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Glossary

Additionality
"Additionality is the simple concept that a project will be additional if it can demonstrate that the emission reductions or removals occurred only due to the intervention of the scheme. Additionality is an important requirement for offsetting mechanisms". (COWI et al., 2020)

Albedo Effect
The capacity of a surface to reflect sunlight back into space is known as the albedo effect. A surface's reflectivity is measured by albedo, with higher values indicating greater reflectivity and lower values suggesting greater solar energy absorption.

Biomass
"Biomass is organic matter consisting of or recently derived from living organisms excluding peat, and includes products, by-products and waste derived from such material (IPCC 2006, Glossary)."(Jörß et al., 2022)

Carbon Leakage
"Carbon leakage is defined as the displacement of economic activities that directly or indirectly result in GHG emissions to be displaced from a jurisdiction with GHG constraints to another jurisdiction with no or less GHG constraints. This displacement could potentially lead to an increase in their total emissions"(COWI et al., 2020)

Eutrophication
The build-up of anthropogenic nutients in natural waterways primarily due to leaching and run-off from agricultural processes

Greenwashing
"Greenwashing is a PR tactic used to make a company or product appear environmentally friendly, without meaningfully reducing its environmental impact."(Das, 2022)

Permanence
"Permanence refers to the longevity of a carbon pool and the stability of its stocks, given the management and disturbance of the environment in which it occurs"(COWI et al., 2020)

Polluter Pays Principle
The principle of Polluter Pays entails that the responsibility for pollution prevention, cleanup, and the associated costs, including criminal, civil, and environmental liabilities, rests with those responsible for the actual contamination, ensuring that society does not bear the financial burden of environmental harm.

Carbon Sink
"Carbon reservoirs and conditions that take-in and store more carbon (i.e., carbon

sequestration) than they release. Carbon sinks can serve to partially offset greenhouse gas emissions. Forests and oceans are large carbon sinks."(UNFCCC, nodate)

Carbon sequestration
"The uptake and storage of carbon. Trees and plants, for example, absorb carbon dioxide, release the oxygen and store the carbon. Fossil fuels were at one time biomass and continue to store the carbon until burned"(UNFCCC, nodate)

Nature-based Solutions (NbS)
"Is an umbrella term that describes a wide suite of actions to “protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits” (Lo et al., 2022)

Residues (agricultural)
Organic residue remaining after the harvesting and processing of a crop or livestock production (UNFCCC, nodate)

Acronyms

CA - Corresponding Adjustment
CAP - Common Agricultural Policy
CDR - Carbon Dioxide Removal
CCS - Carbon Capture and Storage
CO_2 - Carbon Dioxide
CH_4 - Methane
DKK - Danish Kroner
EU CRC - European Union Carbon Removal Certification
ESR - Effort Sharing Regulation
ETS - European Union Emission Trading System
GHG - Greenhouse Gas
IA - Impact Assessment IPCC - The Intergovernmental Panel on Climate Change
ITMO - Internationally traded mitigation outcome
LT-LEDS - Long-term Low Greenhouse Gas Emission Development Strategies
LULUCF - Land Use and Land Use Change (regulation)
MT - Million tonnes
NDC - Nationally Determined Contributions
NBS - Nature-Based Solution
NDC - Nationally Determined Contribution
N - Nitrogen
P - Phosphorous
RQ - Research question
SOTA - State of the art
ST - Socio-technical sub-RQ - Sub-research question
VCM - Voluntary Carbon Market

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Problem Analysis 1

1.1 Paris Agreement and NDCs

The Paris Agreement is an international treaty that falls under the United Nations Framework Convention on Climate Change (UNFCCC). It was approved on December 12th, 2015, and went into effect on November 4th, 2016. The agreement aims to keep global warming to 1.5°C and well below 2°C from pre-industrial levels by the year 2100, which is further supported by the Intergovernmental Panel on Climate Change (IPCC) Working Group III report . The agreement is a comprehensive accord that encompasses all facets of climate change such as institutions, finance, technology, capacity building, loss and damage, mitigation, adaptation, and implementation. On its adoption, the Paris Agreement effectively replaced the 1997 Kyoto Protocol as the significant regulatory instrument guiding the world's response to climate change (Bodansky, 2021; P.R. Shukla et al., 2022). The novelty of the Paris Agreement lies in its global, bottom-up approach, relying on transparency to promote accountability rather than being legally binding. Furthermore, it incorporates an iterative process that fosters ambitious progression for the Parties towards fighting climate change. (Bodansky, 2021; P.R. Shukla et al., 2022)

Nationally Determined Contributions

The Paris Agreement aims to increase the ambition of post-2020 climate plans and pledges made by governments to meet the temperature targets through their National Determined Contributions (NDCs) under Article 4 of the Paris Agreement (Bodansky, 2021; den Elzen et al., 2019). Parties are required to submit an updated NDC, every 5 years. With each update, a review is done to inform the Parties whether the collective progress is on track to achieve the targets (Bodansky, 2021; Li & Duan, 2020). Article 4 also encourages the submission of Long-term Low Greenhouse Gas Emission Development Strategies (LT-LEDS) (UNFCCC, 2016), however, unlike the NDCs, these are not mandatory, and there are no requirements for their content or format. As of September 2022, only 53 LT-LEDSs had been submitted, and the submissions have been criticised for the lack of a politically acceptable pathway to achieve climate neutrality (Smith et al., 2022).

According to the United Nations Environment Programme's (2022) Emission Gap report, it is predicted that present policies in NDCs submitted at the 2021 Conference of The Parties (COP26) would cause a 2.8°C increase in global warming, and were therefore inadequate to meet the Paris Agreement goals. Consequently, in order to keep global warming to 1.5°C, global annual greenhouse gas (GHG) emissions must be reduced by 45% by 2030, from projections under current policies, and systemic reforms including of the financial and food systems are required (United Nations Environment Programme, 2022).

1.2 EU climate policy

The EU is one of the largest GHG emitters globally (Lundberg & Fridahl, 2022), and is perceived as a leader in international climate policy (Lundberg & Fridahl, 2022; Schenuit & Geden, 2022; Tamme & Beck, 2021). EU policy can therefore have an impact on debate and governance under multilateral forums such as the UNFCCC (McLaughlin et al., 2023; Schenuit & Geden, 2022).

The European Union and its member states submit a joint NDC under the Paris Agreement. Therefore the Paris Agreement does not recognise the individual contributions of the EU member states, yet, the UNFCCC continue to monitor the emission levels allotted to each member state, the details of which must be reported to the UNFCCC secretariat (legalresponse.org, 2022). In 2020, The EU pledged to reduce GHG emissions by at least 55% by 2030 compared to 1990 levels was added on December 17th, which is one of the most ambitious among the wealthiest nations (European Commission, 2019; Geden et al., 2018; Li & Duan, 2020).

1.2.1 Green deal and climate law

The EU Commission's primary policy tool to achieve this emission reduction target is the Green Deal. The Green Deal aspires to transform the society and economy of the EU by containing the explicit goal of making the EU *"the first climate neutral continent"* by 2050, with resource consumption decoupled from economic growth (European Commission, 2019). The EU's NDC pledges and Green Deal targets are made legally binding via the European Climate Law ((EU) 2021/1119).

In-line with the United Nations Environment Programme's (2022) Emission Gap report, the findings from the impact assessment and public discussion conducted in the spring of 2020 concluded that the EU climate policy framework was found to be insufficient to achieve climate neutrality by 2050. Moreover, it was determined that in order to avoid placing a greater burden on future generations, the EU must now enhance its goals for this decade (European Union, 2020).

Thus, a new climate policy called "2030 Climate Target Plan"increased the 2030 GHG reduction target to at least 55% as per the latest NDC revision, and couples this with a revised plan for the European Climate Law. In addition to establishing brand-new legal initiatives, the Climate Target Plan proposes changes to a number of the framework's existing 2030 climate and energy laws. The majority of the legislative proposals are incorporated into the Fit for 55 package, which is part of the European Commission's 2021 work program (Pérez De Las Heras, 2022). The 2030 Climate plan, therefore, tackles targets of GHG emissions reductions through three key pieces of climate legislation:

- the Emissions Trading System Directive (Directive (EU) 2018/410 amending Directive 2003/87/EC), *"which sets up a cap and trade system for large industrial and power sector installations and the aviation sector to reduce emissions by 43% by 2030 compared to 2005"*(European Union, 2020)
- the Effort Sharing Regulation (ESR) (Regulation (EU) 2018/842), *"with binding greenhouse gas emissions pathways at Member State level for the remaining*

emissions, adding up to a reduction of 30% by 2030 compared to 2005"(European Union, 2020)

- the Land Use, Land Use Change and Forestry (LULUCF) Regulation (Regulation (EU) 2018/841) *"obliges Member States to ensure that the net carbon sink from land use does not deteriorate compared to how it would have evolved continuing existing land use management practices"*(European Union, 2020)

An overview of these three pillars of EU climate policy are summarized in table 1.1.

Regulations:	**ETS (Directive 96/61/EC)**	**LULUCF \\ (Regulation (EU) 2018/841)**	**ESR \\ (Regulation (EU) No 525/2013)**
Overview	Based on a cap and trade system limits emissions for 10,000 installations	EU Member States must ensure balance between emissions and removals from land use, land use change, and forestry.	Establishes a different reduction target and freedom on how to achieved, for each Member state for all non-ETS sectors and excluding emisisons from LULUCF regulation
GHG cover	Covers around 40% of the EU's greenhouse gas emissions: CO2, N20 and perfluorocarbons (PFCs)	All GHG	All GHG
Industries	Energy sector, manufacturing industry (considered heavy industry) and aircraft operators	Forestry industry and agricultural industry	sectors not included in the EU Emissions Trading System \\ (ETS), such as transport, \\ buildings, agriculture and waste.
Regulation mechanism	'Cap and trade system'	'No debit rule'	Different reduction target for each member state

Figure 1.1. A summary the current EU regulatory climate framework under the Green Deal and Climate Law

1.2.2 The EU Emission Trading System

The EU Emission Trading System (ETS) is designed to lower greenhouse gas emissions in an efficient and cost-effective manner. It is the largest carbon market in the world, covering 11,000 installations within the most GHG-intensive sectors - power, manufacturing and aviation (European Commission, 2021a; Karpf et al., 2018).

In order to create incentives to reduce emissions, the ETS sets a cap on total emissions allowed from all facilities that are covered by the system. An operator must surrender enough credits each year to adequately cover its emissions or face large fines. If a facility lowers its emissions, it can keep the extra allowances to satisfy its needs in the future or sell them to another operator who needs them (European Commission, 2021a). This mechanism of emissions trading is an extension of the polluter pays principle (The Carbon Pricing Leadership Coalition, 2021), ensuring that a price is placed on carbon pollution, and was designed to allow emitters to use the most cost-effective means of emission reduction available. If the carbon price is sufficiently high, carbon markets can incentivise investment into climate change mitigation and emission reduction technologies, but only when paired with other policies that address market sectors and mechanisms not affected by carbon price (Howard, 2018; Org & Kennedy, 2019).

1.2.3 LULUCF

Land Use and Land Use Change and Forestry (LULUCF) plays an important role in the climate system, as both a source and a sink for GHGs. However, it wasn't until 2020 that this concept was taken into account for the achievement of EU's climate change mitigation target (Romppanen, 2020; Savaresi et al., 2020), because it has historically been seen as difficult to regulate (Böttcher et al., 2019; Savaresi et al., 2020). Nevertheless, the LULUCF Regulation was approved in the EU parliament in May 2018, and the EU set for the first time, emission and removals targets for the 2021 to 2030 period in the LULUCF sector (Böttcher et al., 2019). This is a key factor for EU 2030 climate Targets since the United Nations Environment Programme's (2022) Emission Gap report highlights that emissions and removals from LULUCF make a huge impact on the emission inventories of countries when activities in this sector are not correctly accounted (Savaresi et al., 2020).

The main rule of the LULUCF Regulation is that emissions cannot exceed removals within the LULUCF sector, also known as *no debit rule*. Although the LULUCF sector does not have a defined reduction objective, the rule stipulates that emissions and removals must be at or below zero. The no-debit rule includes, for example, removals from forest management (afforestation, deforestation) or emissions from draining of peatlands. It also covers the emissions and removals from the management of agricultural land, grassland, wetlands, and settlements. More than 75% of the EU's land area is made up of agricultural and forested areas, and both are seen as an opportunity to develop natural sinks in trees and soil organic carbon, to mitigate climate change (Verschuuren, 2022).

This balance between emissions and removals is a significant contribution to achieving Paris agreement targets because the mitigation objectives mandated by the Paris Agreement depend on achieving and maintaining net zero global anthropogenic CO2 emissions by fully accounting for both positive and negative emissions (Romppanen, 2020).

1.2.4 Effort Sharing regulation (ESR)

The Effort Sharing Regulation (ESR), approved in 2018, establishes a national emissions reduction target for all sectors not included in the ETS regulation and excludes emissions accounted-for in the LULUCF. The ESR regulation includes road transport, heating of buildings, agriculture, small industrial installations and waste management. The ESR target is based on Member State's GDP per capita and annual emissions allowance, which gradually decreases until 2030. Furthermore, It allows Member States the freedom to select the instruments and sectors they want to reduce emissions from (European Commission, nodate-b; Verschuuren, 2022). Agricultural sector activities fall between LULUCF and ESR regulations. LULUCF emissions cover emissions from the agricultural sector directly from land and land use changes but it does not include emissions from livestock that fall into the ESR pillar. This has given member states the freedom to leave livestock emissions out of their reduction targets (Møllgaard et al., 2023; Verde & Chiaramonte, 2021; Verschuuren, 2022).

Current flexibilities between LULUCF and ESR

Existing Flexibilities between ESR and LULUCF regulations allow Member States with net-negative LULUCF emissions to use additional reductions for ESR targets. Member States can offset up to 280 million tonnes of ESR emissions by LULUCF removals between 2021 and 2030. This flexibility encourages exceeding LULUCF balance requirements by enhancing reduction or removal to compensate for ESR emissions. These flexibilities recognize the limited mitigation capacity of the agriculture sector under the ESR, since removals are not accounted for, while increasing potential reduction and removal in LULUCF (European Commission, 2021b; Verde & Chiaramonte, 2021; Verschuuren, 2022).

1.3 Net-zero implies the need for carbon dioxide removal

Since the publication of the IPCC's Fifth Assessment Report (AR5) in 2014 (Geden et al., 2018), and especially following the IPCC's 2018 special report on 1.5 °C warming, there has been increasing focus on the role of carbon dioxide removal (CDR) in supranational policy for achieving the Paris Agreement targets (Lundberg & Fridahl, 2022). With the updated NDC approved in December 2020, the EU has opened the way to using CDR to achieve the Paris Agreement targets, primarily through the LULUCF regulation (Erbach & Victoria, 2021; European Commission, 2020a). The EU's climate ambition is further reflected in the net-zero vision in the European Green Deal and Climate Law (Tamme & Beck, 2021).

The Intergovernmental Panel on Climate Change (IPCC) defines CDR as:

> *"Anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage, but excludes natural CO_2 uptake not directly caused by human activities."* (P.R. Shukla et al., 2022)

Paris Agreement climate policy prioritises emission reduction over removal, which is known as the *mitigation hierarchy*. This is evident in Article 4.1 of the Paris agreement which states that the first emissions goal is to rapidly reduce global emissions, while the second goal is to achieve net-zero emissions after 2050 (Bodansky, 2021). *'Net-zero'* implies that the continued emission of *'hard-to-abate'* or *'residual'* GHGs will be balanced out by CDR, while net-negative emissions can only be achieved with CDR (P.R. Shukla et al., 2022; Schenuit & Geden, 2022; Smith et al., 2022; Tamme & Beck, 2021). Figure 1.2 (Smith et al., 2022), depicts three scenarios for achieving the 1.5°C and 2°C targets assessed by the IPCC (P.R. Shukla et al., 2022). The graph shows that under the 1.5°C scenario with little or no overshoot, net-zero will be achieved at the earliest at 2055, at which point CDR is projected to begin dominating mitigation activity.

