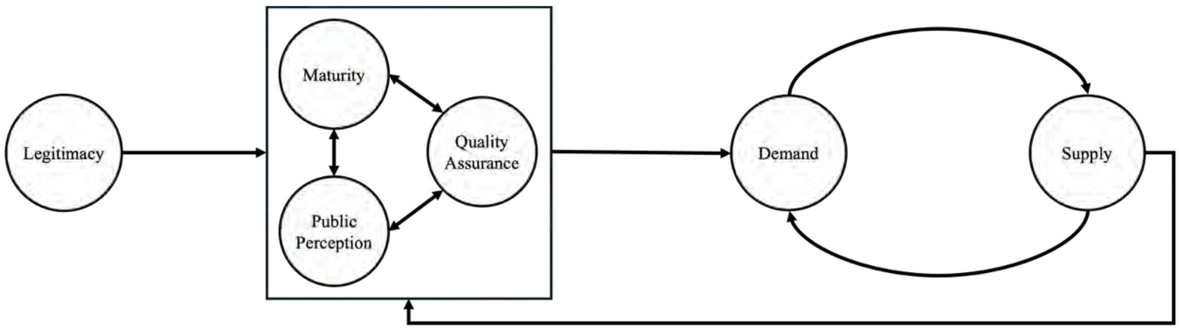
Scaling supply requires translating existing innovation and ambition into tangible projects. As described, a lack of project-level financing and regional factors often hinder this process. The second part of this thesis will explore how policies can facilitate such scaling of supply.

[32] See Appendix A
[33] See Appendix A
[34] See Appendix A

## A Systems Thinking View on the Dynamics of Key Variables

Following the individual analysis of different variables, mapping their interconnections helps to understand their dynamics. Figure 22 illustrates a Systems Thinking Model derived from the qualitative analysis of the political economy of permanent CDR.

*Figure 22: A Systems Thinking Model of the political economy of permanent CDR*




Permanent CDR is recognised by most actors for its potential to offer a cost-effective pathway to reach net-zero and potentially net-negative emissions thereafter while also bringing additional economic benefits such as GDP growth and job creation. However, actors also acknowledge that if deployed poorly, permanent CDR risks deterring short-term mitigation efforts and could cause adverse environmental impacts.

These concerns surrounding the deployment of permanent CDR lead to a situation where its perceived legitimacy does not directly translate into sufficient demand. Instead, actors often call for increased maturity and the establishment of robust quality assurance schemes before significant deployment occurs. Negative public perception, stemming from associations with EOR, fossil-fuel CCS, and controversies surrounding offset credits, contributes to this development. Eventually, without the necessary safeguards and public confidence, permanent CDR may not receive the societal license to scale.

Currently, demand for permanent CDR offset credits remains insufficient for large-scale deployment. This is mainly because the perceived value of permanent CDR does not yet exceed its cost. The perceived value is influenced by a complex interplay between the recognition of permanent CDR in public or market-driven climate policy frameworks (reflecting its legitimacy and maturity), the safeguards put in place to ensure safe deployment, and public perception.

Demand is also significantly influenced by the cost of supply. In the current context, where $CO_2$ reduction is the main priority in climate change mitigation, permanent CDR is a costly alternative to reduction measures and is only competitive in sectors where the cost of additional abatement is prohibitively high. This situation arises since the ability to compensate for hard-to-abate emissions or to manage overshoot scenarios in the future is not sufficiently valued in today’s market context. Moreover, the absence of pressing market urgency encourages market actors to free-ride on the investments of others, leading to collective inaction.

The low demand creates a challenge in building supply, as these two factors reinforce each other in a feedback loop. If demand is low, project developers struggle to finance their projects, investment remains unattractive, and prices remain high. Conversely, high demand stimulates project deployment, creating economies of scale, attracting investment for innovation and infrastructure, and thereby reducing costs per unit, which in turn stimulates further demand.

Increasing supply is crucial for advancing maturity and developing quality assurance schemes, another feedback loop. It could also contribute to greater public awareness and help mitigate concerns of the public. However, since supply currently remains negligible, the interviewees rarely mentioned these potential connections.

Building on the outlined understanding of the political economy of permanent CDR and assuming that a large-scale deployment of permanent CDR is in the interest of the EU, the second part of this thesis will analyse current policies and potential policy options, assessing their influence on the variables and overall dynamics within the political economy to identify pathways for large-scale deployment.

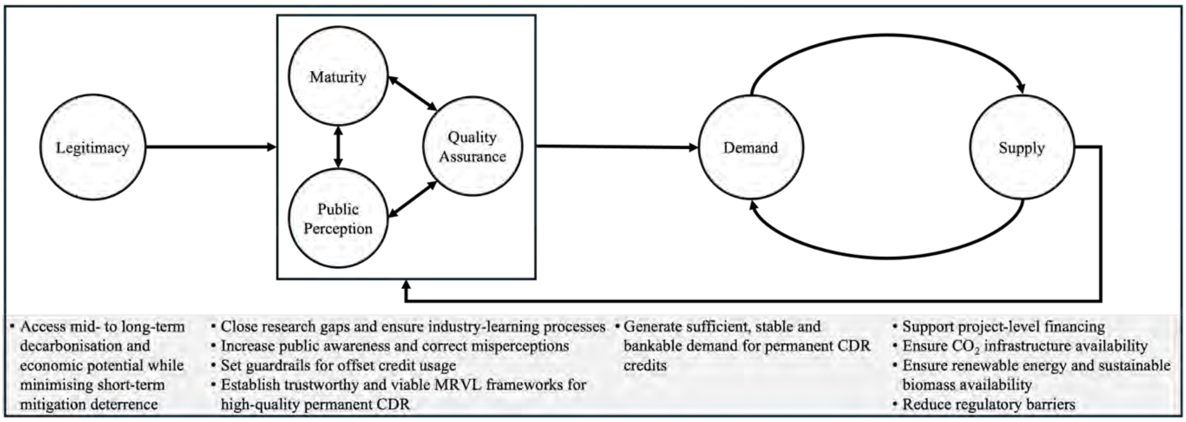
# Part 2: Assessing Policy Impacts on the Political Economy of Permanent CDR

## Assessment Criteria

Before assessing specific current policies and potential policy options, it is crucial to establish clear assessment criteria in order to evaluate whether policies can unlock a large-scale deployment of permanent CDR in the EU.

As developed in the first part of this thesis, comprehensive policy support is indispensable across the six identified variables that influence the political economy of permanent CDR. Consequently, policies should be evaluated based on their efficacy in positively impacting these variables. Figure 23 provides a summary of the challenges identified within this analysis.

*Figure 23: Summary of challenges across the identified variables*




*Note. For a larger version, please refer to Appendix C, "Visualisation of Research Findings"*