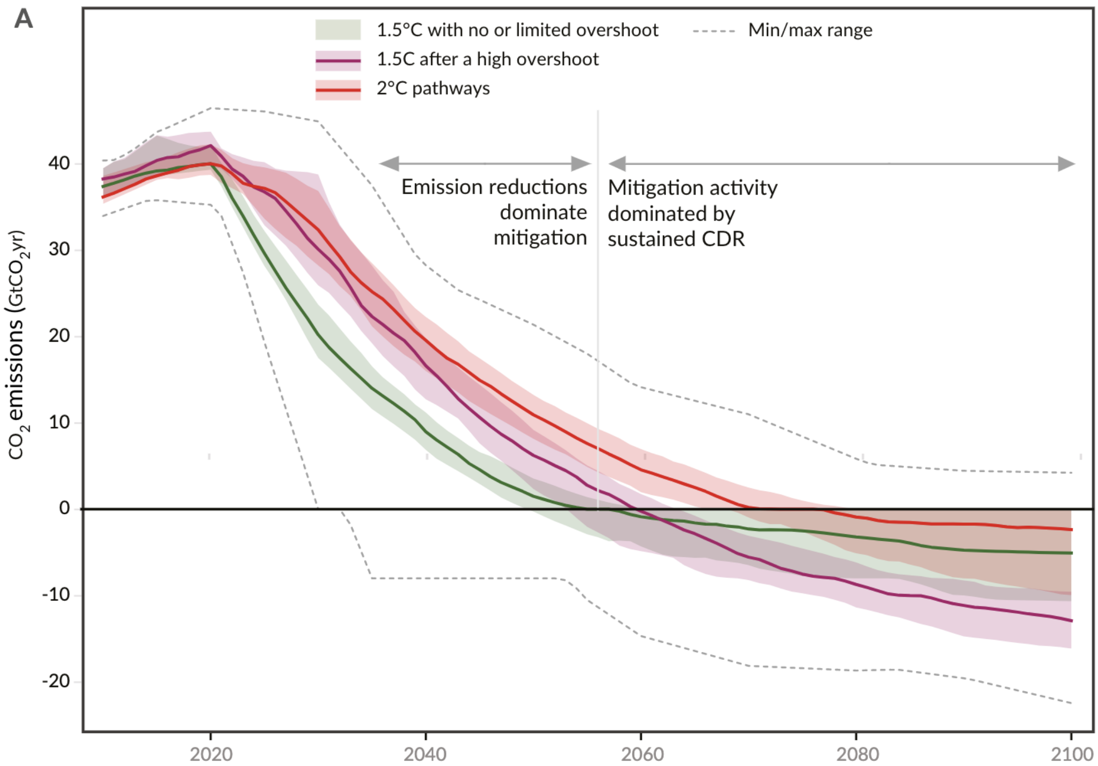

Figure 1.2. The global net CO_2 emissions for scenarios assessed in the IPCC Sixth Assessment Report 2022 (Smith et al., 2022).

Some scenarios to achieve the 1.5°C and 2°C targets do not require rapid deployment of CDR, however they require immediate and comprehensive reductions in emissions, which are considered unlikely given the findings of the United Nations Environment Programme's (2022) Emission Gap report and the EU Commission's impact assessment (Minx et al., 2018; Smith et al., 2022; Tamme & Beck, 2021), otherwise referred-to as the *"mitigation gap"*(Tamme & Beck, 2021) or "ambition gap"(Smith et al., 2022). The current emissions reduction trajectory therefore suggests a fundamental dependence upon CDR by 2030 to achieve the 2°C target (Geden et al., 2018; Minx et al., 2018).

1.3.1 Defining carbon dioxide removal

In line with the IPCC definition of carbon dioxide removal (CDR) (P.R. Shukla et al., 2022), Smith et al. (2022) follow three key principles when defining CDR, serving to differentiate CDR as net-negative technologies as opposed to net-zero mitigation technologies:

> **Principle 1**: The CO_2 captured must come from the atmosphere, not from fossil sources[1,2]. The removal activity may capture atmospheric CO_2 directly or indirectly, for instance via biomass or seawater.
> **Principle 2**: The subsequent storage must be durable, such that CO_2 is not soon reintroduced to the atmosphere.
> **Principle 3**: The removal must be a result of human intervention, additional to Earth's natural processes (Smith et al., 2022)[3]

Permanence of CDR storage methods

The IPCC in the 2018 special report on 1.5 °C warming states *"Reaching and sustaining net-zero global anthropogenic CO_2 emissions and declining net non-CO_2 radiative forcing*[4] *would halt anthropogenic global warming on multi-decadal timescales"*. (Masson-Delmotte et al., 2018). The long-term effects of current anthropogenic CO_2 emissions on global warming means that the permanence (or durability) of carbon storage in various carbon sinks is an important consideration when assessing the viability of CDR methods (Fankhauser et al., 2021; Smith et al., 2022). There is no scientific consensus for what constitutes a sufficiently permanent storage of carbon, however, various policies and standards have set a minimum permanence of between 25 years and 100 years (Smith et al., 2022).

The above IPCC statement also highlights the importance of acknowledging non-CO_2 radiative forcing drivers. These include other greenhouse gasses such as methane and nitrous oxide. Some IPCC global warming limiting scenarios focus more heavily on deployment of CDR, largely due to residual non-CO_2 emissions including from the agricultural sector (Smith et al., 2022). CDR methods discussed in this report are carbon sequestration methods, however, some methods such as biochar (defined in table 1.3) can, depending on the use-case, have secondary benefits including the reduction of non-CO_2 emissions from soil (Smith et al., 2022).

Figure 1.3 provides definitions of important CDR methods, together with consensus data on the permanence of carbon storage, costs at scale and climate change mitigation potential in tonnes of CO_2 sequestered per year for each method. The table is not a complete list of all available CDR technologies/methods and omits methods such as wetland

[1] The capture and storage of fossil fuel carbon is not counted as CDR as it does not result in net removal of carbon from the atmosphere (net-negative emissions). These activities are counted as emission reductions (Jörß et al., 2022; Smith et al., 2022)

[2] CDR methods only sequester CO_2. However, they also impact other GHGs such as NO_2 and CH_4 via a knock-on effect. Therefore, the total climactic effect of CDR is commonly reported as CO_2 eq. Paris agreement and EU targets regulates all greenhouse gasses, and converts GHG measurements to CO_2 eq (Smith et al., 2022)

[3] Meaning natural forests falling under EU LULUCF regulation are not considered CDR

[4] Radiative forcing is the process of the net increase in the sun's energy being trapped in the earth's atmosphere due to atmospheric GHGs, leading to climate change (P.R. Shukla et al., 2022)

restoration, ocean fertilisation and ocean alkalinisation. The latter two are considered more speculative with few scientific studies conducted (P.R. Shukla et al., 2022), with too little evidence for estimated mitigation potential at present (Minx et al., 2018), and very low level of technological readiness (Smith et al., 2022). Technological methods are those that involve some level of engineering of industrial processing (Smith et al., 2022), while Nature-based solutions (NBS) have been defined by the European Commission as: *"Solutions to societal challenges that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience"* (European Environment Agency, 2021).

CDR Method	Definition	Mode of storage	Permanent Carbon Sink	Technological readiness	Permanence (years)	Reversibility	Costs at scale ($/t CO2)	Mitigation potential (Gt CO2/yr)
Conventional Methods or Nature-Based Solutions (NBS)								
Forestry	Reforestation and afforestation	Biological storage, product storage	Forest biomass, wood for construction	High	10 - 1,000	High	0 - 240	0.5 - 10
Carbon farming	Any farming practice that aims to store carbon in the agricultural soil or biomass including agroforestry, no-till and cover cropping.	Biological storage	Soil, Biomass	High	10 - 1,000	High	'-45 - 100'	Soil carbon - 0.6 - 9.3 Agroforestry - 0.3 - 9.4
Blue carbon	The use of natural coastal and marine processes for storing carbon in marine carbon sinks. E.G. Mangrove forest.	Biological storage	Coastal sediment and biomass	Medium	10 - 1,000	High	Insufficien t data	<1
Technological Novel Methods								
Bioenergy with Carbon Capture and Storage (BECCS)	Energy generation method where biomass is burned and carbon is captured and stored from the flue gas, and subsequently permanently stored in geological formations (depleted oil reservoirs or in scilicate minerals) .	Geochemic al storage	Geological Formations	Low	10,000-1000,000	Low	100–200	0.5 - 11
Direct Air Carbon Capture and Storage (DACCS)	Direct air carbon capture and storage involves the chemical capture and temporary storage of CO2 directly from the atmosphere, and subsequent permanent storage in geological formations (depleted oil reservoirs or in scilicate minerals.	Geochemic al storage	Geological Formations	Low	10,000-1000,000	Low	100–300	5 - 40
Technological Novel methods combined with nature-based methods								
Biochar	Waste biomass undergoes pyrolysis to form a charcoal-like product. The most frequently discussed use case is as a soil additive.	Product storage	Biochar product, Soil	Low	10 - 10,000	Low	30-120	0.3 - 6.6
Enhanced rock weathering	Fine crushing of basalt rock and subsequent spreading over agricultural land or in the ocean to accelerate the weathering process of minerals in the rock that absorbs CO2.	Geochemic al storage	Soil	Medium	10 - 1,000	High	50 – 200	2 - 4

Figure 1.3. Summary table of CDR methods including definitions, pathway to carbon storage, status of technological readiness, permanence of carbon storage, estimated cost at scale and estimated climate change mitigation potential. Costs and mitigation potential figures are highly indicative and uncertain for those methods of medium of lower technological readiness. Data from (Minx et al., 2018; P.R. Shukla et al., 2022; Smith et al., 2022)

As shown in figure 1.3 CDR methods can be categorised as 'novel' methods and 'conventional' (Smith et al., 2022) or 'nature-based' and 'technological' (Buylova et al., 2021; Minx et al., 2018). Enhanced rock weathering and Biochar are often categorised separately due to dependence upon costly industrial processing, whilst predominantly being used as a soil additive leading to soil carbon sequestration (Buylova et al., 2021). Nature-based CDR methods generally fall under the EU LULUCF regulation, along with natural sinks that are not the result of human intervention (Savaresi et al., 2020).

Technological readiness

Estimates of technological readiness relate to the stage at which the CDR technology is ready to be deployed at scale. The designations 'low', 'medium' and 'high' are reflections of data from Smith et al. (2022) and Minx et al. (2018). Perceptions of technological readiness will typically indicate the scale at-which the technologies are currently deployed globally, and therefore which technologies are prioritised in climate policy. More technologically ready methods such as afforestation are the dominant CDR methods (Smith et al., 2022). 'Low' describes technologies in their infancy and 'High' describes operationally proven systems Smith et al. (2022) use a scale of 1 (lowest) to 9 (Highest). Minx et al. (2018) use designations of 'ready' or 'not ready'.

Reversibility

Reversibility or risk of reversal refers to how likely the carbon is to be re-released into the atmosphere after storage. It is deemed to be higher for nature-based CDR methods (Gehrig-Fasel et al., 2021; Minx et al., 2018; Savaresi et al., 2020) due to climate change impacts such as sea-level rise, and human disturbance such as land-use change, and natural disturbance such as forest fires (P.R. Shukla et al., 2022; Savaresi et al., 2020). More technologically ready CDR methods such as afforestation have a higher risk of reversal, and are increasingly being seen as having a lower mitigation potential for achieving Paris Agreement targets than the less established technologies such as BECCS and DACCS (defined in figure 1.3.1) (Savaresi et al., 2020).

Mode of carbon storage

The mode of carbon storage refers to the process by which the carbon is stored and is related to the carbon reservoir (or sink) used. Figure 1.3 refers to geochemical storage, biological storage and product storage. Biological storage has a higher technological readiness, but also a higher risk of reversal than geochemical storage.

- **Biological storage** can occur on land and in oceans in the form of photosynthesis leading to storage of organic carbon in trees, natural storage of carbon in soils and wetlands, and storage of biomass in aquatic sediments (Smith et al., 2022).
- **Product storage** consists of biochar and wood for construction. Other products such as carbonated drinks and fuels and chemicals do not qualify as CDR because they can quickly release their carbon back into the atmosphere (Smith et al., 2022).
- **Geochemical** storage involves storing concentrated CO_2 in reactive minerals such as in basalt rock or ocean carbonates, or in geological formations of depleted oil and gas reservoirs (Smith et al., 2022).

1.4 CDR in EU policy

In parallel with the IPCC's work on climate change mitigation, the Green Deal identifies two routes to increasing the levels of CDR within the EU. Firstly, the European Commission seeks to enable systems that incentivise land managers to sequester carbon, referred-to by the European Commission as *'Carbon Farming'*, as an agricultural NBS. Secondly, through the creation of an EU market for CDR, it seeks to incentivise industrial removal activities such as DACCS and BECCS (European Commission, 2020b). In line with this strategy, European Commission launched the carbon farming initiative in 2021, and published the proposal for carbon removal certification (EU CRC) in November 2022 (European Commission, 2022b). According to the EU Commission, the proposal is "essential to the EU's goal of becoming the world's first climate-neutral continent by 2050"(European Commission, 2022d). It is hoped that by 2030, carbon farming initiatives in the EU will contribute to the LULUCF net removals target of -310 Mt CO_2eq, while industrial technologies could remove at least 5 Mt CO_2eq per year by 2030 in the EU"(European Commission, 2022b).

1.4.1 Carbon Farming Initiative

The carbon farming initiative aims to directly incentivise the agriculture and forestry sectors to support the European Green Deal and take action on climate change and biodiversity. The initiative is open to participation from EU organisations, member states, and private initiatives (Bumbiere et al., 2022).

One policy tool at the EU's disposal to incentivise carbon farming is the Common Agricultural Policy. The CAP was initiated in 1962 to ensure food security in the EU by subsidising agricultural production. Since then, it has evolved to support environmental protection and climate mitigation by offering subsidies and direct payments to farmers who apply, and follow certain rules. Due to voluntary participation however, its impact on climate mitigation has been limited (Verschuuren, 2022). It is hoped however that CAP rules can used to be guide carbon farming projects to ensure permanence and additionality (European Commission, 2020b).

1.4.2 Proposal for EU carbon removal certification

In line with the IPCC definition of CDR noted in section 1.3.1, the proposal outlines a CDR certification framework covering carbon farming, carbon capture and storage (CCS) and carbon storage in long-lasting products. The ultimate goal of the framework is to advance the scale-up of high-quality CDR. It seeks to do this by;

- Incentivising all sectors including agriculture, forestry and heavy industries to adopt CDR solutions,
- Developing a trustworthy and credible system free from greenwashing,
- Increasing the capacity of EUs legislative frameworks to accommodate quantification, monitoring, reporting and verification of CDR,
- Encouraging the development of public and private funding mechanisms. (European Commission, 2022c)

With this proposal, the EU commission acknowledges and tries to address the two main risks for the carbon market. First that it is difficult and costly for stakeholders of the carbon market to assess the quality of removal activities, leading to investment in removal projects that are unreliable in their mitigation potential. Second is the loss of trust in currently certified credits due to potentially unreliable certification schemes (European Commission, 2020b) that result from the difficulties in ensuring permanence. If a CDR carbon credit representing 100 years of permanence is sold, while the ton of carbon it represents is re-released into the atmosphere after 50 years, this leads to a loss of trust in the market. The CRC can therefore serve to support the voluntary carbon market for the long-term development of permanent carbon sinks and adherence to Article 6 of the Paris agreement, which is further discussed below (European Commission, 2022a). Furthermore, EU Green Deal policies do not currently incentivise CDR beyond traditional forestry under LULUCF (Meyer-Ohlendorf & Spasova, 2022), and it is hoped that the EU CRC could eventually enable these pillars to regulate CDR (Elkerbout & Bryhn, 2022; Tamme & Beck, 2021).

1.5 The role of carbon markets for incentivising CDR

Carbon markets can contribute to NDC via Article 6 of the Paris Agreement. Since the effective replacement of the kyoto protocol's Clean Development Mechanism by the Paris Agreement's Article 6, there has been a lack of climate mitigation programs under the Paris Agreement due to ongoing negotiations around the operationalisation of Article 6 rules (Gehrig-Fasel et al., 2021). This means that despite the risks that the carbon market is currently exposed to, the voluntary carbon market (VCM) has been an important driver for climate mitigation projects. The VCM has enabled the funding of climate mitigation projects through the development of measurement, recording and verification (MRV) methodologies that are necessary to certify mitigation outcomes for sale on a market. (Gehrig-Fasel et al., 2021; Howard, 2018). MRV processes are resource-intensive, requiring quantification of GHG abatement, and verification of the activity and additionality requirements, and this can include methods such as on-the-ground manual data collection and remote sensing (Verra, 2022). It is these MRV processes that are being adapted and strengthened for adoption by the EU under the EU CRC (European Commission, 2022a).

The VCM is used by companies, organisations and regions to buy credits representing an emission reduction or removal in another sector (Allen et al., 2020), to offset their unavoidable emissions[5]. The offsets can contribute to either a climate-neutral product claims, or a contribution to organisation, regional or national reduction targets (Howard & Greiner, 2022). A taxonomy of offsets is provided below in figure 1.4.

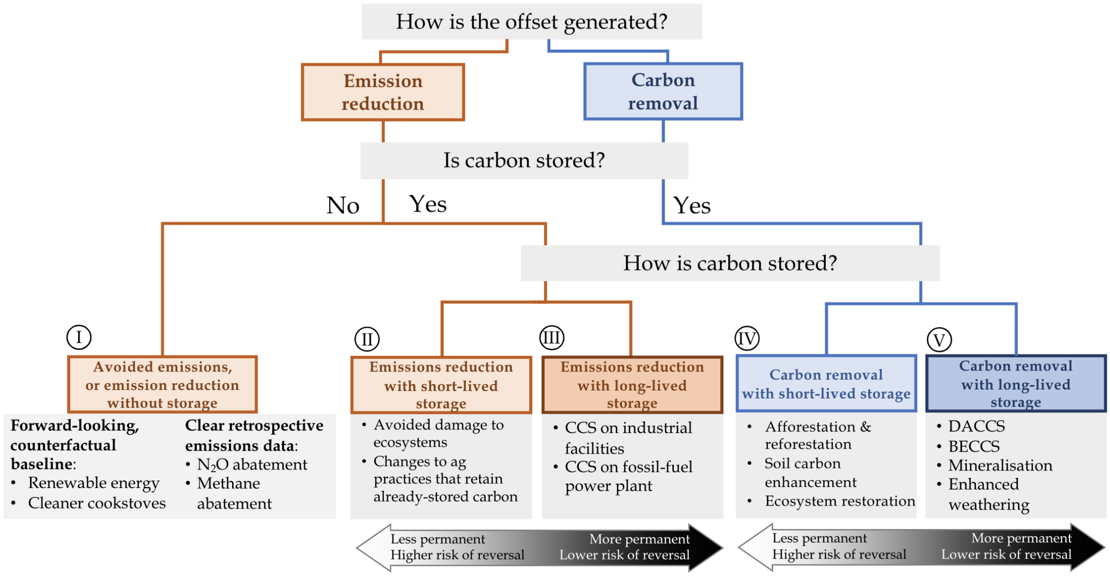

Figure 1.4. A simplified depiction of the classification of the five main types of carbon offset from Allen et al. (2020). The diagram characterises removal credits and reduction credits to point out the distinction between them. The five types constitute the full range of permanence achievable. Avoided emissions (I) involve measures that mean that less GHGs will be emitted, such as replacing fossil fuels with wind energy. These are the least permanent reduction because the fossil fuel can still be used by someone else. Emission reductions involving storage (II & III) include CCS systems on fossil-fuel burning facilities, or projects which protect forests from deforestation. CCS with storage in geological formations is the more permanent than avoided deforestation, as forests always remain at risk of deforestation. Carbon removal (IV & V) includes reforestation (planting trees) which is less permanent due to risks of deforestation, and CCS attached to biomass-burning facilities, which is more permanent due to storage in geological formations. The diagram ultimately shows how emission reduction can only ever contribute to the journey towards net-zero, while carbon removal can eventually result in net-zero and even net-negative emissions (Allen et al., 2020).

Figure 1.4 shows the taxonomy of carbon offsets tradable on the VCM. The diagram distinguishes between reduction and removal credits. Reduction credits can represent avoided emissions, for example where renewable energy replaces fossil fuel energy, or CCS where it has been used to capture CO_2 from industrial flue gas or fossil fuels (as noted in section 1.3.1. Removal credits can be derived from the CDR methods defined in section 1.3.1.

Carbon markets in the Paris Agreement

Article 6 of the Paris Agreement essentially establishes an international carbon market (The World Bank, 2022), allowing parties to the Paris Agreement to voluntarily cooperate

[5]Credits certified for the VCM cannot be traded on a compliance market such as the ETS (Wylie et al., 2016)

to make contributions to their NDCs. Article 6 is interpreted as a framework to establish an international carbon market which ensures continued emission reductions, and ensures that removals are additional and verifiable (Di Leva & Vaughan, 2021). It also establishes an accounting system to prevent double-counting [6] of NDC contributions, termed a *corresponding adjustment (CA)* (Bodansky, 2021; Marcu, 2021).

At the Cop26 negotiations, rules were established that are expected to blur the lines between compliance markets such as the EU ETS and the VCM (Gehrig-Fasel et al., 2021), providing a mechanism by-which credits generated through the VCM as well as compliance markets, could contribute to NDCs (Climate Focus, 2023; Zwick, 2021). For the VCM, internationally traded mitigation outcomes (ITMOs) can only count to the host country's NDC, and the international purchasing organisation can use the ITMO for other purposes such as marketing (Marcu, 2021; Zwick, 2021). For compliance markets such as the ETS, an ITMO's contribution to an NDC is decided in an agreement between the two parties. For both the VCM and the compliance market, wherever an ITMO is transacted, a corresponding adjustment can be made to avoid double-counting.

[6] Double counting is when a single GHG emission reduction or removal credit is registered to national or international carbon registries more than once. In the context of internationally traded mitigation outcomes (ITMOs) (or carbon credits), two parties to the Paris agreement could potentially both record an ITMO to contribute to their targets under the Paris Agreement (COWI et al., 2020)

1.6 Novel CDR for 1.5°C and 2°C pathways

The limited progress in making substantial emissions reductions, and the challenges of permanence and technological readiness that each CDR solution faces, suggests that governments will need to pursue a broad portfolio of CDR options (Minx et al., 2018; National Academies of Sciences & Medicine, 2018; Tamme & Beck, 2021). Novel CDR methods, encompassing new technologies that are relatively un-tested at scale (see figure 1.3), are included in nearly all scenarios to meet the 1.5°C or 2°C targets. However, as shown in figure 1.5, current global carbon removal represents 2 Gt CO_2/yr and is mostly achieved through conventional NBS approaches. Only 0.002 GtCO_2/yr of the 2 GT total comes from novel CDR methods. To put this into perspective, the 1.5°C pathway with limited or no overshoot requires a global reduction of 20 Gt CO_2/yr by 2030 (Smith et al., 2022). Novel CDR therefore makes a very minor contribution to global climate mitigation, and is not currently fulfilling its potential (Smith et al., 2022). These technologies could reduce the reliance on conventional methods such as afforestation/reforestation and carbon farming, that carry a higher risk of reversal, greater limitations due to competition for land, and limited rates of carbon uptake (National Academies of Sciences & Medicine, 2018; P.R. Shukla et al., 2022).

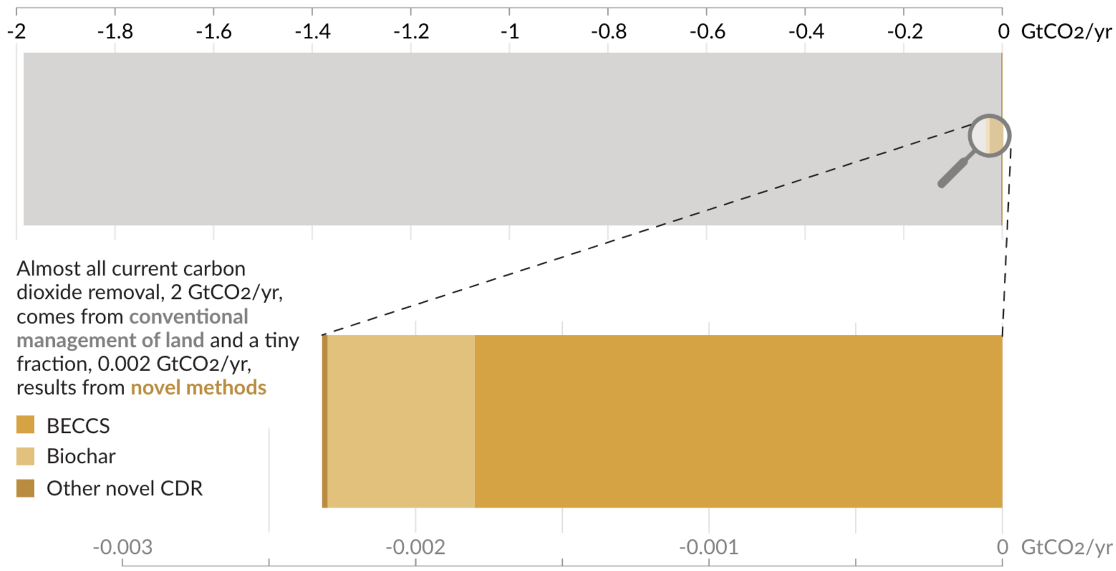

Figure 1.5. "Total current amount of carbon dioxide removal (2 GtCO_2/yr), split into conventional and novel methods"(Smith et al., 2022)

Figure 1.6 shows the role that conventional and novel CDR methods will play in the IPCC's scenarios for both the 1.5°C and 2°C pathways. Conventional CDR on land is responsible for 99% of CDR from now until 2030 and is expected to peak around 2050, while novel CDR methods begin an upward trajectory from 2030 (Smith et al., 2022).

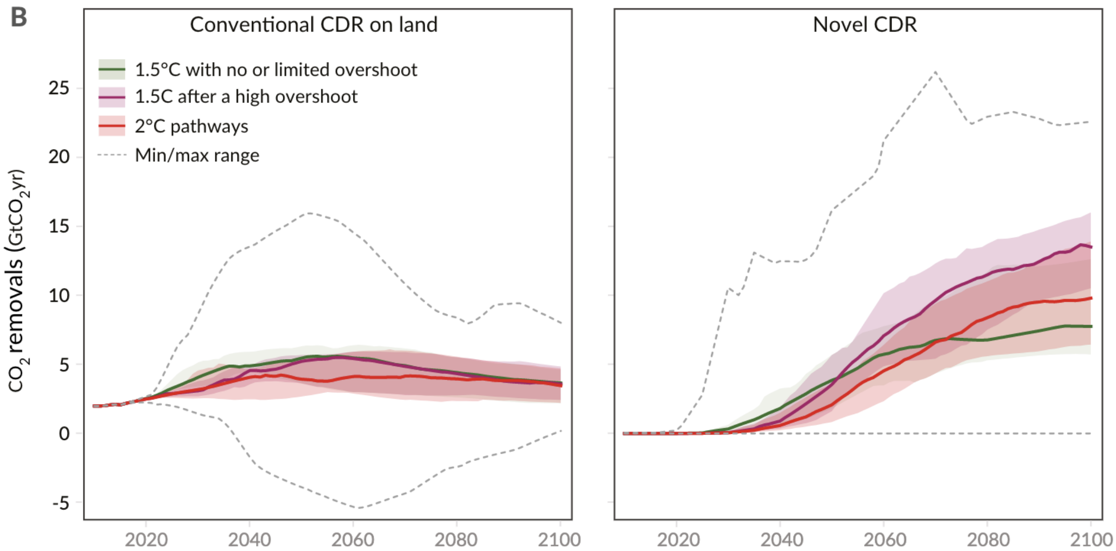

Figure 1.6. Levels of conventional and novel CDR required under the different IPCC Climate Change Sixth Assessment Report 2022 scenarios (Smith et al., 2022)

Governments play an important role in advancing novel technologies in both incentivising the development of new technology on the supply side, and the demand side for technological adoption by 2050. A mix of policies should therefore be used to forward climate change mitigation efforts (Masson-Delmotte et al., 2018). Smith et al. (2022) note however that no NDCs currently detail plans to scale-up novel CDR. Given the time and capital it takes for new technologies to be tested and become widely adopted (Buylova et al., 2021; G. F. Nemet et al., 2018; Tamme & Beck, 2021), governments should not rely upon or prioritise technologically ready methods and wait to deploy more novel technologies (Buylova et al., 2021; Tamme & Beck, 2021). The next ten years are crucial for developing these technologies in-time for at-scale deployment by 2050 (Smith et al., 2022).

1.7 Biochar

Biochar is one such novel CDR method that will require innovation and scale-up in order to fulfil its climate mitigation potential. It has gained attention in recent years as a potentially significant contributor to ambitious climate goals. Due to its numerous co-benefits when applied to soil, it has gained the attention of agriculturally-dependent countries such as Denmark as a way to both sequester carbon and reduce emissions of the agricultural sector (Elsgaard et al., 2022). Furthermore, it is considered one of the more accessible CDR technologies, available at smaller scales as well as larger industrial scales, and at comparatively lower costs (Azzi et al., 2021).

1.7.1 What is biochar?

Biochar is defined as a recalcitrant form of organic carbon[7] (similar to charcoal) produced from the pyrolysis of biomass (P.R. Shukla et al., 2022). The resulting biochar is not intended for burning as an energy source (Thomsen, 2022).

The pyrolysis process involves "the thermal decomposition of organic materials at elevated temperatures in a sufficiently inert atmosphere"(Thomsen, 2022). In industrial settings, *inert atmosphere* means the absence of oxygen. The process produces a volatile (gaseous) fraction and a solid fraction being the char itself. The biochar can retain around half of the carbon that was in the biomass, and rest of the carbon is in the volatile fraction that can be condensed to produce bio-oil. In modern pyrolysis plants, the volatile fraction can also be combusted to produce enough heat for the pyrolysis process to be self-sustaining (Thomsen, 2022).

The CDR potential of biochar relies on the use of waste biomass as feedstock so that it does not compete with food production (Azzi et al., 2021; Weisberg et al., 2010). Many waste biomass feedstocks have been tested including vine prunings, woodchips of various types, straw, cow manure, sewage sludge and various food processing residues (Thomsen, 2022).

1.7.2 The climate mitigation potential of biochar

The application of biochar to agricultural soil is the most frequently discussed use-case as having the greatest climate mitigation potential at scale (Azzi et al., 2021). Due to its resistance to biological degradation compared to untreated biomass such as manure or compost, its contained CO_2 is prevented from being re-emitted to the atmosphere (Elsgaard et al., 2022). The permanence of biochar depends on soil type and temperature, environmental conditions, and biochar production temperatures, and can vary between a few decades and several centuries (Elsgaard et al., 2022; Minx et al., 2018; P.R. Shukla et al., 2022).

Estimates of the global CO_2 sequestration potential of biochar vary widely (Minx et al., 2018). Lower estimates result from the limitations of availability of biomass feedstock, or where waste biomass is not necessarily used as a feedstock for pyrolysis. In this case, biomass is grown specifically for pyrolysis, which then competes with food production and has a larger carbon footprint due to land-use change implications[8] (P.R. Shukla et al., 2022). The higher estimates of sequestration potential carry a high level of uncertainty relating to economic and political feasibility (Roe et al., 2019). Recent estimates resulting from literature reviews include between 0.3 – 4.9 Gt CO_2 (Roe et al., 2019), and between 1 and 35 Gt CO_2 /yr in the year 2050 (P.R. Shukla et al., 2022). Biochar also has secondary climate mitigation benefits where it has been shown to reduce N_2O and CH_4 soil emissions (Azzi et al., 2021; Hu et al., 2023; P.R. Shukla et al., 2022). Moreover, its application in

[7] Recalcitrant organic carbon is organic material largely unavailable to microorganisms and is therefore resistant to decomposition (Queensland Government, 2023)

[8] Humanity's increasing resource consumption for land use, biodiversity conservation, and carbon sequestration limits available arable land and forests. Any land-based activity can cause land-use shifts, such as converting grazing land to cropland leading to deforestation elsewhere to meet livestock production demand (Food and Agriculture Organisation of the United Nations, 2017)

agricultural soils could allow for partial substitution of conventional fertiliser (Hu et al., 2023), and the European Union has updated its rules on fertiliser products to allow for biochar to be sold as a soil amendment (Elsgaard et al., 2022).

Co-Benefits of biochar

Depending on the feedstock used, biochar can retain high concentrations of bio-available nutrients including phosphorus, potassium and magnesium, while the nitrogen is destroyed during pyrolysis (Chandran & Thomas, 2019; Thomsen, 2022). Furthermore, it is effective in improving soil water holding capacity, and retaining and keeping nutrients available for plants (Azzi et al., 2021). When added to agricultural soil, biochar has therefore been shown to increase crop yields (Fuss et al., 2018; Thomsen, 2022; Verde & Chiaramonte, 2021). It therefore also has climate change adaptation benefits, contributing to drought resilience (Azzi et al., 2021). Due to its porous structure, biochar can also improve microbial abundance in soil, thereby increasing levels of soil organic carbon (Fuss et al., 2018; Scheid et al., 2023; Singh et al., 2022). However, some negative effects have been recorded including a decrease in crop yields in certain environmental conditions, decrease in surface albedo effect and release of dust leading to reduced air quality (Fuss et al., 2018).

1.7.3 Barriers to deployment of biochar at scale

As mentioned in section 1.3.1, the categorisation of biochar is contested (Bellamy & Geden, 2019; Smith et al., 2022). Some authors including Smith et al. (2022) and Buylova et al. (2021) classify biochar in the 'novel' and 'technological' camp with the carbon sink being a product. Others, such as Minx et al. (2018), Verde & Chiaramonte (2021) and Wiese et al. (2021) put it in the category of a nature-based solution (NBS) for its agricultural co-benefits, with the carbon sink being soil. Mcdonald et al. (2023) argue, however, that biochar cannot be categorised as an NBS due to the risk of the addition of biochar to soil negatively impacting soil health. Depending on the classification as either 'natural' or 'technological' (engineered), it can have an affect on its social and political acceptance, with implications carrying through to policy design (Bellamy & Geden, 2019). For example, Geden & Schenuit (2020) note that NBS is likely to have a higher level of public acceptance than technological solutions. The European Parliament places biochar in the category of an NBS, and intends to focus on NBS when developing policy for developing a portfolio of CDR options (Erbach & Victoria, 2021). Achieving biochar's full climate mitigation potential relies upon its amendment into agricultural soils, and therefore public acceptance from a farming community perspective will have a significant influence on its deployment at scale (G. F. Nemet et al., 2018).

Lastly, pyrolysis can be framed as a waste management and circular economy tool. This way of conceptualising biochar comes from the premise that infrastructure to remove CO_2 is a public good [9] and is therefore society's responsibility to take care of (Geden & Schenuit, 2020). Municipalities and private organisations can use pyrolysis to manage organic waste or residues, such as from industry or households, while capturing CO_2 from the atmosphere (S. Jeffery et al., 2015; Pourhashem et al., 2019). This conceptualisation carries positive

[9] a commodity or service that is made available to all members of a society for-which national governments and the tax payer, and polluting industries are responsible, much like for sewage treatment (Fernando, 2022)

implications for the public acceptance of biochar and therefore its deployment at scale, because it fulfils a societal need of managing waste (Lackner & Jospe, 2017). However, using waste as feedstocks can have negative implications where legislation limits biochar's application to soil depending on the origin of the waste feedstock (S. Jeffery et al., 2015).