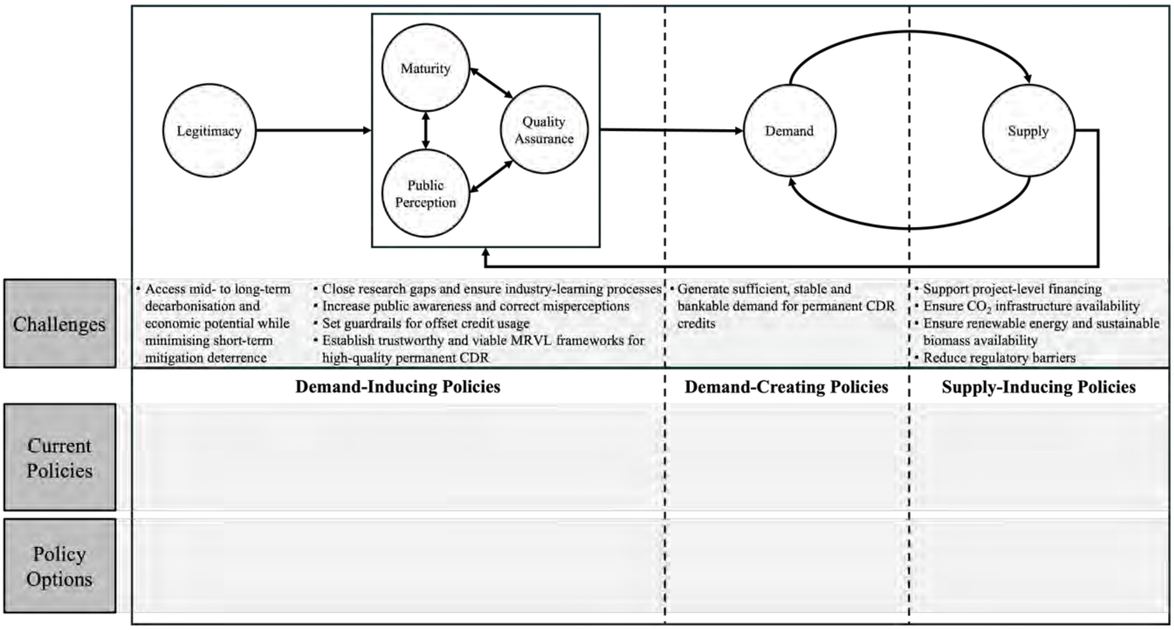
In the following chapters, current policies and policy options will be assessed against the described criteria to determine whether policies can unlock a large-scale deployment of permanent CDR in the EU. This assessment is structured around three distinct policy types:

1. **Demand-inducing policies**: These policies encourage actors to voluntarily increase demand for permanent CDR credits by influencing the variables that translate legitimacy into actual demand.
2. **Demand-creating policies**: These policies directly create demand by integrating permanent CDR into compliance schemes or leveraging public procurement schemes.

3. **Supply-inducing policies**: These policies incentivise and facilitate the development of permanent CDR capacities by co-funding projects and developing an enabling environment.

Figure 24 visualises the integration of these policies within the Systems Thinking Model of the political economy of permanent CDR. It should be noted that this classification primarily serves to structure the assessment and does not inherently affect the subsequent findings. Other authors might have chosen alternative configurations.

*Figure 24: Integration of policy typologies into the developed Systems Thinking Model*




*Note. For a larger version, please refer to Appendix C, "Visualisation of Research Findings"*

## Demand-Inducing Policies

The legitimacy of permanent CDR within the EU is intrinsically linked to its target-setting policy instruments. This category encompasses three interconnected yet distinct policies: Nationally Determined Contributions (NDCs), the European Climate Law (ECL), and National Energy & Climate Plans (NECPs).

The NDC, submitted on behalf of the member states, establishes the EU's overarching climate ambition under international law and serves as its official commitment under the Paris Agreement. Currently, the NDC stipulates that the "EU and its Member States, acting jointly, are committed to a legally binding target of a domestic reduction of net greenhouse gas emissions by at least 55% compared to 1990 by 2030" (EU, 2023, p. 8).

The ECL formally transposes the NDC targets into Union law. Amended in 2021, the ECL establishes the overarching objective for the EU to achieve a net emission reduction of 55% by 2030 and climate neutrality by 2050 (Regulation (EU) 2021/1119, 2021). Furthermore, the ECL establishes a framework designed to ensure that relevant Union legislation and policies are consistent with and actively contribute to this climate-neutrality objective, including the mandate for EU member states to create NECPs. According to the regulation, NECPs serve as the primary planning and implementation documents through which member states articulate their national policies, measures, and trajectories to collectively contribute to the overarching EU targets stipulated in the NDC and ECL.

In its recent report on the integration of CDR into EU policies, the ESABCC (2025) criticises current EU target-setting policies. Firstly, it highlights a critical policy gap in the ECL due to its lack of explicit differentiation between emission reductions, permanent CDR, and temporary CDR. This omission leads to vague policy instruments for permanent CDR. For example, while temporary CDR is addressed through the LULUCF Regulation and emission reductions via the EU ETS and Effort Sharing Regulations, specific policies for permanent CDR remain largely absent. Only the Net Zero Industry Act (NZIA) establishes a $CO_2$ storage target of 50 Mt $CO_2$ by 2030; however, it fails to distinguish between fossil-fuel CCS and permanent CDR.

Secondly, the ESABCC points to the absence of clear targets for CDR beyond 2030. Although the ECL sets a maximum contribution of CDR to the EU's 2030 target, capped at 225 million tonnes of $CO_2e$, the advisory board notes a lack of guiding targets for CDR beyond 2030 to achieve net-zero and net-negative emissions. Figure 25 illustrates the relevant target-setting policies in current EU climate legislation.

*Figure 25: Relevant target-setting policies in current EU climate legislation*


*Note. Figure from ESABCC (2025, p. 89)*

Complementary to the ESABCC analysis is a report by Bellona Europa (2024), which undertakes a comprehensive evaluation of EU member states' draft NECPs concerning their integration of fossil-fuel CCS and permanent CDR. The authors' findings reveal a significant discrepancy: despite the European Commission's recommendations for CCS inclusion and the subsequent release of the NZIA and Industrial Carbon Management Strategy (ICMS), substantive engagement with permanent CDR remains minimal across most NECPs. Moreover, when CCS is referenced, it is frequently prioritised for the power sector in the frame of fossil-fuel CCS, with demonstrably less attention directed towards technologies enabling permanent CDR such as BECCS and DACCS.

The European Commission's (2025b) recent assessment of the final NECPs indicates an improvement in member states' ambitions for CCS. It highlights that member states aim to capture 42.4 Mt $CO_2$ annually by 2030, with 14.9 Mt $CO_2$ originating from biogenic sources. Additionally, the Commission notes that member states project an injection capacity ranging from 27.1 to 45.1 Mt $CO_2$ per year by 2030. While this largely aligns with the 50 Mt $CO_2$ storage target of the NZIA, the assessment fails to distinguish between fossil-fuel CCS and permanent CDR. This suggests that permanent CDR is viewed as a subset of CCS rather than a distinct tool for counterbalancing residual emissions and achieving net-zero scenarios.

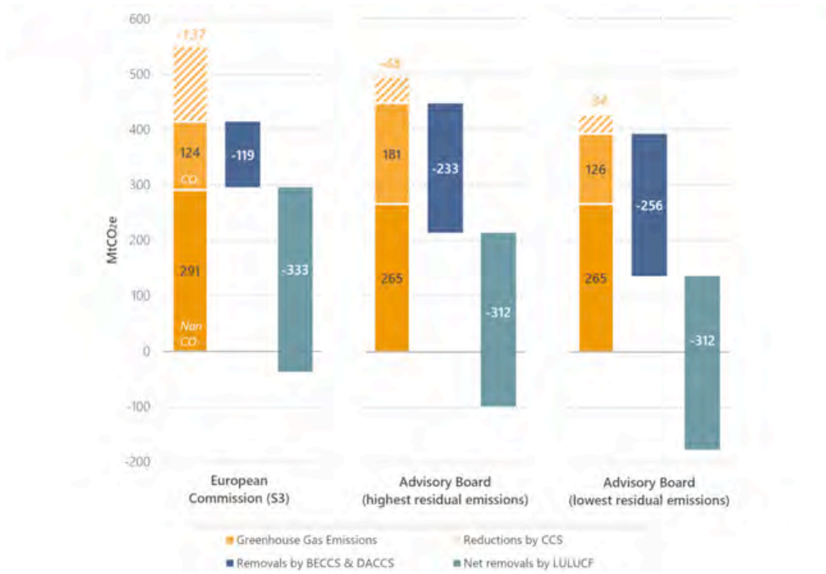
Interviewed stakeholders consistently underscored the importance of clear targets for permanent CDR, asserting that such targets reflect legitimacy and provide a stable direction for CDR deployment. Nevertheless, they acknowledged the inherent complexity in setting these targets, primarily due to the perceived conflict between the mid- to long-term decarbonisation potential of CDR and the risk of short-term mitigation deterrence, coupled with divergent views on how to reconcile this tension. Some interviewed actors proposed that this conflict could be resolved through the establishment of separate targets for emission reduction, temporary CDR, and permanent CDR. Other stakeholders explained the possibility of a market-based approach to resolving this dilemma, wherein the optimal quantities of emission reduction, temporary CDR, and permanent CDR are determined by the respective marginal costs of abatement and removal.[35]

Considering the significant complexity inherent in establishing an environment conducive to a market-based approach, a topic to be explored in greater detail in subsequent chapters, a "triple target" framework appears more viable. To this end, a potential target could be

[35] See Appendix A

anchored in the ESABCC's projected scenarios, which anticipate annual permanent CDR volumes ranging from 233 to 256 Mt $CO_2$ by 2050. This projection notably surpasses the European Commission's latest modelled scenario, which estimated annual permanent CDR at 119 Mt $CO_2$ (Figure 26).