The deployment of biochar at scale as an NBS in the agricultural sector could also be hindered on the demand-side, due to regulatory issues (Gehrig-Fasel et al., 2021; G. F. Nemet et al., 2018). Other studies point to limitations in the maximum safe holding capacity of soils (Minx et al., 2018; P.R. Shukla et al., 2022). On the supply-side, barriers include access to up front capital and cost of pyrolysis (Gehrig-Fasel et al., 2021; Minx et al., 2018), limitations related to pyrolysis capacity (Elsgaard et al., 2022), and limited availability of biomass feedstock (Minx et al., 2018; P.R. Shukla et al., 2022). New policy instruments are required for overcoming these barriers to incentivise adoption by farmers and reduce the cost of pyrolysis (G. F. Nemet et al., 2018; Verde & Chiaramonte, 2021). Carbon offsetting is another suggested method for incentivising biochar production and adoption, however difficulties in measuring soil carbon could be a barrier (Fuss et al., 2018).

Biochar is regarded as a technology with high climate mitigation potential, especially in rural areas with a large supply of carbon and agricultural land to both provide feedstock and apply the biochar product. However, biochar as a technology requires further research and development to be deployed at scale (McLaughlin et al., 2023). The European Commission assesses the scalability of biochar to be uncertain, and large-scale field testing is required to increased certainty around carbon storage permanence and environmental impacts before it can be legislated within any of the three policy pillars of the Green Deal (European Commission, 2018; Rickels et al., 2021).

1.8 Biochar in Danish legislation

Biochar is considered by the Danish government to be in the demonstration phase of technological development, and they consider biochar's potential for scale-up as uncertain (Danish Ministry of Climate Energy and Utilities, 2020) due to technological challenges to scaling, environmental challenges such as how it will affect agricultural soils, and policy challenges relating to how to incentivise production and demand (Danish Ministry of Climate Energy and Utilities, 2020). A pyrolysis strategy as part of the *roadmap for brown biorefining* has been developed to mature the technology, focusing on resolving the uncertainties, including confirming the CDR potential of biochar, documenting the environmental and agronomic effects of biochar, and developing policy to incentivise farmers to use biochar in their soils for CDR purposes (Danish Ministry for Climate Energy and Utilities, 2022).

The government estimates that biochar has a potential to contribute 6 million tonnes (MT) CO_2 eq to emission reduction targets from the pyrolysis of straw and secondary feedstocks such as organic household waste and manure. Of the 6MT, it has been determined that 2MT can be achieved by 2030, if the technology can be scaled up. This has led the government to allocate approximately 2,000,000t (2MT) CO_2 eq reduction in agriculture to biochar. (Danish Ministry for Climate Energy and Utilities, 2022).

1.8.1 Danish climate policy

The government's sequestration targets using biochar form part of the national climate policy. The Climate Act was passed on June 26, 2020, setting one of the most ambitious climate targets in the world. The Act calls for a reduction in greenhouse gas emissions of 70% by 2030, compared to the baseline year of 1990, and achieving climate neutrality no later than 2050 (Danish Ministry for Climate Energy and Utilities, 2022). The targets are aligned with the Green Deal by following the regulatory framework on the EU Climate Law and Fit 55 package (Danish Ministry for Climate Energy and Utilities, 2022). The Danish Government's strategy follows two tracks; the implementation track and the development track. The development track is allocating funding and developing legislation to aid in the innovation and advancement of green technologies by reducing costs and enabling scale-up (Danish Ministry for Climate Energy and Utilities, 2022). These are depicted in figure 1.7, which was developed by the Danish Council on Climate Change. Denmark has acknowledged the importance of CDR in their Climate Act and in their LT-LEDs to meet its long-term climate targets for 2050 (Danish Ministry of Climate Energy and Utilities, 2020), and one of the key components of the innovation agenda is the creation of affordable carbon capture and storage (CCS) solutions.

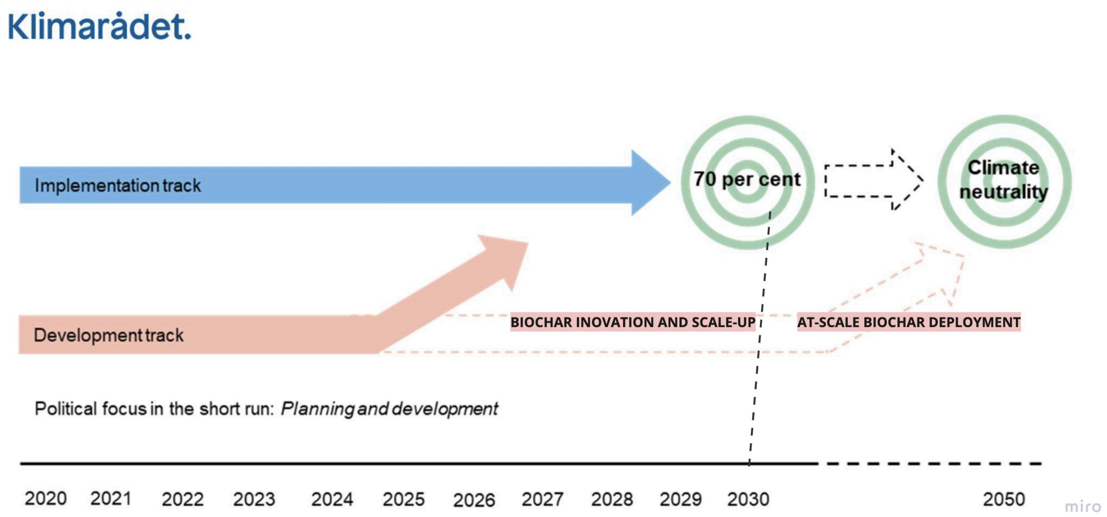

Figure 1.7. Diagram adapted from Danish Council on Climate Change placing both the implementation track and development track on a timeline to achieve the Danish government's target of becoming climate neutral by 2050. The dashed red arrow illustrates that the development track will contribute to both 2030 and 2050 targets. Biochar is part of the development track, and achieving Denmark's targets will require full-scale deployment of biochar by 2030. The diagram describes, with the red dotted arrows, that there is doubt as-to the potential for scale-up of certain technologies, including biochar, by 2030. Although potential for these technologies may increase in the future (Danish Council on Climate Change, 2020; Danish Ministry for Climate Energy and Utilities, 2022)

Another component of the development track is to reduce the climate and environmental impact of conventional food production and farming, including emissions from livestock, fertiliser application, land use change, and negative impacts on biodiversity (Danish Ministry for Climate Energy and Utilities, 2022). The Danish agricultural sector accounts for the 23% of the total Danish emissions due to Denmark being a largely agricultural country (Batini et al., 2020), placing it high of the government's climate agenda. The government is therefore promoting biochar as a potential emission reduction tool for agriculture.

1.9 Problem summary

CDR is increasingly being accepted as a necessary pathway to achieving net-zero and net-negative pledges within Paris Agreement and EU climate targets. In acknowledgement of this, CDR is gradually being incorporated into the EU policy framework. Biochar is one such CDR method that requires technological innovation and scale-up. Biochar is identified as having competitive climate mitigation potential compared to other methods, due to being relatively cheap compared to CCS, offering relatively high permanence compared to conventional NBS, and also bringing co-benefits to agriculture such as providing essential plant nutrients.

Biochar brings numerous opportunities for climate mitigation, and this is recognised by the Danish government, as evidenced by the political support biochar is receiving in Denmark, owing to Denmark's context-specific challenges of needing to reduce agricultural emissions. However, there are many uncertainties pertaining to both the supply and demand-side of biochar, while there is a sense of urgency in reaching at-scale deployment in time to contribute to Denmark's ambitious 2030 targets. This is happening against the backdrop of a rapidly evolving EU policy environment, adding to the uncertainties. The early stages of adoption of biochar as a CDR in Denmark and indeed globally, mean that the potential for scaling of biochar will be highly dependent upon the public policies and VCM affecting biochar deployment, the needs of the biochar technical innovators and producers, and the needs of biochar's primary users - the agricultural industry.

1.10 Research Question and Delimitation

Authors have noted a lack of context-specific literature pertaining to the social-science analysis of CDR (Smith et al., 2022), and specifically the socio-political aspects (Sovacool et al., 2023). The literature focuses more on the technological aspects of CDR, while assuming that the at-scale deployment of CDR is socio-technically viable. This has led to the criticism that CDR's role in global climate policy has been cemented, without a full understanding of its implications when compared to alternative mitigation options (Sovacool et al., 2023). The goal for the project is therefore to conduct an analysis of the interrelation of policy, supply of biochar technology, and demand of biochar technology, to determine it's potential to be used to contribute to reduction targets in agriculture. By analysing the socio-technical aspects of biochar in the specific context of Denmark, certain aspects of biochar's role as a CDR technology in society can be more closely analysed, and therefore its potential for climate mitigation can be discussed, beyond its technical limitations. Furthermore, a more critical view of the Danish government's strategy to employ biochar as a CDR to meet emission reduction targets can be achieved.

Danish biochar stakeholders Lindholst and Thomsen were interviewed as part of the problem definition stage of the project. It is their opinion that the Danish government has not demonstrated how the removal of 2MT of CO_2 eq for the agricultural industry using

biochar can be achieved. The lack of government strategy has led to this project's original problem statement (or question), as articulated by Lindholst and Thomsen:
"How do you produce and 700,000 t biochar in 7 years?" [10].

The following research question (RQ) has therefore been formulated to meet the goals of the project:

> *How can the diffusion and scaling of biochar technology in Denmark be incentivised to fulfil the Danish government's 2030 emission reduction target?*

In order to fully answer the research question, the following sub-research questions (sub-RQ) have been formulated:

1. *What is the current understanding in the literature of how EU and Danish policies can incentivise biochar's scaling as a CDR?*
2. *What are the enabling and constraining conditions for Denmark in meeting its emissions targets using biochar?*

1.10.1 Delimitations

The following delimitations of the scope of the project are detailed below.

Definitions of diffusion and scaling

Diffusion is understood and used in this project to describe the process by which innovations, such as new technologies or practices proliferate and become incorporated into existing socio-technical systems (Geels, 2004). Scaling is defined as the process of increasing the deployment, capacity, and efficiency of CDR technologies, providing the necessary climate change mitigation outcome (Sovacool et al., 2023). The use of these terms in this project is further elaborated upon in chapter 4.

Definitions of incentives, and enabling and constraining conditions for this project

Incentives are rewards or motivations designed to encourage or persuade stakeholders of the biochar system to take a specific action or behave in a certain way. They can be financial or non-financial and are used by organisations, governments, or individuals to achieve the desired outcome of climate mitigation using biochar.

Enabling and constraining conditions are factors or circumstances specific to the Danish context, that either facilitate or limit the scaling or diffusion of biochar technology.

[10] In Skyclean's pyrolysis process, 2MT CO_2 eq is represented by 700,000t of biochar through the following calculations;
1kg pure carbon = 3.67 kilos of CO_2 eq
2MT CO_2 eq / 3.67 = amount of pure carbon you need to store
Biochar is not pure carbon so 2MT is divided by 3, not 3.67
So 700,000 X 3 = approximately 2MT CO_2eq
(Interview, Lindholst)

Conditions including environmental, societal, financial, or legal, can significantly shape the possibilities and limitations of the biochar system. Enabling conditions remove barriers or provide resources that support the development of the system, while constraining conditions impose barriers or restrictions on the development of the system. Certain conditions can be either enabling or constraining depending on the perspective, and so it is necessary to always approach the analysis from both directions.

Delimitation of the Danish biochar system

Otte & Vik (2017), Azzi et al. (2021), Verde & Chiaramonte (2021) all refer to the *'biochar system'* which describes the whole value chain of biochar from feedstock, production methods and supply, to biochar use cases. We, therefore, refer to the *biochar system* within this project to define the system boundary of the dominant biochar technology value chain in Denmark. In this project, we focus on biochar as a CDR method, while a biochar system could also include other mitigation outcomes, such as the substitution of fossil fuels within Denmark's energy systems, by the energy produced during pyrolysis. Therefore, to answer the research question, we analyse biochar's potential as a CDR, and do not analyse in detail, the climate mitigation potential of the resulting substitution mechanisms.

Information on the various technical conditions affecting biochar production and application in Denmark can be obtained from Thomsen (2022) and Elsgaard et al. (2022).

Different ways of assessing the emission gap

The emission gap is assessed through analysing carbon accounting (mechanisms incentivising the development of biochar technology), and commercialisation problems (the methods of carbon accounting and the determination of baselines and additionality). This study analyses the commercialisation problems rather than accounting problems. We therefore do not analyse the impact of MRV methodologies on the biochar system. Furthermore, in-line with the project's purpose of analysing the socio-technical context of biochar in Denmark, we do not analyse the quantifiable nature of biochar as a CDR such as how its CDR performance can be measured in the soil.

The state of the art of policy

Sub-research question 1 will be answered via a state of the art analysis. It should be noted that conducting a state of the art analysis on how the *technical* aspects of biochar defines its climate mitigation potential would have been equally relevant to answer the research question. However, this has already been done in numerous articles including (Azzi et al., 2021; Chandran & Thomas, 2019; Fuss et al., 2018; S. Jeffery et al., 2015; Kamali et al., 2022).

Research Design, Epistemology & Methodology 2

The following chapter first gives an outline of the research design, followed by a description of the project's ontological and epistemological foundation, and how these informed the overall methodology for scientific reasoning used in the project.

2.1 Research Design

This project's research design is presented in figure 2.1.

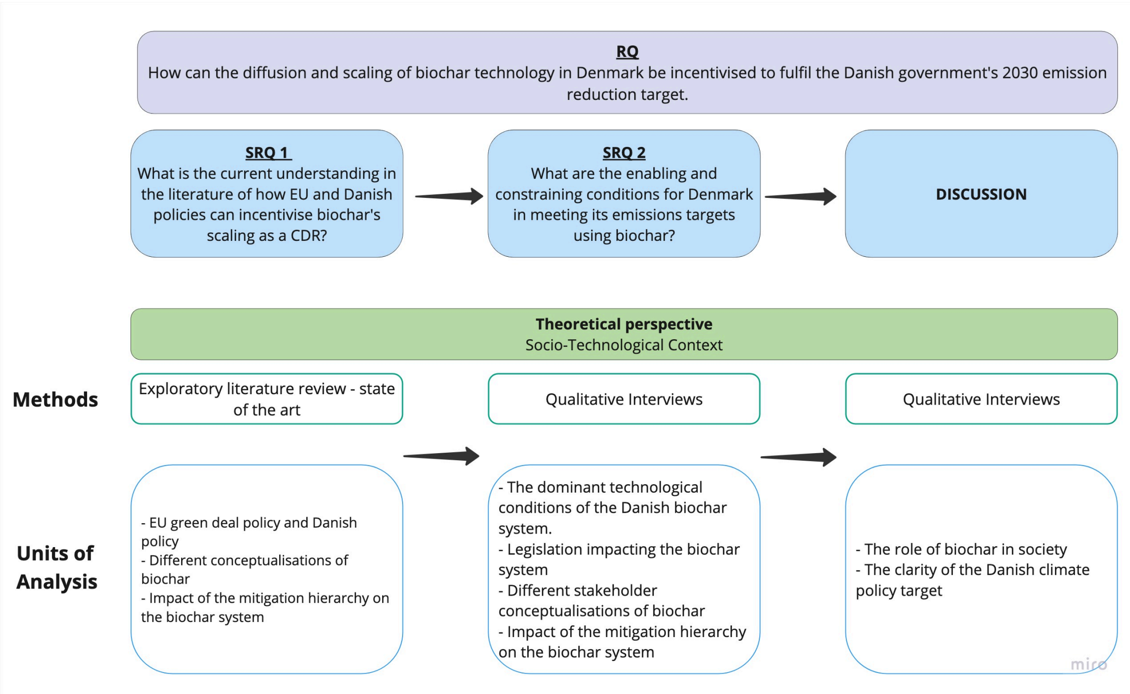

Figure 2.1. The project's research design, describing how the project's research methods and conceptual framework contribute to answering the main research question

The conceptual framework was designed based-on the original Socio-technical theory from Geels (2004). It provides the analytical perspective from which to answer the RQ and Sub-RQs.

The policy constitutes an essential component of the conceptual framework, and so a state of the art (SOTA) of policy analyses is completed using the method of exploratory literature review to answer sub-RQ1. The SOTA will analyse how the different conceptualisations of biochar affect how EU policy can impact the Danish biochar system. The SOTA analysis serves to support and strengthen the subsequent analysis for sub-RQ2. Sub-RQ2 is answered primarily using data from qualitative interviews with key informants and subject matter experts of the Danish biochar system. This will allow for an in-depth context-specific analysis of the potential for biochar to contribute to Danish climate targets.

The purpose of the discussion is to analyse how biochar's role in society will impact how the Danish government uses biochar to contribute to achieving climate targets. It is completed with interview data and knowledge gained from the previous two analyses.