*Figure 26: Comparison of residual emissions and CDR in Advisory Board and European Commission scenarios for 2050*




*Note. Figure from ESABCC (2025, p. 32)*

As comprehensive targets for permanent CDR remain absent at the EU level, it is significant to observe the proactive development of such targets at the national scale. Although not a member state of the EU, Switzerland, for example, has articulated distinct targets for both fossil-fuel CCS and permanent CDR within its National Long-Term Climate Strategy (Swiss Federal Council, 2022). Their strategy aims for an annual removal of 7 Mt $CO_2$ by 2050, with 2 Mt $CO_2$ projected to occur domestically, predominantly through BECCS and 5 Mt $CO_2$ anticipated from international CDR projects, primarily employing DACCS.

Also, in EU member states, the first efforts to integrate permanent CDR targets have become apparent. For example, in Germany, the recently formed government coalition between CDU, CSU, and SPD has recognised the imperative of permanent CDR for reaching the 2040 climate objectives in their coalition treaty (CDU et al., 2025). The forthcoming Long-Term Strategy for Negative Emissions will reveal whether this stated ambition materialises into dedicated targets.

Carbon Gap (2025b) points out that Denmark also develops permanent CDR targets. It calculates that Denmark's objective of an ambitious 110% reduction in GHG emissions by 2050, relative to 1990 levels, would necessitate approximately 8 Mt of $CO_2$ removal annually in 2050. Additionally, Carbon Gap highlights that Denmark's NECP already includes preliminary targets for fossil-fuel CCUS (Carbon Capture Utilisation and Storage) and permanent CDR for 2030, and projections from the Danish Energy Agency indicate a potential annual capture of 1-10 Mt $CO_2$ from biogenic sources by 2030, primarily through BECCS and biochar CDR technologies.

Across various sources and frequently mentioned in the interviews, the establishment of clear targets at different governance levels is consistently regarded as indispensable for the large-scale deployment of permanent CDR. Such targets not only reflect the technology's legitimacy, recognising its crucial functions in achieving net-zero emissions and subsequent net-negative scenarios, but also effectively manage potential conflicts related to emission reduction, temporary CDR, and permanent CDR. This is achieved by delineating clear areas (or volumes of CDR) of manoeuvre where specific trade-offs are deemed acceptable. Furthermore, targets facilitate progress monitoring and can offer crucial insights into the validity of concerns regarding mitigation deterrence.[36]

While current EU and most national policies exhibit a notable deficiency in explicit targets for permanent CDR, the forthcoming 2040 targets present a significant window of opportunity for their integration and for emphasising the inclusion of permanent CDR in member states' NECPs. Switzerland and Denmark have demonstrated that permanent CDR can contribute to national climate strategies, affirming the feasibility of setting specific targets for this technology.

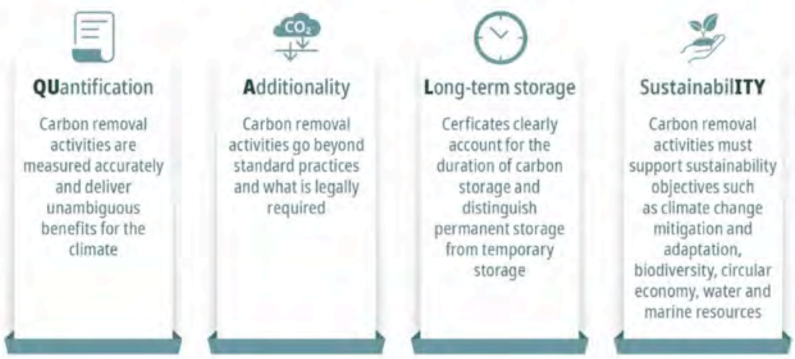
Beyond target-setting instruments, transparency-increasing and standard-setting information instruments can significantly contribute to inducing demand for permanent CDR. A key policy in this regard is the Carbon Removal and Carbon Farming (CRCF) framework, a Union-level legislative measure adopted by the EU in 2024 (Regulation (EU) 2024/3012, 2024). Its primary role is to establish a standardised certification and MRV system for both temporary and permanent CDR within the EU. Additionally, it enables the accounting of permanent CDR within the framework of the ECL and NDC, as the resulting credits are intended to contribute to achieving NDC targets. Hence, it presents a significant opportunity to meet the need for establishing trustworthy and viable MRVL frameworks for generating high-quality permanent CDR credits.

[36] See Appendix A

The ESABCC (2025) regards the CRCF as a crucial tool for ensuring the social and environmental integrity of CDR activities, boosting investor confidence, and driving the market for CDR offset credits. The advisory board outlines the following benefits of the CRCF:

1. **Establishes quality criteria**: It sets out key quality criteria for CDR activities (Figure 27), which are fundamental for establishing trustworthy MRVL processes.
2. **Includes sustainability safeguards**: Removal activities must comply with relevant EU laws, such as the CCS Directive and the Renewable Energy Directives.
3. **Supports data quality and transparency**: A foreseen 'Union registry' supports CRCF data comparability. The transparency of data and methodologies is highlighted as important for market growth.
4. **Mandates methodology updates**: It mandates regular updates (at least every five years) to certification methodologies to incorporate technological advancements and scientific evidence.
5. **Requires third-party verification**: The framework mandates third-party verification of CDR activities by accredited certification bodies.

*Figure 27: QU.A.L.ITY criteria of the EU's CRCF framework*




*Note. Figure from ESABCC (2025, p. 118)*

Despite these benefits, the CRCF has been publicly criticised for its insufficient stringency and detail regarding quality criteria and methodologies. For example, Carbon Market Watch contends that crucial criteria are often vague, and important details are omitted from the primary legislation (De Simone, 2023). Other authors argue that the draft methodologies for BECCS and DACCS, in their present form, are likely to lead to an overestimation of actual CDR (Schneider et al., 2024). Even though the CRCF is far from perfect and questions regarding the currently developed technical methodologies remain open, it is nonetheless a crucial element for enabling the integration of CDR into broader policy frameworks, as pointed out by an interviewed civil servant working for the European Commission[37].

Another key information instrument influencing public perception of permanent CDR is the Green Claims Directive (GCD), a legislative proposal from the European Commission currently under negotiation. The GCD holds particular importance for permanent CDR as it seeks to regulate climate-related claims, especially those concerning "climate neutrality" or "net zero", which are frequently substantiated by offsetting emissions (Carbon Gap, 2025c). As established in the first part of this thesis, the public's perception of permanent CDR and subsequent offset credit purchasing behaviour is heavily influenced by controversies surrounding poor-quality offset credits and a lack of clear guidance for offsetting practices. The GCD possesses the potential to positively influence public perception by providing guardrails for the use of offset credits through the establishment of key principles, thereby potentially incentivising the uptake of permanent CDR credits.