2.2 Epistemology and Ontology

We, as researchers, are working within the pragmatism paradigm for this research project. Our research is rooted in the view that truth and knowledge are represented by empirical evidence for the environment and its condition, combined with an individual's worldview and interactions with the environment, as defined by their cultural and historical background. As such, we study the adaptive behaviours of individuals and the groups and networks that they form, caused by an environment in constant flux (Hall, 2013).

Knowledge is therefore derived through this research project, through the practical application of concepts and ideas from a subjectivist perspective (Lincoln & Guba, 2005) with a goal of problem-solving (Hall, 2013). We take point of departure from our problem analysis and research question, and employ a pluralism of methods necessary to explore the technocal, social and political contexts embodied in the research question (Creswell, 2009; Hall, 2013). While pragmatism is frequently associated with mixed methods research representing a mix of qualitative and quantitative methods (Creswell, 2009; Hall, 2013), we employ mixed qualitative methods, integrating the different approaches at different stages of the inquiry (Creswell, 2009). At each stage, we consider the interview data as being representative of, at times, an objective "truth", i.e. the information can be analysed on a factual or counter-factual basis, and at times, a subjective "truth"i.e. an expression of the interviewee's own experience. We understand both as being a valid contribution to the analysis, as our ontological perspective is that understanding the stakeholder's interaction with their environment cannot be separated from understanding the environment itself.

2.3 Methodology

We adopted an abductive methodological approach to this research project as described by Kennedy & Thornberg (2018) and Conaty (2021). Whereas deduction follows a logic of reasoning that seeks to analyse data according to a rule, and induction seeks to define a rule based on observations, abduction employs a circular method of reasoning. With adbuction, a hypothesis can be formed and adapted with successive rounds of enquiry, and is therefore a process of discovery (Kennedy & Thornberg, 2018). This methodology was deemed appropriate due to the currency and uncertainty of the debate around the implementation of CDR and its governing policy, and that biochar technology is at the early stages of adoption in Denmark, and therefore an exploratory style of research was required.

The abductive approach and our adoption of sociotechnical theory, both reflect our pragmatic ontological perspective. As (Hall, 2013) state, *"The task of identifying the components of a problem, like truth, is never completely settled and continues throughout the evaluation process as new understandings come into focus."* The abductive approach acknowledges the researcher's prior knowledge and cultural background as having a relevant impact on the research (Conaty, 2021), and also provides the opportunity for reflexivity on our potential bias throughout the developmental stages of the project as described in figure 2.2. As international students in Denmark, we consider ourselves "outsiders"to Danish culture. We have no prior knowledge of CDR in the Danish context, or of the Danish agricultural industry. Our prior knowledge is defined by our education in environmental sciences and adherence to the conventional understanding of anthropogenic climate change. While we acknowledge the debate within climate research, that the solution to anthropogenic climate change is either technological or behaviour-based (Dubner, 2018; Nelson & Allwood, 2021; Ribeiro & Soromenho-Marques, 2022), we adopt a balanced view and are not proponents of either argument. Socio-technical theory analyses the relationship of a technology to its social, political and environmental context (Geels, 2004). It, therefore, reflects our perspective that the use of CDR and biochar as a new technology, and the policy governing it, is heavily dependent upon how it is perceived within society, and the social and cultural norms of stakeholders in Denmark.

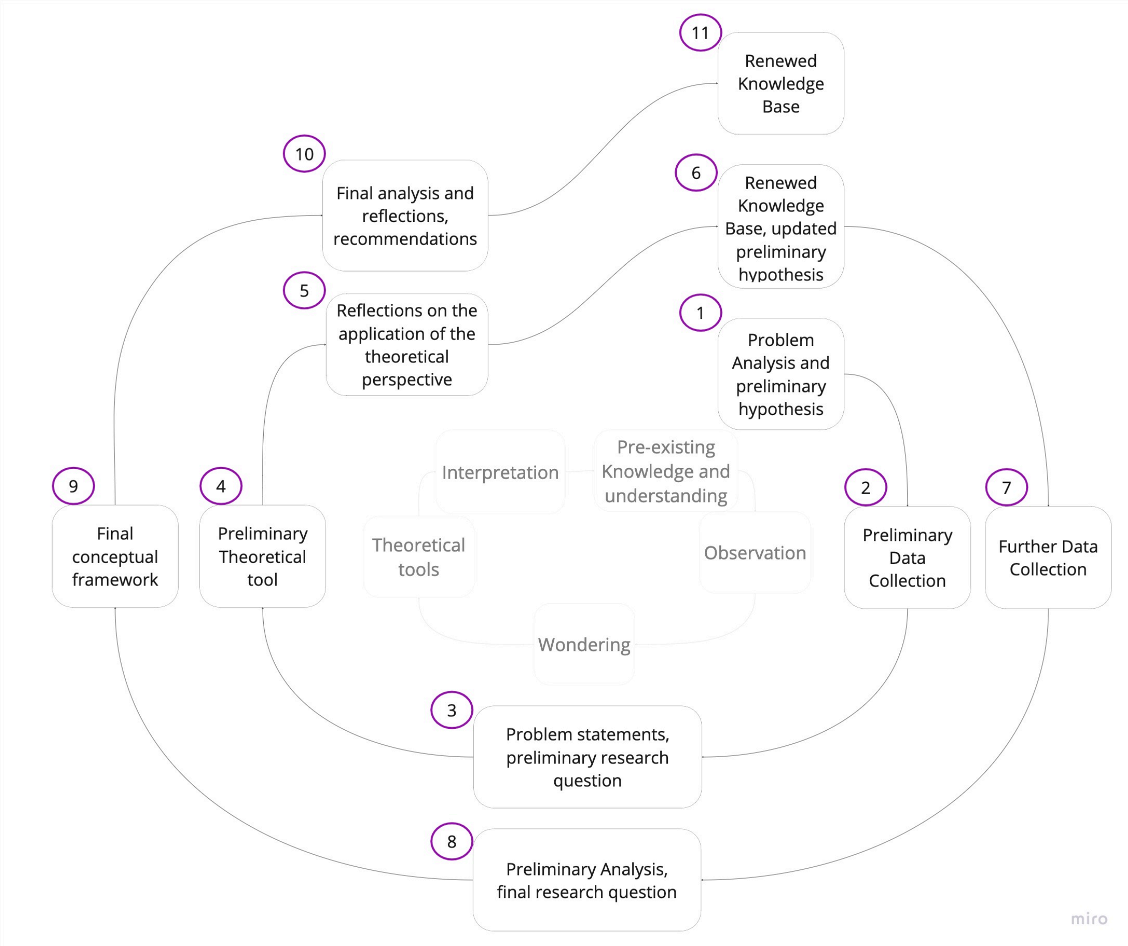

Figure 2.2. The abductive research methodology, adapted from Schwartz-Shea et.al. 2013 and Nielsen et al. (2023). The original Schwartz-Shea et.al. 2013 terminology is incorporated in grey in the centre of the diagram

The abductive approach to this project is shown in figure 2.2. It is purely indicative of our research process, and in reality, there were more than two cycles of data gathering, reflection, refinement and so on. The process is briefly described below, with the numbers aligning with the numbers in the figure:

- The starting point for the research consisted of our prior knowledge and values, in combination with some preliminary research to gain a better understanding of the key problem areas. This contributed to the problem analysis **(1)**.

- Following a preliminary review of the literature, documents from the Danish government and the EU commission, and interviews with a subject-matter experts in Denmark, the following problem statement was developed:
- *"How can Denmark produce 700,000t of biochar in 7 years"*
- This problem statement served as a starting point for further research, and a rough conceptual framework based on sociotechnical theory was identified as the best fit for the problem area **(4)**.
- Reflections on how to apply the theoretical perspective **(5)** and the renewed knowledge base **(6)** allowed for more targeted interviews and literature review **(7)**. In subsequent iterations of the abductive process, completion of the state of the art informed the data collection and content of the second half of the analysis.
- The research question was then finalised **(8)**, the conceptual framework refined **(9)**, and the analysis of the data from a specific theoretical perspective was then possible **(10)**.
- The unique contribution of this analysis to the literature provides a renewed knowledge base on-which to recommend further research **(11)**.

Through the abductive process, literature, documents and interviews were used to collect data. The data was analysed to identify themes and patterns in order to define the problem represented by the research question, and explore the present conditions of the socio-technical system of study, and stakeholders and change agents of that system. These methods will be presented in the following chapter.

Methods 3

The following chapter describes the primary methods of exploratory literature review and qualitative semi-structured interview, as well as the limitations of those methods, and any potential limitations for the projects results related to how the methods were used.

3.1 Exploratory Literature Review

An exploratory literature review was used to establish the state of the art (SOTA) with regards to the current policy landscape incentivising the adoption of biochar as a climate mitigation method in Denmark, thereby answering sub-RQ1; *What is the current understanding in the literature of how EU and Danish policies can incentivise biochar's scaling as a CDR?* The SOTA provides an analysis that directly answers the sub-RQ1, and also identifies knowledge gaps in the literature for-which qualitative interviews and document review in subsequent sections of the analysis can provide an answer.

The literature review is *exploratory* in that it intends to "explore the research questions and does not intend to offer final and conclusive solutions to existing problems"(Dash, 2019). This is considered an appropriate methodology as the problem cannot be clearly defined (Dash, 2019), being a problem area with much uncertainty, unknowns, and room for interpretation. The exploratory literature review allows for changes in analytical direction based on new learnings, and therefore aligns with the abductive approach to this research project. A non-systematic approach was taken, as opposed to a more traditional systematic review (Wohlin et al., 2022). This is because a systematic review, confined to a handful of journal databases, would not have yielded sufficient literature, due to the currency of the policy debate and the need for the inclusion of both policy briefs, reports and journal literature. Furthermore, a systematic review would not have provided the flexibility necessary to adjust the focus of the analysis as the review progressed.

Selection Criteria

EU policy concerning CDR has evolved in recent years, especially since 2020, and so literature was selected for it's currency to ensure relevance. Articles discussing policy from 2019 and earlier were considered out-of-date. Articles were also chosen based on their geographical relevance. For example, articles relating to policy in the USA or China were omitted as their policy is deemed to have little or no influence on the biochar system of Denmark.

Peer-reviewed journal articles were prioritised for their high-scientific integrity whereby the risk of bias affecting the analysis is considered lower than other research outputs (Rienecker et al., 2013). Where the journal literature was insufficient, grey literature was used to either provide alternative or more up-to-date analyses of the policy or support the journal literature. Grey literature represents diverse and heterogeneous research contributions that that are publicly available but fall outside of the traditional peer-review process (Adams et al., 2017). Technical reports and policy briefs from think tanks or research institutes, and conference proceedings were all used, and are identified in Appendix A.1. Grey literature excluded were websites, newspaper articles, and policy analyses published by governmental organisations as they were not considered relevant for answering the sub-RQ.

Search Method

The literature review combined the *'random search'* method with the *'chain searching'* method (Rienecker et al., 2013). The random search was conducted during March and early April 2023 using multiple databases and evolving key words to find important and current reports on CDR, and other related literature. Google search was used, as well as the journal databases Aalborg University Library (AUB), ScienceDirect, Google Scholar, frontiersin.org. For the grey literature, databases including policycommons.net, and the Danish-specific online literature database bibliotek.dk were used. This initial search stage served to identify broad themes within the literature on-which to base the structure of the SOTA. Search strings used were "carbon AND removal", "net zero OR net-zero", "climate", plus variations of these to include "AND policy", "EU OR European"or "Denmark OR Danish"and "AND waste"or "AND waste AND management". Searching was conducted in both English and Danish using google translate. Searches in Danish were considered necessary due to the lack of context-specific literature for Denmark, however no relevant danish language literature was found. All literature analysed was therefore in the English language.

The chain searching method was used concurrently, to find literature to support the random search. The chain search also allowed us to identify when articles or reports were being cited by numerous authors, thereby allowing us to identify the subject matter's core texts (Rienecker et al., 2013), and also showing that a representative sample of the literature was being reviewed. For example, an initial google search identified the Smith et al. (2022) report "The State of Carbon Dioxide Removal", and multiple relevant grey literature and journal articles were found through a chain search based on that report. The chain search also allowed us to identify key authors of the subject matter, and authors and co-authors of core texts were also searched-for to expand the review.

Limitations of the data

The limitations of the non-systematic methods used are that the search is less easy to replicate, and therefore the reliability of the SOTA is less easily confirmed. Furthermore, it increases the chance of our own biases influencing the line argument of the SOTA, whereas a systematic search would have provided a more objective selection of the literature. Furthermore, chain searching has limitations in that it can lead to a lack of identification of diverging opinions (Rienecker et al., 2013). The combination of random search and chain search reduced this problem, and care was taken to review enough literature, to observe the repetition of arguments, indicating that most view-points were represented in the analysis. It should be noted that Smith et al. (2022) identify a lack of context-specific literature in the social sciences concerning CDR, and this is reflected in the SOTA for the Danish context.

Limitations of use grey literature

Grey literature was extensively used in the SOTA, which carries inherent limitations. The lack of peer-review process can lead to inaccuracies, and author or publisher's biases may influence the content. Furthermore, grey literature can lack transparency of methodology or data sources, making judgements on validity of the literature more difficult. For these reasons, quality may be highly variable (Adams et al., 2017), and care was taken to only select grey literature from reputable authors or organisations. Some reports were commissioned by state governments, and care was taken to only select those with quality statements confirming independence of the authors. Furthermore, heterogeneity of grey literature limits it's availability, and this can have a negative impact on the reliability of the resulting analysis (Adams et al., 2017).

3.2 Qualitative Research Interviews

Semi-structured qualitative interviews as defined by Roulston & Choi (2018) were conducted between February and May 2023. The interviews provided insights from subject-matter experts on the biochar system in Denmark and the Nordic region, and on sustainability in the Danish agricultural sector. All interviews were conducted online using Microsoft Teams, with the exception of the interview with Mott, which was conducted in person. All interviewees were previously unknown to us except for Mott, who was an acquaintance. A list of all interviews is provided in figures 3.1 and 3.2.

Name	Occupation	Date, Length	Sub-system	Purpose
Tobias Pape Thomsen	Associate Professor, Roskilde University, Denmark	#1 - 08.02.23, 1hr #2 - 03.04.23, 1hr 23m	Technology, Policy and VCM	Thomsen is a researcher primarily working on LCAs of the biochar value chain, and a board member of the Nordic Biochar Network. He contributed to the project as technical pyrolysis specialist whilst also providing an overview of the socio-technical system. The first interview was part of the preliminary stage of interviews, and served as an introduction to the biochar problem area in the Danish context. Thomsen helped us identify key stakeholders, and where current understanding of the biochar system in Denmark was lacking, in order to help us develop a research question. Thomsen provided the contact details of Lindholst and Esko. The interview was not recorded or transcribed. The second interview was more targeted towards specific problem areas which needed elaboration regarding policy implications, pyrolysis technology and political support for biochar.
Peter Lindholst	Strategic Business Developer, Stiesdal, Aarhus	#1 - 20.02.23, 25m #2 - 14.04.23, 53m #3 - 17.04.23, 1hr 08m	Technology, Policy and VCM, Public acceptance	Lindholst is an engineer, working as a business developer on the Skyclean project. Skyclean is a subsidiary of Steisdal, a Danish engineering company. Peter contributed to our project with insights into the whole socio-technical system from the perspective of a biochar producer and an environmentalist. The first interview was part of the preliminary stage of interviews, and helped us to analyse the problem area and develop the research question. The second two interviews were targeted specifically towards understanding Skyclean's role in the Danish biochar system, and the main enabling and constraining conditions for their business from a technical and policy perspective, together with some insights into the demand side of biochar.
Salo Esko	Research Scientist at VTT, Doctoral Student at JSBE, VP at Nordic Biochar Network, Helsinki	01.03.23, 1hr 14m	Technology	Salo Esko is on the board of the Nordic Biochar Network, and a researcher currently focusing on the drivers for the development of the biochar market. The interview was part of the preliminary stage of interviews. Esko provided insights into the implications of the EU policy reforms as well as technical aspects of the Nordic biochar system. Giving us the Finish perspective on Biochar helped contextualise the Danish biochar problem.
Thorkild Qvist Frandsen	Senior Consultant, Agriculture Sustainability Arla Foods amba Denmark	18.04.23, 1hr 10m	Policy and VCM, Public Acceptance	Arla is a Danish farming cooperative owned by members of the farming community. Frandsen has only worked with Arla for 1 month, however he has had a long career in sustainability in the agricultural sector in Denmark, including in research and development of technologies for reducing agricultural emissions. Frandsen was recommended for the interview by an existing contact within Arla. The interview was part of the second round of interviews and served to provide insights into the demand-side of the Danish biochar system. Arla are one of the largest food production companies in Denmark and could therefore have a significant impact on the demand and potentially the supply of biochar. Thorkild provided insights into how biochar could fit into the incentive system at Arla, and the potential impact of the green tax on agriculture.
Christian Ege Jørgensen	Senior Consultant, Rådet for Grøn Omstilling (RGO)	25.04.23, 1hr	Technology	With RGO, Jørgensen has developed policy recommendations relating to many aspects of the green transition including circular economy and energy. His current focus is in agriculture and bioresources. Interviews with RGO were originally sought for insights into the political perspective. However, Jørgensen instead provided insights into the technical aspects of the biogas/pyrolysis symbiosis and the green tax on agriculture.