Despite its promising potential, Carbon Gap (2025c) has already identified several shortcomings in the initial proposal. For instance, the proposal permits companies to utilise credits derived from emission reductions and avoidance projects to substantiate carbon neutrality claims. This allowance is criticised for its misalignment with the scientific consensus, such as the IPCC's definition of net zero, which necessitates balancing residual emissions with temporary or permanent CDR. Additionally, Carbon Gap explains that the proposal fails to enshrine the 'like-for-like' principle in EU law. This principle mandates that long-lived, hard-to-abate fossil fuel emissions should exclusively be balanced by permanent CDR as only they match the atmospheric lifespan of fossil fuel emissions. Furthermore, Carbon Gap stresses that while the proposal encourages companies to use offset credits only for their residual emissions (which constitutes the correct application of CDR in a net-zero context), it does not provide a clear, explicit definition of "residual emissions", further contributing to confusion regarding offsetting practices.

These points of critique align with the insights gathered from the interviewed stakeholders. They asserted that the GCD has the potential to significantly boost demand for permanent CDR within the voluntary market, provided that net-zero claims are contingent on the compensation of clearly defined residual emissions with high-quality permanent CDR. However, the current proposal is deemed insufficient for effectively inducing demand. Some

[37] See Appendix B

interviewed actors even highlighted potential detrimental effects on the uptake of permanent CDRs within the voluntary market if the GCD fails to effectively increase the value of permanent CDR credits relative to other offset credits for substantiating net-zero claims.[38]

While the CRCF aids in assuring the quality of permanent CDR credits and the GCD establishes guardrails for the usage of offset credits, a notable gap persists in information policies designed to clarify the distinctions between permanent CDR, fossil-fuel CCS, and the varying decarbonisation value of different offset credits. As previously highlighted, low public awareness and increasing misconceptions negatively influence the public perception of permanent CDR. Within the framework of the ICMS, the importance of public awareness and engagement is acknowledged (European Commission, 2024b), but the focus remains on fossil-fuel CCS, suggesting that the specific challenges of misperceptions surrounding permanent CDR have not yet been sufficiently recognised. Therefore, targeted information campaigns could be an effective additional policy option to address this critical issue.

Lastly, innovation instruments are crucial for inducing demand for permanent CDR. Innovation accelerates the maturity of permanent CDR by effectively closing research gaps. Policies supporting innovation primarily refer to Research, Development, and Innovation (RD&I) funding. In the EU, the main tools for permanent CDR RD&I funding are Horizon Europe and the Innovation Fund (IF). Whereas Horizon Europe specialises in research and innovation, the IF primarily supports first commercial examples and large-scale demonstrations, bridging the gap between early-stage innovation and commercial viability. Both funds operate at significant budgets, with €95.5 billion for the period from 2021 to 2027 for Horizon Europe (European Council, 2025) and approximately €40 billion between 2020 and 2030 for the IF (European Commission, 2025e).

Despite the promising availability of funds, a recent report published by Carbon Gap (2025e) highlights that less than 0.5%, totalling €646.5 million, of the available budget from these funds has been allocated to projects that directly benefit permanent CDR (Figure 28). The report also stresses that the current funding level in the EU is significantly lower than that in the USA, which exceeds the EU's by a factor of four. Additionally, the authors emphasise that scaling permanent CDR to the levels suggested by the IPCC would require an RD&I funding contribution from the EU ranging from €2.88 billion to €5.85 billion over the next 15 to 20 years. The findings of this report suggest that if the EU aims to close research gaps

[38] See Appendix A and B

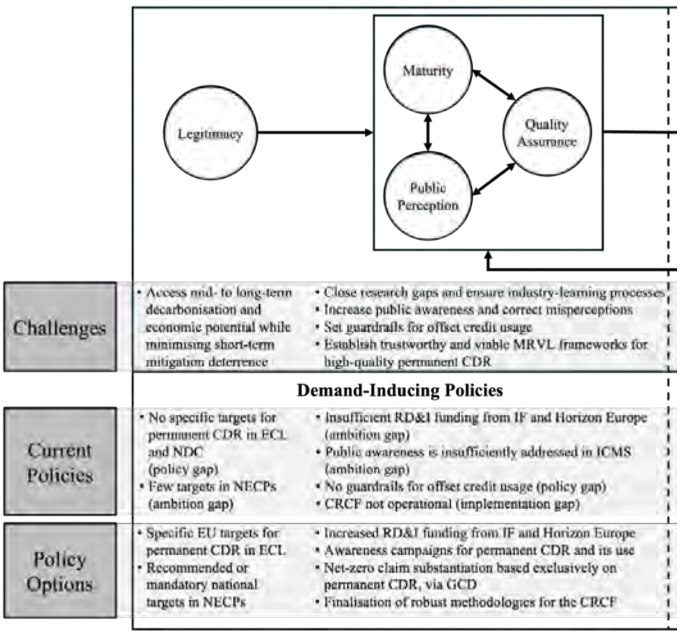
and support industry-learning processes effectively, a significant increase in RD&I funding is required.

*Figure 28: Direct RD&I funding for CDR at the EU level*


*Note. Figure from Carbon Gap (2025e, p. 11)*
*(LIFE Programme primarily funds temporary CDR)*

The assessment of demand-inducing policies has shown that current target-setting mechanisms are notably absent, and existing innovation instruments are insufficiently ambitious. While information instruments contributing to the quality assurance of permanent CDR credits are progressing, the policies governing the effective utilisation of these credits are currently deemed inadequate for stimulating sufficient demand. In addition, the critical need to enhance public awareness and correct misperceptions surrounding permanent CDR largely remains unaddressed. Figure 29 provides a comprehensive summary of this evaluation of existing EU policies and outlines discussed policy options.

*Figure 29: Assessment overview - demand-inducing policies*




*Note. For a larger version, please refer to Appendix C, "Visualisation of Research Findings"*

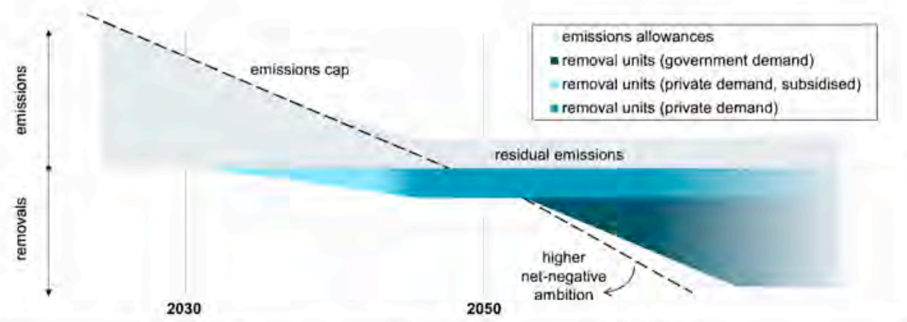
In conclusion, while demand-inducing policies for permanent CDR operate through a diverse range of policy instruments and address some of the support-requiring areas, they are currently deemed insufficient to induce the demand levels necessary for large-scale deployment, suggesting a need for either integrating the discussed policy options or for additional policy instruments that go beyond demand induction.

## Demand-Creating Policies

As elaborated in the previous chapter, demand-inducing policies alone are considered insufficient for unlocking a large-scale deployment of permanent CDR. A complementary pathway could be presented by demand-creating policies, which encompass the integration of permanent CDR into GHG pricing instruments, mandates and take-back obligations, and public procurement schemes. It is noteworthy that these instruments are crucial not only for the initial deployment of permanent CDR technologies but also for enabling the important function of permanent CDR to manage emission overshoot in the long term. Notably, the integration of permanent CDR into the EU ETS represents a particularly prominent topic of discussion. The EU ETS is described as the world's oldest and most liquid compliance carbon market. It covers nearly 40% of the EU's total GHG emissions (European Commission, 2024a) and reached a trading volume of approximately €781 billion in 2024 (Veyt, 2025). Accessing this market could present a promising opportunity for the uptake of permanent CDR.