Figure 3.1. Table identifying four out of the ten interviewees, and purpose of interviews

Name	Occupation	Date, Length	Sub-system	Purpose
Trevor Mott	De Glade Gartner - Grower, farm owner, Northern Jutland	26.04.23, 1hr 15m	Public accpetance	Mott owns an 18 hectar farm which includes christmas trees, forest, meadow and 9 hectars of crop fields. The interview was not recorded and transcribed as the interview occurred in person and outside, with background noise. Mott provided insights into the potential impacts of the green tax on agriculture, and awareness of biochar and carbon farming in his farming community, and farming practices that could affect the adoption of biochar.
Expert1	Policy expert within a voluntary carbon market certification organisation	28.04.23, 1hr	Policy and VCM	Expert1 has extensive experience in the development of the EU emission trading system. They currently work to raise the profile of removals in the VCM, and track the evolving EU and VCM policy landscape. They declined to be recorded and transcribed. Expert1 provided insights into the implications of the EU policy reform on the VCM in relation to biochar CDR credits, how biochar compared to CCS in EU policy, and the timeline of the implementation of the EU CRC.
Tobias Johan Sørensen	Senior Analyst, Concito, Copenhagen	03.05.23, 30m	Policy and VCM	Concito is a Danish environmental think tank. Sørensen has worked at Concito since 2019. He is an analyst in the areas of circular economy, waste and municipal climate planning, and has a current focus in CCS in Denmark. Sørensen provided insights into the Danish government's perspective on biochar and the implications on policy.
Niels Peter Nørring	Climate Director, Landbrug & Fødevarer, Copenhagen	12.05.23, 30m	Public Acceptance, Policy and VCM	Landbrug & Fødeverer (food and agriculture) is a business organization for agriculture, the food and agro industry, with member across the whole agricultural value chain. Nørring has been in the organisation since 2019. He is actively involved in Lobbying at a Danish national and EU level on behalf of the Danish agricultural industry. He campaigned to put biochar on the political agenda during the 2019 governmental election campaigns. The interview provided insights into the Danish political perspective of biochar, the organisation's role in promoting biochar for the purposes of reducing emissions in the agricultural sector, and how current developments in Danish and EU policy could impact the adoption of biochar in Denmark.
Søren Greve Olesen	Chief consultant in Plant advice, LandboNord, Northern Jutland, Denmark	17.05.23, 55m	Public Acceptance	LandboNord is an agricultural consultancy, and Olesen is an advisor to farmers across Jutland in Denmark. He is also on the board of the Skyclean Vraa project, advising on where and how to use the biochar, and facilitating the field testing of Skyclean's biochar. The interview provided insights into the potential for the adoption of biochar by the Danish agricultural industry, current farming practices and how they might impact the use of biochar, and challenges encountered during the field testing.

Figure 3.2. Table identifying six out of the ten interviewees, and purpose of interviews

Preliminary interviews consisted of the first interviews with Lindholst and Thomsen, and later with Esko. They were conducted in February and March 2023 to help with the synthesis of the research problem. Interview guides were prepared and sent to the interviewee before the interview in order to establish the purpose of the interview and the general problem area. However, the purpose of the interviews were not to follow the guides, but to discover context-specific analytical angles to the problem area.

A second round of more targeted interviews were conducted in April and May 2023 after the research question and sub-questions had been drafted, to contribute to answering sub-RQ2 and the discussion. Interviewees were selected for their ability to contribute data pertaining to elements of the conceptual framework. This ensured that the interviews remained relevant to the research question, and that all aspects of the conceptual framework could be analysed from the Danish context. More targeted interview guides were prepared and sent to the interviewee before the interview, and the semi-structured approach ensured that the interview remained relevant to the research question while allowing for flexibility to ask follow-up questions and explore issues previously unknown to us (Roulston & Choi, 2018).

All interviews were conducted in English. The questions formulated were a mixture of open and closed questions, and allowed us to collect data that was either treated as a factual account of the current situation, or a subjective impression of the current situation or future possibilities. The open questions allowed interviewees to emphasise opinions important to them, while the more closed questions ensured that specific details were learned (Maxwell, 2009). Therefore, the data allowed us to learn *"facts"* about the current situation in Denmark and in this way, the interviewees were treated as subject matter experts. The interviewees were also treated as key informants, whereby we learned how current stakeholders *perceive and interpret* the current policy environment, and how they perceive biochar as a climate mitigation solution for Denmark. The interview with Jørgensen is one exception, who spoke only on behalf of RGO rather than expressing his own opinions or perceptions.

Interview data is cited as (Interview, Interviewee name)

Personal communication

Lindholst was contacted via email on 17/05/2023 and phone on 25/5/23 to clarify certain aspects of the interview data. Information from email communication is cited as (Personal communication, Lindholst).

Data Handling

All Interviews were recorded and automatically transcribed with permission of the interviewee using the Microsoft Teams transcribe function, with the exception of the preliminary interview with Peter Lindholst, the interview with Expert 1 and the interview with Trevor Mott. Expert 1 declined to be recorded and transcribed, and it was agreed with them that they would be anonymised for the report. All other interviewees agreed to the use of their name and professional affiliation.

Data coding was conducted concurrently with the data collection so that subsequent interview questions could be informed by prior interviews and be more focused towards the project's knowledge gaps (Maxwell, 2009). Data was recorded through note-taking during the interview, AI transcript generation within Microsoft Teams, and video recording of the interview. Recordings were used to double-check omissions from the notes or errors in the transcript. The data from notes and transcripts were initially organised through the process of deductive coding (Robson & McCartan, 2016), guided by categories relating to elements of the conceptual framework - climate policy, public acceptance, and technology. Data could then be further categorised inductively, to identify new themes, interrelations and storylines (Robson & McCartan, 2016) that emerge from the links between the conceptual elements, namely *Policy incentivising supply*, *Policy incentivising demand*, *Costs and benefits to agriculture*, and *Implications of the different conceptualisations of biochar*. The bases for interpreting the data therefore lay primarily in the conceptual framework, but also themes that emerged from the analysis of the state of the art.

3.2.1 Document support

EU and Danish governmental policy documents and policy analyses were used to answer sub-RQ2. The documents were treated differently from the SOTA literature, as while literature is selected for the author's impartiality, documents are included with the knowledge that political biases are inherent within them. Documents were therefore selected on the basis of being able to back-up and further develop arguments derived from the qualitative interview data. Documents also served to provide data where it was lacking, due to knowledge gaps in the SOTA concerning how recent EU and Danish policy developments influence the biochar system specifically. Documents in the Danish language were translated using Google Translate.

3.2.2 Limitations of the data

Interview method

All interviewees were Danish-speaking, and the interviews were conducted in English, which was their second language. All interviewees had a very high standard of English, and although communication between us and the interviewee was to a small extent hindered, the fact that the interview guides were sent to the interviewee in advance meant that they could prepare for the interview. Furthermore, the ability to ask follow-up questions and clarify answers meant that the results were not negatively affected.

The use of follow-up questions is characteristic of the semi-structured interview method. In using this method, it is important to understand how our values could influence the results of the analysis (Maxwell, 2009). A limitation of this method is that there is a danger of the follow-up questions becoming leading questions, thereby providing an opportunity for our own values to influence the interviewee's answer (Brinkmann & Kvale, 2018). During the interview process, it is possible that through clarification of the specific meaning of the question, the question formulation could have become leading. This could have been a concern when the interviewee expressed their own opinions and perceptions, however the impact on the results of the analysis is expected to be insignificant in this case.

Choice of Interviewee

As previously stated, interviewees were selected based on their abilities to contribute data pertaining to elements of the conceptual framework; however, in some instances, there were limitations in the choice of interviewee. While Frandsen remained a valid subject matter expert for the analysis, his short tenure at Arla meant that he was not familiar enough with certain aspects of the company to answer some of the prepared questions. Furthermore, interviewees Sørensen from Concito and Jørgensen form RGO were initially approached to provide insights into the political perspective at the Danish national level; however they provided data pertaining more to technology and policy in general. Documents from the Danish Parliament were then used to fill certain knowledge gaps. The use of literature and documents to support interview data is characteristic of methodological triangulation, whereby the interview data analysis was supported by the literature and documents to improve the overall validity of the findings. This was particularly necessary due to the limited number of interviews that were carried-out for this project (Roulston & Choi, 2018).

Furthermore, we were not able to secure interviews with Danish farmers, and Mott represented a sector of the farming industry that would not be immediately relevant for the adoption of biochar. We therefore experienced challenges with securing interviews to contribute to both the political and public acceptance dimensions of the conceptual framework, and this could be seen as a limitation for the project. The challenges of securing certain interviews was a potential challenge for data triangulation. This refers to the use of diverse data sources, and in interview research, can pertain to interviewing *"multiple members of a social setting in order to gain different perspectives of the phenomenon of research interest"* (Roulston & Choi, 2018). It was our intention to interview people from the agricultural sector, pyrolysis technology development, and policy spheres, to ensure that the analysis avoided being based on systemic biases of any one group, and provided perspective on the general applicability of the answers to make the results more valid overall (Maxwell, 2009). We were successful in conducting interviews to represent all three sub-systems, and we found that many similar arguments were made by different interviewees, and therefore we deemed the data to accurately represent the Danish case, and the interview data reliability to be high.

Conceptual Framework 4

This project employs the socio-technical analytical method originally developed by Geels (2004). This section briefly explains the history of socio-technical analysis with a diagrammatic interpretation of Geels's (2004) work. Then we explain how various CDR scholars have employed this theoretical perspective to inspire our conceptual framework, and finally a description of our framework itself.

4.1 Socio-Technical Systems

Socio-technical (ST) frameworks evolved from being used to analyse innovation system transitions where the focus was placed on the technologies alone, to analysing a wider range of elements in a systems thinking approach. By incorporating production, use, and diffusion of technologies, socio-technical frameworks were considered more suitable to analyse sustainable transitions. (Geels, 2004; Kern et al., 2017). ST-systems are defined by Geels (2004) as "the linkages between elements necessary to fulfil societal functions"and recognise that technologies are embedded in bigger social, political, cultural, market, and economic sub-systems. The linkages between the different sub-systems are considered to be a key element for technologies to provide societal functions such as energy, housing, heat, or food. Furthermore, Geels (2004) puts the emphasis on the diffusion and user side to understand the success of technological innovations in society. In ST-systems theory, the importance of fulfilling a society's needs becomes central, and this is analysed by studying how technology is used and understood, and therefore diffused in society (Geels, 2004). Finally, Geels (2004) argue that what completes ST-systems are human factors formed by the actors, rules in society, knowledge, science, government regulation or policies, values or cultural norms.

Therefore, the ST-systems framework is composed of sub-systems, actors, and rules that evolve together to fulfil societal functions when sustainable transitions occur (Geels, 2004; Kern, 2012). As shown in figure 4.1, the sub-systems and linkages between them have to adapt to the new needs of society when sustainable transitions occur. ST-systems are also strongly influenced by external factors that are beyond their control (Geels, 2004). Factors like climate change and basic societal needs such as food and water can be included here, as they strongly influence national-level policy and technological development, whereas they themselves are not immediately influenceable (Lefvert et al., 2022).

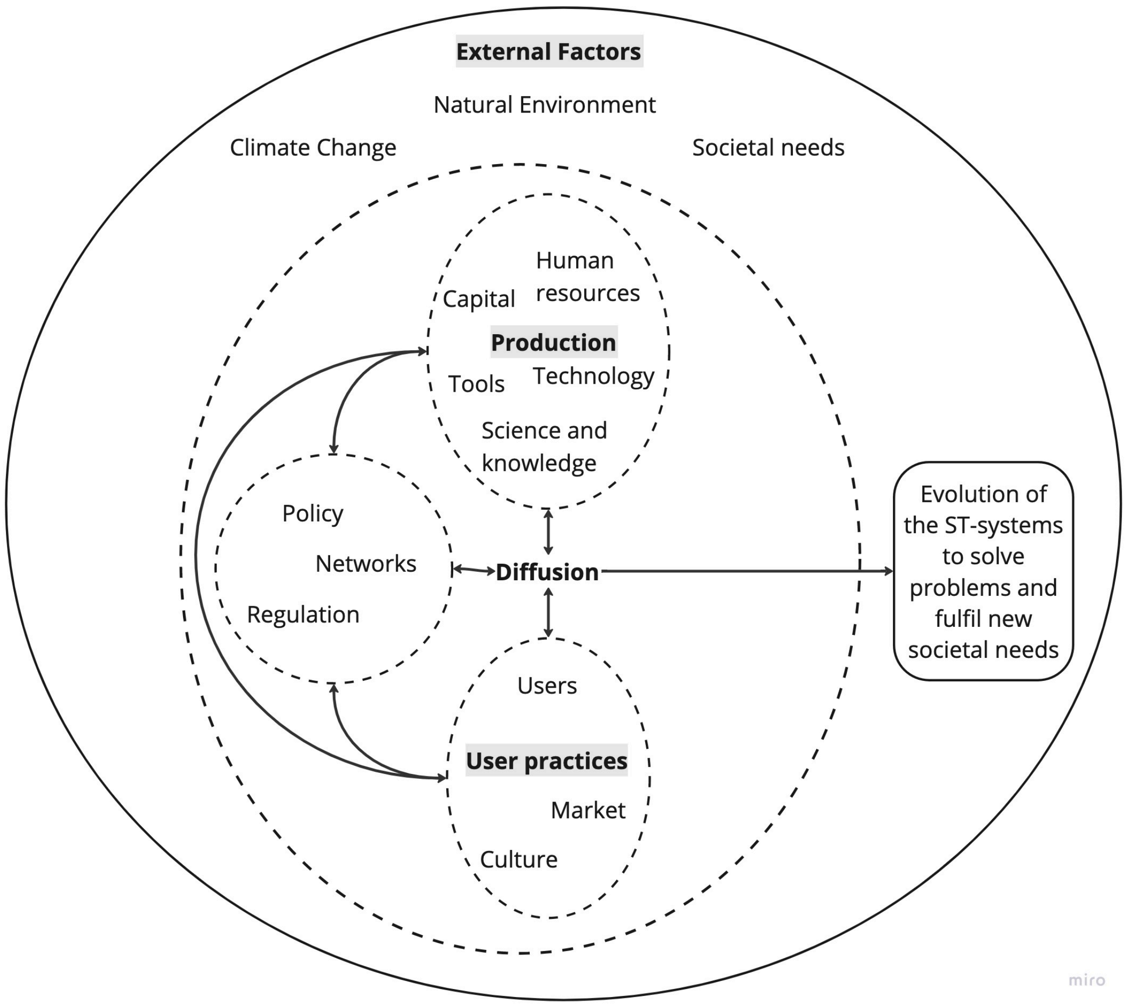

Figure 4.1. Representation of the ST-systems inspired by Geels (2004) and Lefvert et al. (2022). Production is formed by sub-systems such as technology, science and knowledge, human resources, capital and tools. The diffusion of technology happens through policy, regulation, and networks, but diffusion is also the link between supply and demand side that allows technology to fulfil societal needs. User practices define the demand for technology and are determined by identifying potential users, cultures, and markets. On the outside of the ST-system, there are external factors influencing the ST-systems to change, such as the natural environment and climate change. Continuous arrows represent the links between systems, dotted circles represent changing configurations of the sub-systems and ST-systems, and continuous circle represent the whole ST-system.

Geels(2004) argue that to understand how ST-systems fulfil societal needs, we must include technological innovation as part of the ST-system evolution. For instance, innovation in carbon removal can be understood as producing better climate mitigation results, lower costs, fewer negative side effects, and greater societal acceptance (G. F. Nemet et al., 2018). CDR technologies are seen as key tools for fulfilling net zero climate targets and therefore, transitioning to a system where CDR is adopted, requires innovation to adapt to new society needs (Sovacool et al., 2023). ST-systems provide a more holistic framework for analyzing the factors involving the innovation and use of CDR such as biochar in net-zero targets. Furthermore Sovacool et al. (2023), argue that there is a need to analyse innovative CDR technologies from an ST-system approach to understand how its purpose to remove CO_2 fits into the current and future social needs. For instance, because the CDR goal is to remove CO_2 it has to be used in a manner that doesn't jeopardise emission reduction targets (Sovacool et al., 2023).

4.1.1 CDR in Socio-Technical Systems

Authors have recently applied ST-systems analysis to the development of CDR, to understand the socio-economic and technical constraints that define an individual CDR technology's place in the climate mitigation regime. G. F. Nemet et al. (2018) state that CDR technologies ought to address climate change by being produced at a commercially affordable cost, providing climate and non-climate benefits, and minimizing negative impacts. They use ST-systems to analyse the supply-side capacity to scale up CDR technology to a planetary level and the consequences that this might cause on society. They argue that scaling-up CDR is challenged by the social acceptance and adoption of the technologies among users and society. Another example from Sovacool et al.(2023) examines four distinct aspects of ST-systems in CDR that are crucial to the deployment and scaling of carbon removal in the future: societal acceptance, innovation, and policy. Their study also highlights the influence of connections between actors and legislation on CDR.

Otte & Vik (2017) focus on biochar systems embedded in 6 interrelated sub-systems: goals, people, infrastructure, technology, culture and, process and procedures. Those sub-systems are analysed based on influences from regulatory frameworks, financial factors and stakeholders' networks. They argue that the framework helps understand the potential trade-offs that could arise from the implementation of biochar. A biochar system might require new forms of organizations, infrastructure, policy changes, and changing user practices (Otte & Vik, 2017).

The different interpretations of the socio-technical system framework have been adapted for this project, tailored to analyse the specific context of biochar in Denmark.

4.2 Our ST-system framework to analyse the Danish biochar system

In light of the arguments for taking an ST systems approach made above, even if biochar has a high technical mitigation potential to reduce emissions, the diffusion of the technology among the user side of biochar should not be taken for granted. There is a need to acknowledge the whole Danish ST-system to understand the different enabling and constraining factors influencing its full mitigation potential. Thus, the ST-system approach used in this project is shown in figure 4.2, and focuses on 3 different sub-systems relevant to the Danish context.

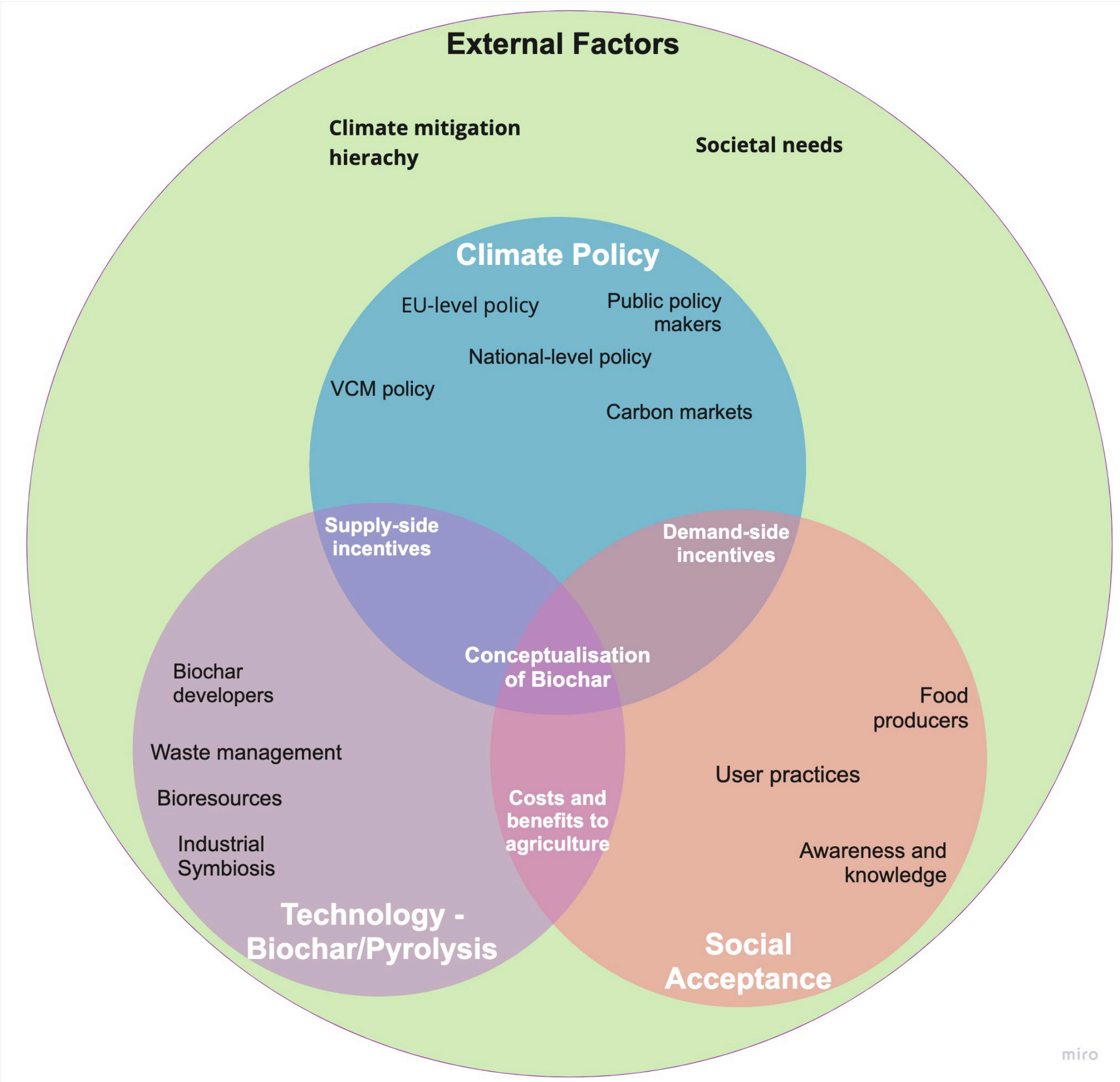

Figure 4.2. This figure depicts the conceptual framework used in the analysis of this project. The model is inspired by previous works on ST systems by Geels (2004), Sovacool et al. (2023), Otte & Vik (2017) and Lefvert et al. (2022). The sub-systems are 'technology', 'Climate policy' and 'social acceptance'. Each sub-system is comprised of different elements that require analysis, for example the primary stakeholders from each sub-system, being food producers, policy makers and biochar technology developers. Systems interact with each other through links represented by 'Cost and benefits to agriculture', 'Supply-side incentives' and 'Demand-side incentives'

The three sub-systems represent socio-technical environments for the biochar system that require identification and description. These are:

- Technology
- Climate policy
- Public acceptance

The technology sub-system is formed by the production and supply side of the technology, while the public acceptance sub-system includes social acceptance within the agricultural industry representing the demand side. The climate policy sub-system includes public policy at national and EU level, and VCM policy.

These three sub-systems are analysed in terms of the evolving Danish biochar system and the viewpoints and perceptions of its stakeholders. The links between different sub-systems provide the necessary conditions to enable biochar's climate mitigation potential. These links reside within the overlaps between the sub-systems, creating four analytical environments:

- Climate policy incentivising technology supply,
- Climate policy incentivising demand from agriculture,
- Technology incentivising public acceptance, through the the costs and benefits for the agricultural sector,
- And the implications of how each sub-system conceptualises biochar.

Conceptualisation of biochar is the interlink between all three sub-systems, and relates to the different ways in which biochar can be categorised as described in section 1.7.3. How different stakeholders categorise biochar will determine the supply and demand mechanisms that control its potential to be diffused and scaled-up to meet the 2MT CO_2 eq. reduction target.

External factors are represented by the outer green circle and include the climate mitigation hierarchy as a response to anthropogenic global warming, and basic societal needs such as food production.

Constraining and enabling conditions can be found in the sub-systems and in the interactions between them, while the links between the sub-systems are where the analysis of the interactions between the systems can take place, as the sub-systems do not operate or exist in isolation.

Climate policy

Climate policy consists of public policy at a national and EU level, and private policies that create and define the VCM.

According to the literature on sustainability transitions, public policy can play a significant role in affecting the speed and direction of sustainable transitions (Edmondson et al., 2019; Kern, 2012). In particular, the role of policy has been highlighted in various papers as a key part of CDR and biochar deployment. For instance, Sovacool et al.(2023) outlined how CDR is poorly understood by policymakers due to its complexity. G. Nemet et al.(2023) highlighted the importance of policy as a crucial aspect to incentivise the supply side of

CDR and its influence in providing diffusion among society by lowering the legislative barriers. G. Nemet et al. (2019) study also points out that policy helps the diffusion of biochar by influencing change in business practices, bringing consumer education and helping expand the market. The policy is also seen as a key factor for the biochar value chain from securing feedstock to the production of biochar (supply) and distribution (demand).

Denmark is one of the few countries that have explicitly committed to the use of biochar in its 2030 climate strategy, as mentioned in section 1.8. However, due to the aforementioned lack of strategy in place (see section 1.8) to enable the diffusion and scaling of biochar, we analyse how the evolving EU and Danish policy landscape introduced in the problem analysis chapter could incentivise biochar CDR in Denmark.

Due to the lack of public policy incentivising biochar, the VCM and private policies that define how the market functions, become a significant factor for scaling biochar. The VCM has been up to now, the most important economic mechanism available, to incentivise CDR at the international, EU or Danish level, operating outside the influence of public policy. However, through the EU CRC, public policy is likely to have a significant role in the potential of VCM to incentivise the scaling of biochar, as noted in the 1.4 and thus an important element included in this sub-system.

Technology

The technological sub-system of biochar in Denmark is understood as the supply side of biochar. In this system, developers and their interests and motivations, technical knowledge, infrastructure and feedstock are some of the elements that encompass the technology system. The analysis of the technology sub-system will begin with a description of the dominant biochar system and the enabling and constraining factors to scale biochar related to the technology and how it can meet societal needs, and political needs.

Social acceptance

Social acceptance of the CDR has been discussed in various studies. Sovacool et al. (2023) and G. Nemet et al. (2023) connect social acceptance to behavioural and environmental aspects, as a core part of CDR in an ST-system. When social acceptance of CDR is incorporated into the analysis, some types of CDR become obsolete and must be completely ruled out. A CDR technology has to meet the societal and environmental needs that are implicit in an analysis of social acceptance, for it to be adopted (G. Nemet et al., 2023; Sovacool et al., 2023). Furthermore, Otte & Vik (2017) highlight the importance of taking into consideration the knowledge and acceptance of biochar of farmers and their networks (advisors, clients and food consumers). How farmers see the costs and benefits of biochar is key to understanding the demand side of biochar (Otte & Vik, 2017).

For this project, social acceptance refers to the agricultural industry, and its need to urgently reduce emissions while continuing to produce food for a growing population. This, for instance, is related to the dominance of livestock farming, and the potential of biochar to managing manure. It is also represented by the possible co-benefits that biochar technology can bring to the industry, or the potential of biochar being a fertilizer product. Therefore we analyse how biochar's ability to contribute to the agricultural industry's needs are understood and accepted.

External factors and the conceptualisation of biochar

Geels (2004) describe how sub-systems are not only influenced by each other but also external factors directly influence the sub-systems. In this framework, the external influence is represented by the environmental crisis of anthropogenic global warming. Attached to this, is the mitigation hierarchy which represents the global scientific and political consensus on how to mitigate the climate crisis, being the prioritisation of emission reduction over removal.

As explained in 1.7.3, biochar can be defined and understood as an engineered or nature-based carbon removal solution, while Danish climate policy uses biochar to contribute to a reduction target for the agriculture sector. The relationship between policy and the mitigation hierarchy is analysed with regard to policy's conceptualisation of biochar as either an NBS or engineered technology, and how this influences its use as a reduction or a removal method. The mitigation hierarchy defines how much political and societal acceptance there is for biochar as a CDR, and the main goals of any climate policy that incentivises biochar. The conceptualisation of biochar is analysed based on the impact of the links between sub-systems.

Having a concrete conceptualisation of technology, is important from a ST-system perspective, to understand how it can be diffused properly and hence scaled and embedded in society in the long term (Geels, 2004). *Conceptualisation of biochar* is therefore placed at the centre of the model, as we analyse the interlinks between the policy, technology and social acceptance sub-systems to identify how the different stakeholder's conceptualisation and categorisation of biochar will influence the adoption of biochar in Denmark.

4.2.1 Diffusion and scaling of biochar

This framework is finalised by conceptualising two key processes; *'Diffusion'* and *'scaling'*, and how they are used in the research question and throughout the analysis.

Figure 4.3 shows the concepts of scaling and diffusion in relation to the conceptual framework model.

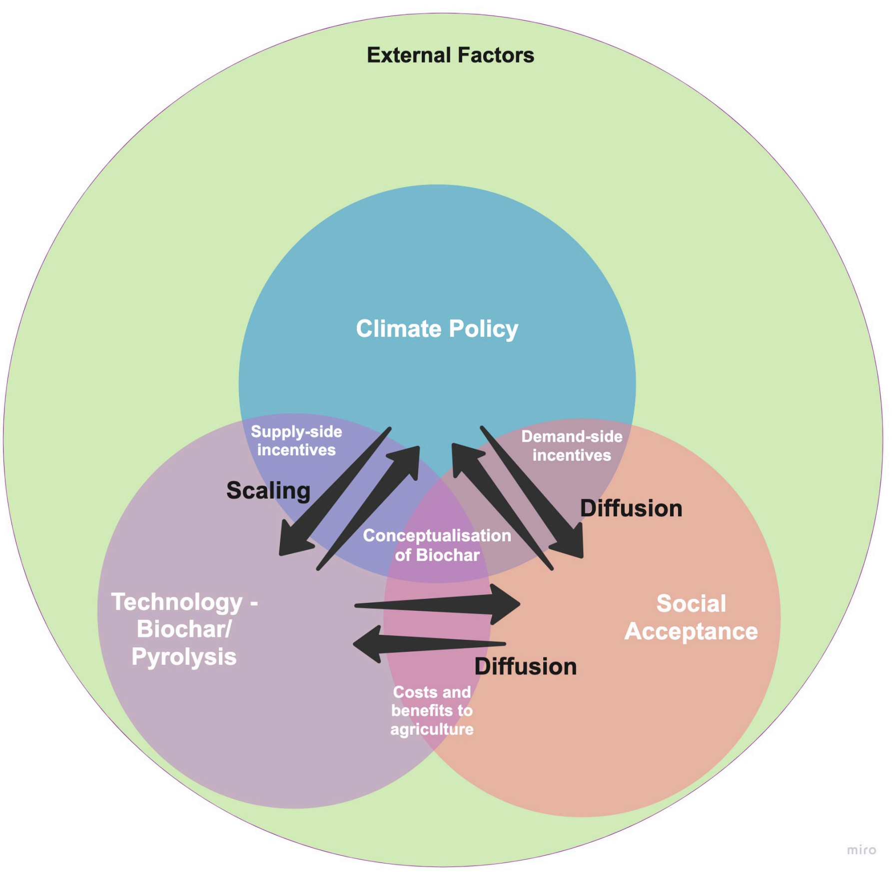

Figure 4.3. The concepts of diffusion and scaling in relation to the project's conceptual framework model. Scaling occurs when incentives are created to increase capacity for production. Diffusion occurs when technology meets user needs and policy incentivises demand. The double arrows show that diffusion and demand are an iterative processes, whereby feed-back interactions occur such as political lobbying, and creating networks of users to support the development of a technology.

Conceptualising diffusion

Diffusion is understood and used in this project to describe the process by which innovations, such as new technologies or practices proliferate and become incorporated into existing socio-technical systems (2004). The diffusion of innovations happens through factors such as the needs, motivations, and perceptions of individuals, organisations, communities, and sectors. It encompasses broader socio-economic and political contexts, where institutional arrangements impact the diffusion of innovations at societal level (Geels, 2004).

In the Danish context, diffusion is understood as the process whereby biochar is spread and incorporated through political support and the use of biochar technology to solve societal and user needs. It occurs through the policy support for a technology, and biochar's potential to meet the needs of potential users. Diffusion is further developed when users recognise the value of a technology and actively seek the development of supporting policy, and create networks to support the development of the technology.

Conceptualising scaling

The use of the term scaling in this project is guided by the works of Sovacool et al. (2023) and G. F. Nemet et al. (2018). Scaling is defined as increasing the capacity, and efficiency of CDR technologies and transitioning from smaller pilot projects to larger, more efficient implementations, to provide the necessary climate change mitigation outcome. Key aspects of the scaling definition are considered to be cost-effectiveness between economies and technological advancements, integration with existing industrial processes, and national and international policy support (G. F. Nemet et al., 2018; Sovacool et al., 2023).

In the Danish context, scaling-up biochar technology occurs through the policy incentivisation of biochar technology to achieve the mitigation outcome of producing enough biochar to reduce 2Mt CO_2 eq. for the agricultural sector. Meanwhile, pyrolysis developers are actively working with policymakers to remove legislative barriers.

State of the Art: Policy Analysis 5

This state of the art focusing on EU and Danish-level policy is necessary to help address the *climate policy* sub-system of the conceptual framework. Knowledge from this literature review will support the analysis of the Danish context by identifying aspects of the policy that become enabling and constraining factors for biochar in the context of the Danish biochar system.

5.1 Challenges for climate policy

CDR has two commonly suggested goals. Firstly it will be used to remove residual emissions from industries (like agriculture) that are practically difficult or too costly to decarbonize, in order to achieve a continuous steady state of net-zero emissions. Secondly, CDR will be needed to achieve net-negative emissions targets (Rickels et al., 2022; Tamme & Beck, 2021). There is no consensus on how to design CDR policy however. This is due, in-part, to the uncertainty around the costs of technological innovation required for climate mitigation, and therefore the levels of financial incentives required to meet targets. Moreover, there is a concern that near-term deployment of CDR will detract from the necessary and urgent reduction in emissions (Rickels et al., 2022; Tamme & Beck, 2021; Verde & Chiaramonte, 2021). Policy will need to ensure that CDR implementation does not compete with near-term reduction goals, while incentivising technological innovation now, to allow for the scaling-up of CDR on a medium to long-term time frame (Tamme & Beck, 2021).