Numerous schemes for integrating permanent CDR into the EU ETS are currently discussed, and most of them adhere to a similar structural framework as the one described by Sultani et al. (2024) and illustrated in Figure 30. In the initial phase leading to net zero, EUAs issued by the government and permanent CDR credits generated by removal firms are supplied to the compliance market. Once the EUA cap reaches zero over time, the second phase begins, in which the remaining emissions are compensated by permanent CDR. This net-zero phase would serve as a crucial reference point for defining residual emissions, effectively describing those emissions that are more cost-effective to remove than to abate. Subsequently, in the third phase, governments begin to purchase permanent CDR to reduce potential emission overshoot, leading to a net-negative scenario. According to Sultani et al., the integration of permanent CDR can help the EU ETS avoid a steep rise in EUA prices for hard-to-abate emissions and effectively circumvent its "endgame" phase, which would otherwise begin once the cap is exhausted.

*Figure 30: Structural framework for integrating permanent CDR into the EU ETS*




| | Phase 1: Road to net-zero | Phase 2: Net-zero | Phase 3: Overshoot management |
|---|---|---|---|
| Net emissions | >0 | 0 | <0 |
| Certificate supply | • government<br>• removal firms (permanent) | • removal firms (mainly permanent) | • removal firms (permanent and temporary) |
| Certificate demand | • emitters (all) | • emitters (residual) | • government<br>• emitters (residual)* |

*including perpetual renewal of temporary removals, which could also be mandated to removal firms.

*Note. Figure from Sultani et al. (2024, p. 10)*

In its role of advising the European Commission and proposing tools to reach the targets set in the ECL, the ESABCC (2025) discussed three distinct pathways for integrating CDR into the EU ETS:

1. **Direct, unconstrained integration**: Under this model, entities within the EU ETS would be able to purchase and use CDR credits without any limits or restrictions to counterbalance their emissions within the overall cap.
2. **Integration with supply and demand controls**: This model enables EU ETS entities to purchase and utilise CDR credits directly to offset emissions, subject to specific restrictions. These controls could involve quantitative limits on the amount of CDR used or restrictions on the types of CDR methods accepted.
3. **Integration via an intermediary institution**: In this model, an intermediary body or institution would manage the process of integrating CDR into the EU ETS. This institution could oversee the supply and demand of CDR credits, determining the conditions, quantities, and timing for integrating different CDR methods.

While a detailed assessment of these three types of integration would exceed the scope of this thesis, it is important to highlight that the ESABCC considers the first option as not viable as it carries significant risks, including the potential for mitigation deterrence. Furthermore, other authors have highlighted that the integration of permanent CDR into GHG pricing instruments requires Pigouvian efficiency, meaning that market system prices accurately reflect all external costs associated with permanent CDR (Sultani et al., 2024). Therefore, it is indispensable that permanent CDR credits are of high quality, essentially setting a successful implementation of the CRCF as a precondition of any integration of permanent CDR into the EU ETS.

Although the EU ETS could unleash high demand if permanent CDR credits are integrated favourably, many interviewed actors highlighted that, as of today, it is not integrated, and the long timeline for integration prohibits the short-term demand generation required for scaling. Eventually, the European Commission will not report on any integration of negative emissions technologies in the EU ETS before 2026, and many sources state 2030 as the assumed earliest possible date for such integration (CATF & CONCITO, 2024). Whether an integration would create demand in the first phase of the EU ETS is also challenged. As noted by one interviewee, permanent CDR credits are more costly than today's EUAs[39], indicating that only a combination of integrating permanent CDR into the EU ETS and an additional increase in EUA prices would effectively incentivise permanent CDR credit demand.

Besides the EU ETS, other GHG pricing mechanisms exist that could integrate permanent CDR. However, actors are concerned that a poor integration in other schemes could have negative implications for CDR's integration into the EU ETS. For instance, Manhart and Tamme (2025) discussed integrating permanent CDR into the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), a global market-based mechanism for offsetting $CO_2$ emissions from international flights. In their discussion, they state that CORSIA addresses only a small percentage of emissions, that current eligible credits are significantly cheaper than permanent CDR credits, and that the current system is frequently criticised for having quality issues. In light of the adverse impacts that controversies surrounding low-quality offset credits have had on the public perception of permanent CDR, integrating it into a highly criticised system such as CORSIA could lead to undesired effects.

In the absence of successful integration into GHG pricing instruments, mandates and take-back obligations could establish an alternative source of demand for permanent CDR. The ESABCC (2025) describes these as quantity-based policy concepts that legally compel actors, typically emitters or fossil fuel providers, to remove or pay for the removal of a portion of their emissions. Although the ESABCC considers this a strong incentive tool that does not interfere with emission reduction efforts (as it is supplementary), the advisory board also identifies significant shortcomings. For instance, policymakers would need to determine

[39] See Appendix B

the precise fraction of emissions that would be matched with mandatory permanent CDR credits, which could lead to cost ineffectiveness due to imperfect information on market conditions. Additionally, the ESABCC explains that the effectiveness of mandates and take-back obligations hinges on robust enforcement mechanisms and the sufficient availability of credits.

However, these shortcomings should not be prohibitive for EU legislators, as legacy policies show. For example, the ReFuelEU Aviation Regulation mandates all aviation fuel suppliers at EU airports and all aircraft operators departing from EU airports to use Sustainable Aviation Fuel (European Commission, 2025g). This mandate begins at 2% of total fuel supplied and is set to increase over time, reaching 70% by 2050. The regulation also introduces severe penalties for non-compliance. Another example of mandates in the EU can be found in the NZIA (Regulation (EU) 2024/1735, 2024). This act mandates oil and gas companies operating in the EU to contribute to the development of $CO_2$ infrastructure, primarily related to $CO_2$ storage injection capacities. The regulation also stipulates that member states must develop effective and proportionate penalties if these mandates are not met.

Interviewed stakeholders view mandates and take-back obligations as one of the most effective tools for creating sufficient demand in the short term since they would incentivise predictable and longer offtake agreements with fixed volumes, which are vital for achieving the FID of permanent CDR projects. Nevertheless, they also acknowledge that these policy instruments do not align with the EU's current political agenda, which aims to increase competitiveness and reduce the financial burden on economic actors.[40]

While mandates and take-back obligations appear promising for developing stable demand to scale permanent CDR and align with historic EU legislation, their viability is significantly constrained by the EU's current competitive agenda. Additionally, the ongoing discussions regarding permanent CDR's integration into the EU ETS further divert focus away from mandates and take-back obligations. Given that the integration into GHG pricing instruments is still in its early stages and mandates and take-back obligations seem presently unviable, public procurement emerges as the remaining policy instrument for short-term demand creation.

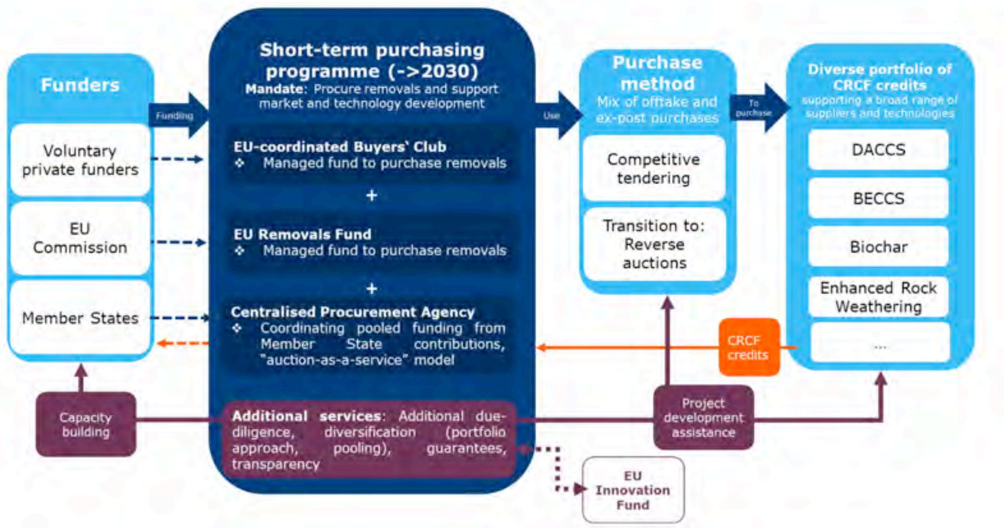
[40] See Appendix A

In this thesis, public procurement is defined as a policy instrument in which the government acts as a direct buyer of permanent CDR credits. According to the climate NGO Carbon180 (2024), public procurement offers both direct and indirect catalytic benefits. The primary direct benefit is its ability to leverage government purchasing power to generate short-term demand. In addition to direct benefits, indirect benefits induce demand by fostering trust in the industry, providing market certainty, and incentivising innovation and high-quality projects when incentives are set appropriately. The U.S. Department of Energy's CDR Purchase Pilot serves as a compelling precedent of these benefits, as Höglund and Preston (2025) explain. Following the selection of semi-finalists, the program successfully attracted private buyers, notably Meta and Google.

Nevertheless, the indirect catalytic effects of public procurement are not assured. It could, conversely, be interpreted as a sign of immaturity, with potentially detrimental impacts on buyer behaviour. Such adverse effects should be explored in future research.

Although no public procurement program currently exists in the EU, the recognised need for such a mechanism has led the European Commission to actively organise workshops aimed at drafting policy proposals (McDonald et al., 2025). Figure 31 illustrates a selection of draft schemes presently under discussion.

*Figure 31: Selection of draft public procurement schemes under discussion*



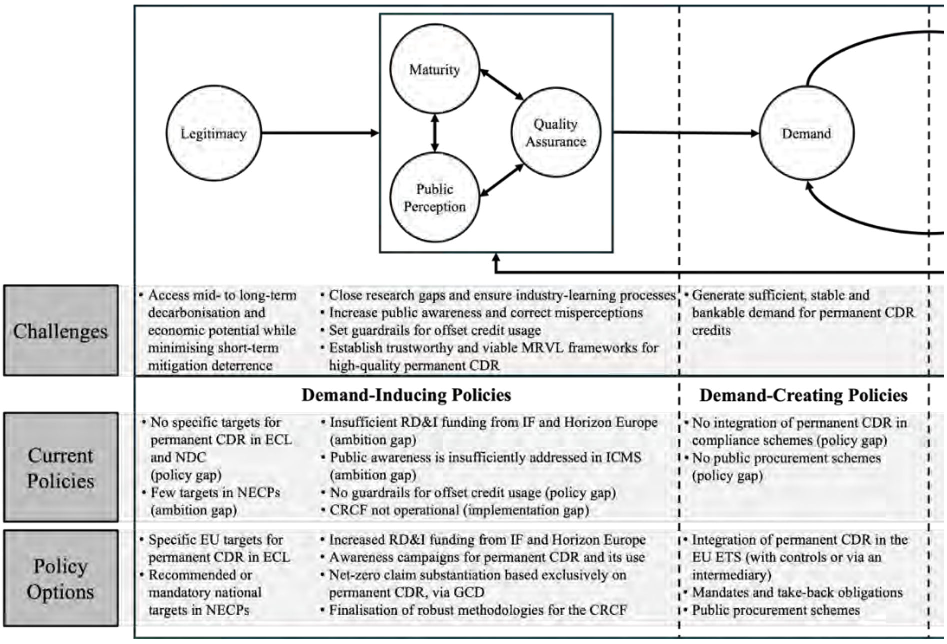

*Note. Figure from McDonald et al. (2025, p. 1)*

Another potential driver for short-term demand generation within public procurement could be the revised Article 6 of the Paris Agreement. As highlighted by Carbon Gap (2025d), Article 6.4 establishes a mechanism allowing countries to voluntarily trade credits from emission reduction and CDR projects. This enables Paris Agreement signatories to purchase credits generated in one country to help fulfil NDCs of another. Carbon Gap notes that the supervisory body of the Paris Agreement plans to finalise methodologies for CDR activities and set up an interim registry in 2025. Nevertheless, technical negotiations on some key topics remain ongoing.

Despite the promising nature of Article 6's evolution, interviewed actors emphasise that it only provides the possibility to purchase foreign permanent CDR credits to meet NDC targets, which does not directly translate into immediate demand.[41]

Demand-creating policies are frequently discussed for their potential to directly support the establishment of sufficient and stable demand, a key issue within the political economy of permanent CDR. Nevertheless, a significant policy gap persists, as no such instruments have been deployed to date. As outlined in this discussion, short-term public procurement schemes, paired with a long-term integration into the EU ETS, are considered the most viable policy options for generating sufficient and stable demand for permanent CDR credits. Figure 32 presents the findings of this chapter, incorporated into the assessment overview.

*Figure 32: Assessment overview - demand-inducing and demand-creating policies*




*Note. For a larger version, please refer to Appendix C, "Visualisation of Research Findings"*

[41] See Appendix A

## Supply-Inducing Policies

As the name suggests, supply-inducing policies operate on the supply side and primarily aim to ensure the financing of permanent CDR projects, reduce the cost of permanent CDR credits, and create a conducive environment.

A central instrument in this category is the deployment subsidy, which is essentially a fund or financial incentive provided by governments to organisations that deploy permanent CDR (ESABCC, 2025).

The 45Q tax credit serves as a relevant example of the importance of subsidies in the development of permanent CDR. According to the US-based business association Carbon Capture Coalition (2025), the 45Q is regarded as the most significant policy driver for DACCS, BECCS, and CCUS in the USA and has contributed to the announcement of over 270 carbon management projects in the country. Notably, 190 of these projects were announced following the enhancement of the tax credit. Since 2022, DACCS and BECCS operators have received a tax credit of \$180 and \$85, respectively, for each tonne of $CO_2$ safely stored in geological formations over a 12-year period following the start of the facility's operation. However, the Carbon Capture Coalition also points out that the positive development induced by the tax credit has significantly slowed down as inflation erodes its economic benefit.

Another successful example of a deployment subsidy is Sweden's reverse auction scheme for BECCS, as highlighted by the ESABCC (2025). In this model, permanent CDR projects submit competitive bids to receive public subsidies per tonne of $CO_2$ removed under long-term government contracts. The project offering the lowest price per tonne of $CO_2$ removed is selected and awarded a fixed subsidy at that winning rate for a period of 15 years. Sweden's scheme was approved by the European Commission in July 2024 and is planned to offer a total of €3 billion in state funding. Stockholm Exergi's BECCS project vividly illustrates the importance of the Swedish subsidy scheme. As their CEO points out, reaching FID would not have been possible without the €1.7 billion subsidy awarded through this reverse auction scheme (Stockholm Exergi, 2025a).

Denmark is also one of the few countries that has deployment subsidy schemes in place. For example, they established a fund for Negative Emission via CCS (NECCS), which has a budget of approximately €350 million and aims to achieve a permanent CDR of 0.5 Mt $CO_2$

per year from 2025 (IEA, 2023). Furthermore, Denmark has announced a plan to subsidise biochar CDR with a budget of €1.3 billion until 2045 (Carbon Gap, 2025b).

During the interviews, actors have repeatedly emphasised the importance of deployment funding in reaching FID. They highlighted that in an environment where bankable demand is low, deployment subsidies are crucial to attract investors and early offtakers[42]. Hence, expanding national deployment subsidy schemes to the EU level could further accelerate the scaling of permanent CDR in the EU.

At this point, it is essential to note that RD&I funding, public procurement, and deployment subsidies are often regarded as a single policy category, as they all operate on the principle of public budgets being utilised to develop and deploy permanent CDR. For instance, Stockholm Exergi's BECCS project also received €180 million in EU funding through the Innovation Fund (Stockholm Exergi, 2022). However, each of these tools comes with distinct targets and benefits. While deployment subsidies primarily aim to reduce initially high costs in order to attract investors and customers, RD&I focuses on de-risking innovation, and public procurement seeks to create and induce demand while setting industry standards.

Besides deployment subsidy schemes, deployment facilitation instruments play an important role in inducing supply. Eventually, permanent CDR cannot be deployed without access to $CO_2$ infrastructure, sustainable biomass, or renewable energy.

As analysing the status of each of these policy fields would exceed the scope of this work, and the current availability of sustainable biomass and renewable energy was not highlighted as insufficient for the early scaling of permanent CDR in the EU, the following section will focus on a few central ambition gaps identified for $CO_2$ infrastructure. However, it is noteworthy that as permanent CDR gains scale, particularly the availability of sustainable biomass could become a new barrier. Moreover, the rising demand for low-carbon electricity by data centres warrants scrutiny, a concern exemplified by the unsuccessful project in Wyoming, USA (Hiar, 2024).

As Figure 33 shows, $CO_2$ infrastructure encompasses the access of $CO_2$ capture facilities to $CO_2$ transportation networks, the transportation network (including pipelines, ships, and tankers), the access of $CO_2$ injection and storage facilities to the transportation network, and the $CO_2$ injection and storage facilities themselves.

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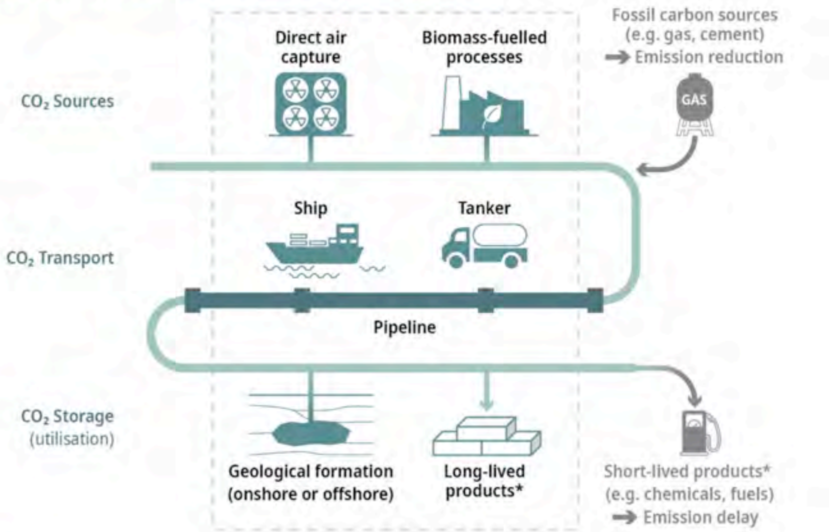
[42] See Appendix A

*Figure 33: $CO_2$ infrastructure across the $CO_2$ value stream*




*Note. Figure from ESABCC (2025, p. 178)*

The ESABCC (2025) assessed that the EU has laid the groundwork for $CO_2$ infrastructure development with the adoption of the CCS Directive in 2009. The recent NZIA builds on this by accelerating permitting procedures and obliging oil and gas companies to actively contribute to the development of $CO_2$ injection capacities. Despite these efforts, the ESABCC concludes that the EU's $CO_2$ transport and storage infrastructure is currently insufficient. The advisory body identified specific gaps, such as the lack of a harmonised $CO_2$ quality standard or network code needed for interoperability and the absence of monitoring and control rules for $CO_2$ capture and transport infrastructure. In addition, it notes that there is currently no systematic tracking of progress in $CO_2$ infrastructure readiness at the EU level. The ESABCC's assessment reveals that current policies might be insufficient to ensure the availability of $CO_2$ infrastructure needed for permanent CDR, indicating an ambition gap.

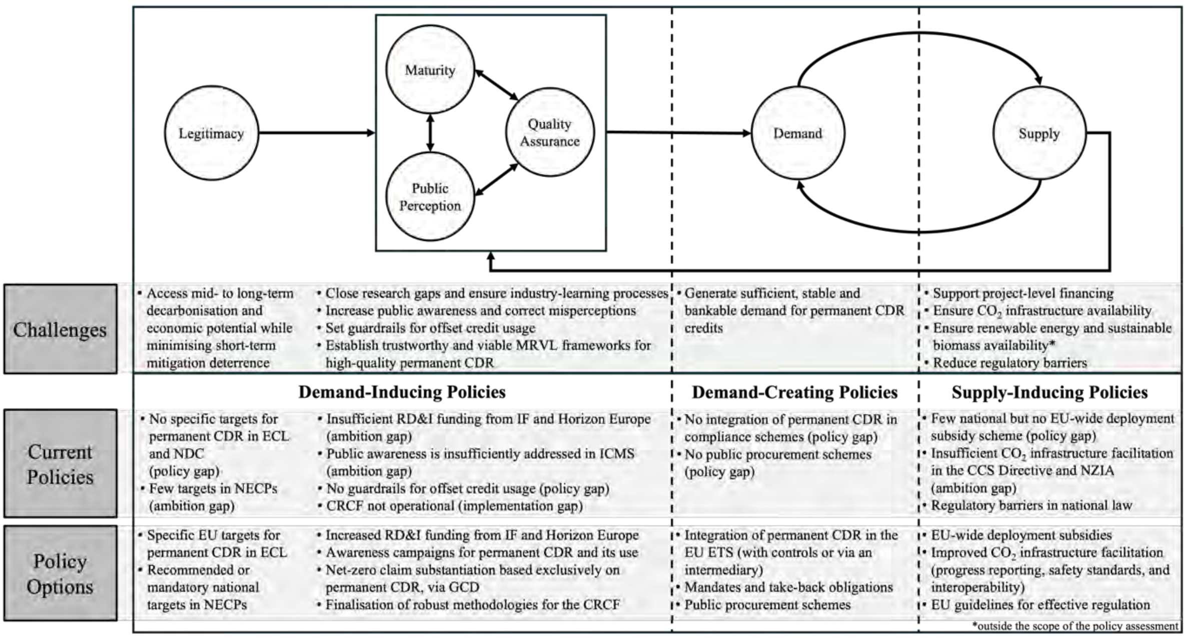
Deployment facilitation also aims to ease regulatory barriers that hinder the deployment of permanent CDR technologies. Examples range from the prohibition of underground $CO_2$ storage to the complicated permitting of pyrolysis plants for biochar CDR, both derived from the German context. In these instances, EU law cannot directly intervene as it falls within the national competence of member states (European Commission, 2025f). However, the EU could propose recommendations or communicate best practices for national regulations that facilitate the deployment of permanent CDR.

To conclude, supply-inducing policies can be powerful instruments, as demonstrated by the 45Q tax credit in the USA. In the EU, some national deployment subsidy schemes already exist, exhibiting their beneficial effects. However, EU-wide schemes supporting project-level financing are largely absent, indicating a policy gap. Other supply-inducing policies that facilitate deployment are already in place in the EU. For instance, the CCS Directive is a crucial tool for facilitating the development of $CO_2$ infrastructure. Nevertheless, sources point out that these policies might be insufficient to build the environment required for scaling permanent CDR, reflecting an ambition gap.

Lastly, EU policies have only a limited impact on easing national regulatory barriers, as member states possess legislative competence. However, EU policies could influence these barriers by recommending certain practices deemed helpful in facilitating the deployment of permanent CDR.

The discussed findings were added to the assessment overview (Figure 34), and the implications of the findings will be discussed in the following concluding part of the thesis.

*Figure 34: Assessment overview - demand-inducing, demand-creating, and supply-inducing policies*




*Note. For a larger version, please refer to Appendix C, "Visualisation of Research Findings"*

# Conclusion, Limitations & Outlook

Before delving into the conclusion of determining whether policies can unlock a large-scale deployment of permanent CDR in the EU, it is crucial to recapitulate the research's key developments and findings.

The first part of this thesis was dedicated to analysing the political economy of permanent CDR. It started by introducing the key actors involved, encompassing *societal*, *market*, and *political actors*. Subsequently, considering the *context* of these actors, their diverse *ideas*, *interests*, and *objectives* concerning the political economy of permanent CDR were analysed and aggregated into distinct variables.

Variables, in this context, refer to dynamic factors within the political economy that are influenced by the conflicting and reinforcing ideas, interests, and objectives of the actors. The identified variables were *legitimacy*, *maturity*, *public perception*, *quality assurance*, *demand*, and *supply*. A primary finding of this research is that each variable inherently presents *challenges* necessitating policy support. For instance, within the variable of legitimacy, it was found that policy support is required to establish a pathway enabling access to permanent CDR's mid- and long-term decarbonisation potential while simultaneously averting short-term mitigation deterrence. Another example, stemming from the variable of demand, reveals that low demand constitutes a key barrier to permanent CDR deployment, as it hinders project developers from securing the necessary financing for project development.

Following this individual analysis, the variables were examined from a holistic perspective to identify system-wide challenges by building a *Systems Thinking Model* of the political economy of permanent CDR. A key finding from this systems analysis was that low demand is a consequence of a complex interplay among maturity, public perception, and quality assurance. Additionally, it was found that resolving a dilemma within one variable might not necessarily result in higher demand due to the influence of other variables. For example, even if quality assurance was not considered an issue, public perception and the maturity of permanent CDR might still prohibit sufficient demand.

However, a systems approach also demonstrates that one factor can positively affect another, thereby creating feedback loops that benefit the entire system. This is particularly evident in the demand and supply loop, where increased supply leads to reduced costs, higher maturity, improved understanding of quality assurance, and potentially enhanced public perception, consequently generating new demand.

The second part of the thesis assessed the impact of policies on the variables and dynamics of this system. For this assessment, challenges identified in the first part of the thesis were established as assessment criteria. Subsequently, various types of current policies and policy options were evaluated against these criteria. These policies were clustered into *demand-inducing*, *demand-creating*, and *supply-inducing* categories.

A key finding of the analysis is that current policies are highly insufficient to resolve current challenges and positively influence the variables of permanent CDR's political economy. Most existing policies either fail to address the issues (policy gap), address them insufficiently (ambition gap), or address them sufficiently but remain unimplemented (implementation gap). Consequently, current policies are unlikely to unlock a large-scale deployment of permanent CDR.

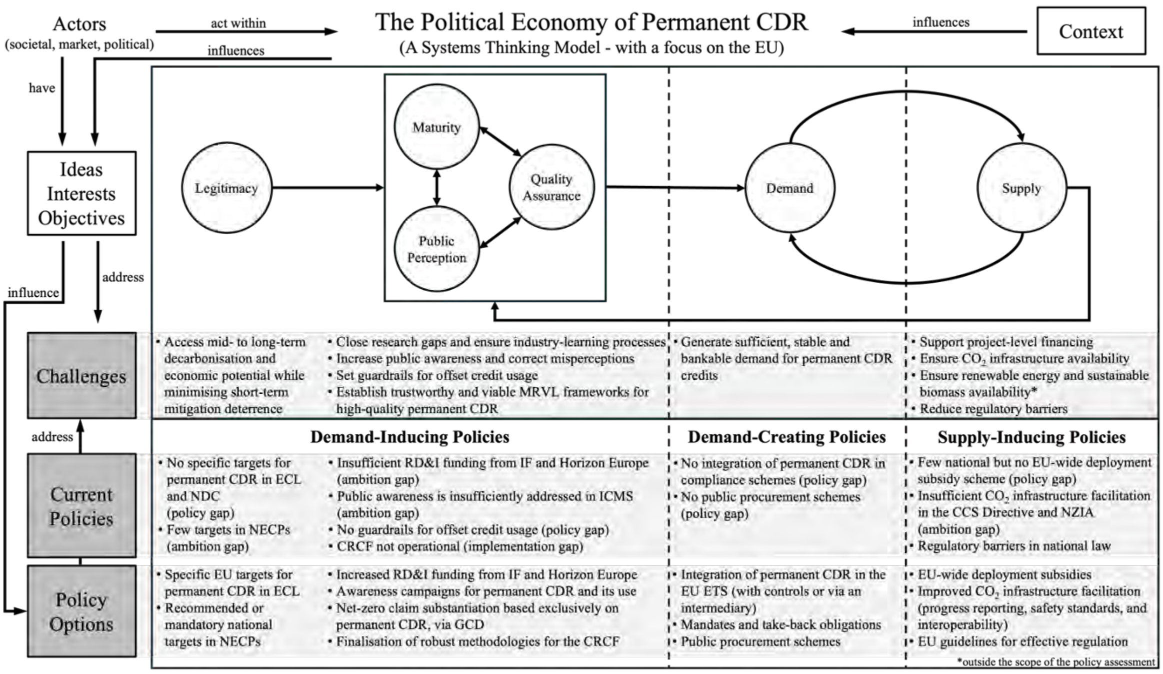
Nevertheless, the assessment also revealed that numerous policy options exist with the potential to resolve the challenges and to positively influence the identified variables. For instance, if EU-wide targets are set, robust quality assurance schemes like the CRCF are operational, public procurement combined with deployment subsidy schemes generate short-term demand, and the integration of permanent CDR into the EU ETS enables long-term demand, large-scale deployment of permanent CDR might become feasible.

This conclusion leads to an overarching finding of the thesis: the analysis of the political economy and the subsequent assessment of current policies and policy options suggest that unlocking a large-scale deployment requires a systems thinking approach, which considers all the complex dynamics of the system and its variables.

Policymakers often tend to address complex challenges in isolation. However, a fragmented approach might not be beneficial for systemic change. Thus, this research suggests the development of a comprehensive, overarching strategy to enable the large-scale deployment of permanent CDR, a strategy currently absent at the EU level.

The research process and its key findings are visualised in Figure 35.

*Figure 35: Visualisation of research findings*




*Note. For a larger version, please refer to Appendix C, "Visualisation of Research Findings"*

Developing an overarching strategy might encounter similar issues and limitations as the development of this research's findings. Analysing a complex system is an iterative and potentially endless process, as the relationships between variables increase disproportionately to the number of variables. Six variables, for example, have 15 potential relationships among them, while 12 variables already have 66 potential relationships among them.

Additionally, the identified variables reflect the political economy and its challenges only as described by the societal, market, and political actors consulted in the research process. It is important to note that non-consulted actors might hold differing views, which could significantly alter the dynamics of the described political economy. Eventually, only a selection of political actors was consulted because many others have not yet formed an opinion on this nascent topic.

Moreover, each variable possesses sub-levels of complexity. For example, within the scope of this research, topics such as intergenerational fairness or cannibalisation effects between temporary and permanent CDR were not addressed by the author, as they were deemed less relevant than others. Also, some topics were explained only at a high level and could have merited greater attention, such as regulatory barriers for biochar CDR.

These subjective selections of topics of importance lead to another limitation. According to Systems Thinking, complex problems are non-linear, meaning that variables omitted from the analysis but present in reality could indeed have significant impacts, either driving or blocking a large-scale deployment of permanent CDR.

Another limitation of the research findings is that the proposed policy options influence the political economy only theoretically. For example, target-setting instruments theoretically address legitimacy issues, but the actual effect of setting targets can only be measured retrospectively.

Lastly, the political economy of permanent CDR is profoundly interlinked with innovation and technological development. For instance, a new CDR method might enable safe and inexpensive permanent CDR, potentially rendering some discussed findings obsolete.

These observations suggest that further research should be dedicated to the optimal systematic analysis of the political economy of permanent CDR and the effectiveness of proposed policy options.

Ultimately, the overarching challenge remains climate change, and permanent CDR could contribute to its mitigation. However, for significant effects to be realised, large-scale deployment is required. This thesis has demonstrated that current policies are insufficient to address the challenges of today's political economy. Nevertheless, it has also shown that policy options exist which might unlock a large-scale deployment of permanent CDR.

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# Appendix A - Interviews with Societal & Market Actors

The Appendix A will be made available by the author upon reasonable request. To obtain a copy, please contact Ole von Wendorff at o.vonwendorff@gmail.com.

## Appendix B - Interview(s) with Political Actor(s)

The Appendix B will be made available by the author upon reasonable request. To obtain a copy, please contact Ole von Wendorff at o.vonwendorff@gmail.com.

# Appendix C - Visualisation of Research Findings