Timely deployment of CDR due to the long planning and innovation lead-times, and cost reductions to achieve at-scale deployment, are two challenges that will need to be addressed by a policy mix that combines carbon market and complementary policies (Gehrig-Fasel et al., 2021; G. F. Nemet et al., 2018; Org & Kennedy, 2019). The urgency to meet 2030 emission reduction targets means planning for the next 10 to 20 years to take into account future cost uncertainties (Org & Kennedy, 2019). This long-term approach will be more expensive and will go against the more economically efficient approach of deploying lower-cost mitigation measures first (Org & Kennedy, 2019). The cheapest first approach is represented in the carbon market, which is designed to pursue emissions reductions where they are cheapest to achieve, and therefore carbon pricing cannot be solely relied upon (McLaren et al., 2019). A lack of long-term planning can cause an overall increase in abatement costs by leading to stakeholders being locked-in to cheaper but less effective technologies (McLaren et al., 2019; Org & Kennedy, 2019), and risk missing long-term targets (Org & Kennedy, 2019).

This state of the art will serve to analyse the policy implications for addressing the challenges noted above, thereby analysing how the evolving EU and Danish policy landscape can incentivise CDR, with a focus on biochar. It will also be analysed how the different ways in-which biochar is conceptualised in policy will determine the mechanisms by-which its production and adoption is incentivised, and therefore the extent to which biochar's technological diffusion can be achieved.

5.2 Current status of EU policy

As stated in section 1.2.1, the EU Green Deal has a legally enforceable 2050 climate neutrality target through the European Climate Law. However, while CDR has been recognised as a crucial tool to achieve ambitious EU targets (Nehler & Fridahl, 2022), precise measures have not yet been established by the EU to reach this objective (McLaughlin et al., 2023). Biochar, along with other CDR methods, has not yet been regulated in any EU pillar. An important reason for reluctance and caution around the governance of CDR are the uncertainties around permanence and risk of reversal, which reduction methods (Meyer-Ohlendorf & Spasova, 2022) or LULUCF sinks, do not suffer from[1]. The many regulatory uncertainties and lack of clear guidance from EU commission is a significant barrier to scaling-up CDR. Current EU policy is likely to support some demonstration-scale CDR initiatives, but falls short of supporting an at-scale deployment timeline, along with cost reductions that would enable more cost-effective technology deployment (Tamme & Beck, 2021). The EU will therefore need to further regulate CDR to meet its targets, however questions remain as-to where CDR fits in the current policy framework, and which actors are involved to coordinate the removal of CO_2 from the atmosphere (Geden & Schenuit, 2020).

The EU's climate goals cannot therefore be met using CDR under the existing policy framework. For instance, EU Member States reporting negative emissions from CDR cannot currently be utilized to meet requirements under any of the three legislative pillars (ERS, ETS, LULUCF) intended to achieve the EU's overall climate change goals for 2030 and 2050. Member states are therefore not encouraged to use or incentivise certain CDR technologies to achieve their obligations (Nehler & Fridahl, 2022). The EU CRC is expected to change the policy landscape towards supporting CDR, as analysed below in section 1.4.2.

[1]Natural removals are covered within the LULUCF work under the no-debit rule, as a balance between emissions and sinks within the land-use sector, rather than as CDR offsets (See section 1.2.3), and so do not currently operate under the same burden of proof of permanence and additionality as CDR (Buylova et al., 2021).
Some CCS installations contribute to emissions reductions under the ETS however these are counted as emissions reductions rather than removal (see 'Type III' offset in figure 1.4) (European Commission, nodate-a)

5.3 EU CRC

With the EU CRC, the EU commission will provide an internationally recognized certification scheme to allow member states to develop national CDR policies (Lundberg & Fridahl, 2022). It has been criticised however, for its lack of robustness for delivering high quality credits with regards to soil-based CDR. Mcdonald et al. (Mcdonald et al., 2023) report limitations in the way the CRC proposal addresses additionality, quantification of carbon storage and the potential negative impacts of soil-based CDR on the environment. Furthermore, the risk of reversal in some soil-based CDR methods means that it is not appropriate for offsetting, and the CRC proposal does not make a sufficient distinction between permanent and non-permanent soil-based CDR (Mcdonald et al., 2023). As stated in section 1.7.3, the EU commission sees similar uncertainties regarding permanence and risk of reversal for biochar when amended to soil, and so it is biochar's conceptualisation as a carbon farming method that creates a challenge to its scaling, enabled by EU policy.

As the EU CRC will certify NBS, technological methods and carbon products, it will be all the more necessary for nations to employ a harmonised policy mix that accounts for trade-offs between mitigation activities. Where NBS and soil carbon is concerned, the EU CRC will need to manage trade-offs between climate mitigation and environmental enhancement factors (Gehrig-Fasel et al., 2021; Scheid et al., 2023). For example, the application of biochar in agricultural soils could conflict with other regenerative farming practices such as no-till, as biochar must be dug-in to prevent wind erosion (S. Jeffery et al., 2015). However, the development of the CRC faces another challenge of providing long-term incentives for the scaling-up of CDR, whilst ensuring the prioritisation of emission reduction before emission removal (Rickels et al., 2022; Tamme & Beck, 2021). Meyer-Ohlendorf & Spasova (2022) identify that while there is a broad consensus that emission reductions should be prioritised above removals (it is better to leave the fossil fuel in the ground in the first place), no EU member state expresses this mitigation hierarchy in their climate plans, which would need to be done in the form of separate targets for each (Meyer-Ohlendorf & Spasova, 2022).

Numerous authors agree that having separate emissions targets for reduction and removal of NDC contributions, rather than the current aggregated net emissions targets, would address the problem of removals conflicting with reduction efforts (Geden & Schenuit, 2020; L. Jeffery et al., 2020; McLaren et al., 2019; Meyer-Ohlendorf & Spasova, 2022; Verde & Chiaramonte, 2021). Separate targets would increase transparency, allowing the practicalities of both elements to be scrutinised separately (L. Jeffery et al., 2020; McLaren et al., 2019), and avoid that funding is diverted from necessary reduction efforts (L. Jeffery et al., 2020). Geden & Schenuit (2020) suggest that the scenarios adopted by the EU's long-term strategy for climate neutrality by 2050 could be represented by a 90:10 ratio of 90% reduction and 10% removal. The 10% removal share is seen as a target that does not interfere with reduction efforts. This would also force governments to provide strategies to support their decision on the weighting between reduction and removal (L. Jeffery et al., 2020)

The CRC is seen in the scientific literature as a key policy for incentivising CDR, however, there is a lack of clarity coming from the EU commission of how it will be implemented (Nehler & Fridahl, 2022; Rickels et al., 2022). It is not known whether it could be used to create tradable units representing 1 ton CO_2 eq, or if it will be used to certify mitigation activities for companies' voluntary activities within their own supply chain (Elkerbout & Bryhn, 2022). Furthermore, how biochar as a CDR is conceptualised in policy will also have implications on which policy mechanisms will be used to incentivise its scaling. Elkerbout & Bryhn (2022) note that in Article 4 of the climate law, natural CDR methods are prioritised over technological ones; *"(the EU and its Member States) shall prioritise swift and predictable emissions reductions and, at the same time, enhance removals by natural sinks"*. However, as mentioned in section 1.7.3, biochar can be regarded as either a natural or technological CDR, adding to the uncertainties of how to legislate it. These uncertainties have led authors to suggest how CDR could be regulated under the LULUCF as carbon farming (an NBS) (Böttcher et al., 2022; Elkerbout & Bryhn, 2022; Kujanpää et al., 2023; Verschuuren, 2022), or ETS as an engineered, industrial CDR (Elkerbout & Bryhn, 2022; Rickels et al., 2021; Rickels et al., 2022; Tamme & Beck, 2021), or as a public good for waste management (Buck, 2020; Geden & Schenuit, 2020; Lackner & Jospe, 2017; G. Nemet et al., 2023). The implications of these various pathways will be analysed below.

5.4 Biochar as carbon farming

The regulation of biochar under the LULUCF will imply its conceptualisation as carbon farming. As explained in the section 1.2.3, the purpose of the LULUCF regulation is to better account for the balancing of emissions and removals from natural sinks, within the land, land use change, and forest management sectors in the EU via the *no debit rule*. Denmark is currently a net-positive LULUCF emitter and has therefore failed to meet the no-debit rule up to now, which places it under pressure to scale LULUCF removals (Smith et al., 2022).

Removals under LULUCF come in the form of forestry management, and the EU has faced challenges in the implementation of a wider range of CDR up to now. This is reflected in the fact that the EU ruled out the inclusion of LULUCF activities in the ETS. These challenges include the difficulty to measure land-based carbon storage within the rules of the ETS, due to uncertainties around human-induced vs. natural emissions, permanence and risk of reversibility of land-based carbon sinks. For these reasons, it would be difficult to support the necessary MRV processes, intrinsic administrative costs (Böttcher et al., 2022; Savaresi et al., 2020). The MRV cost, and whose responsibility it is to cover it, is considered a key challenge (Böttcher et al., 2022). It is argued that biochar, with its co-benefits that help farmers adapt-to and mitigate climate change, will most likely fall under the LULUCF regulation (Kujanpää et al., 2023). But the regulation of biochar under LULUCF has its own specific challenges. First, it has been highlighted that whichever EU or Danish regulations biochar is incorporated into, The sustainability of the feedstock will have to be managed with strong supply chain auditing (Geden et al., 2018). Second, there is no consensus on how to report emission removal from biochar under the IPCC guidelines (Kujanpää et al., 2023).

In July 2021, the European Commission proposed a revision of LULUCF to help overcome these challenges and create a stronger regulatory framework to achieve net-zero targets (Böttcher et al., 2022; Nehler & Fridahl, 2022). The framework is being developed together with several other policies such as the Carbon Farming Initiative and the EU CRC proposal, with the aim of helping the agricultural sector develop its removal potential (Böttcher et al., 2022; Verschuuren, 2022).

5.4.1 LULUCF reform proposal

The LULUCF reform consists of the following proposals:

First, it aims to widen its implications for the agricultural sector. For instance, it will make activities such as enteric fermentation, manure management, rice cultivation, agricultural soils, field burning of agricultural residues, urea application, and other carbon-containing products, net zero by 2035 and net negative thereafter. This will encompass more GHG emissions from the agricultural sector, which will be balanced with a special focus on soil carbon removal methods (Böttcher et al., 2022; Verschuuren, 2022).

Second, the reform will strengthen MRV processes of LULUCF emissions and removals through incorporation with the EU CRC. This is done because the LULUCF sink can potentially play a key role in achieving net-zero targets (Böttcher et al., 2022; Nehler & Fridahl, 2022). As a direct impact of the reform, pressure will be made on other agricultural regulations, such as the CAP, to pursue more carbon removal activities for the agricultural sectors (Verschuuren, 2022), thereby widening the policy instruments available to incentivise carbon removal (Böttcher et al., 2022; Verde & Chiaramonte, 2021). Verde & Chiaramonte (2021) explain that biochar, as carbon farming, could be successfully incentivised in the agricultural sector through the CAP, and this mechanism will be reinforced following the implementation of the LULUCF reform.

Third, Böttcher et al. (2022) point out that the proposal will remove the barriers for balancing emissions and removals between the LULUCF sector and emissions from other sectors. In fact, the EU Commission is preparing to make emissions and removals from the LULUCF sector fungible across non-ETS sectors after 2030, and aims to prepare a fully fungible post-2030 climate framework strategy between these sectors. This means that where countries achieve net-negative emissions via the no-debit rule, these emissions could be used to offset emissions in non-ETS sectors.

The reform will therefore take emissions from the ESR regulation and add them to LULUCF making LULUCF harder to balance. Under the ESR, the reduction of these emissions were at the discretion of individual member states and therefore emissions such as from livestock were not being addressed (Verschuuren, 2022), (also see section 1.2.1) in countries such as Denmark. Moving these emissions to the LULUCF forces Denmark to address emissions from livestock. Verschuuren (2022) highlight the challenge that member states with high numbers of livestock will face in the upcoming years, if the agricultural sector must become a net-sink. They further foresee that the agricultural sector is expected to balance emissions from other sectors to achieve net-zero after 2036, thereby forcing a reduction in livestock. This will force Denmark to create policy to incentivise land-based CDR including biochar, in order to start balancing the agricultural emissions.

LULUCF and future policy mix

As previously stated, the LULUCF reform links the EU CRC and the Carbon Farming initiative. The European Commission is working to supplement the Carbon Farming

Initiative with the EU CRC program, to encourage carbon reductions and removals at the land manager level in agriculture and other land-uses (Lundberg & Fridahl, 2022). Moreover, Nehler & Fridahl (2022) foresee that, in the short term, it will eventually create a nature-based removal market within the LULUCF regulation to serve the no debit rule. Agricultural emissions and sinks will therefore be balanced in a similar way to how forest sinks are already permitted to balance emissions in the forestry industry (Böttcher et al., 2022; Nehler & Fridahl, 2022; Verschuuren, 2022).

Within this carbon market, LULUCF industries could trade removals certificates (Paul et al., 2023; Verschuuren, 2022), so Danish farmers achieving net-negative emissions with biochar could sell carbon certificates to other farmers that have difficulties in reducing their emissions. With the strengthening of the MRV in the reform, the incorporation of the EU CRC proposal, and the subsidies from the CAP and the Carbon Initiative, farmers will have several economic incentives to pursue carbon removal activities such as biochar. This policy mix could be seen as an opportunity for Danish agricultural sector to meet the no-debit rule.

The arguments presented above indicate that the carbon market will begin to play a bigger role in CDR, either as a voluntary market, or compliance market within LULUCF, with EU CRC providing a framework to support both mechanisms. Verschuuren (2022) suggest that the EU CRC could allow for the inclusion of removals from the agricultural sector in the ETS. This would encourage farmers to engage in climate-friendly practices, especially given the strong influence of this pillar in meeting the EU climate targets (Verschuuren, 2022). However, while biochar is perceived as an NBS under LULUCF, this would require further revisions of LULUCF legislation, as there are currently no flexibility mechanisms regarding the reduction or removal of emissions with the ETS (Kujanpää et al., 2023; Rickels et al., 2021; Savaresi et al., 2020). The implications of the EU CRC for the compliance market and VCM will be further explored in subsequent sections of this chapter.

5.5 Biochar as an industrial CDR

There are certainly policy developments suggested for the ETS that could allow for the regulation of biochar under the ETS, and this would require its conceptualisation as an industrial CDR.

It is suggested that the two goals of CDR; balancing residual emissions and achieving net-negative emissions, could be combined through the trading of carbon removal credits, with the net-zero phase and the net-negative phase representing two centrally governed markets (Rickels et al., 2022). This mirrors the approach championed by McLaren et al. (2019) that would require a re-design of the carbon trading system to accommodate separate reduction and removals targets for NDC contributions. This would provide a mechanism that incentivises emission reductions by lowering costs, while also incentivising innovation and scaling-up of costly CDR technologies (McLaren et al., 2019).

In the EU, part of this approach could be to finance innovative and industrial CDR technologies through the trading of removals credits on the ETS (Lundberg & Fridahl, 2022; Rickels et al., 2022; Tamme & Beck, 2021; Verschuuren, 2022). This would require amending the existing ETS directive however (Lundberg & Fridahl, 2022), and Verde

& Chiaramonte (2021) suggest introducing a quota of GHG removals as offsets in the ETS. The end of allowance supply for the ETS has been brought forward by the green deal to 2040, after-which it will need to transition to a net-negative emissions trading system (Rickels et al., 2021; Rickels et al., 2022). In recognition of this, the Plenary of the European Parliament has shown support for the integration of carbon removal in the ETS, and broader support is expected to grow following the adoption of the EU CRC (Rickels et al., 2022).

5.5.1 Equivalence of biochar with industrial CDR

As previously noted, the CRC is being developed for the purpose of creating more robust systems for carbon accounting and MRV of carbon removal through carbon farming, CCS and carbon storage in long-lasting products (see section 1.4. This could allow for equivalent levels of certainty of carbon accounting between all three CDR categories (Tamme & Beck, 2021; Verschuuren, 2022). The EU CRC could provide an equal comparison between nature-based solutions and engineered (or technological) CDR, and would target NBS removals in a way that could be used to offset hard-to-abate emissions from other sectors, rather than balancing agricultural emissions under the LULUCF (Paul et al., 2023; Verschuuren, 2022). Permanence remains the primary concern, and only the most permanent carbon storage should be included in the ETS so as not to compromise the market's integrity (Elkerbout & Bryhn, 2022)

New DACCS and BECCS projects are currently perceived as having a greater chance than biochar of being included in the ETS due to the relatively high certainty of permanence and simpler MRV processes. This is represented through CCS's support in EU legislation with the CCS directive, which makes provisions for dealing with leakage from geological storage of carbon from CCS plants, allowing some plants to generate emission reduction credits (rather than CDR credits) under the ETS (Elkerbout & Bryhn, 2022; European Commission, nodate-a; Rickels et al., 2021). As an NBS, biochar achieving equivalence with CCS would require similar assurances of leakage mitigation within the agricultural sector which is already known to be a challenge (L. Jeffery et al., 2020; Paul et al., 2023). However, Biochar could also warrant being legislated as a technological method, with carbon storage as a product (see section 1.3.1), due to its dependence on costly industrial processing. This would require de-coupling biochar from its use as a soil amendment during its certification as a CDR, which only the permanence requirement is dependent-upon.

5.5.2 The potential for biochar's inclusion in the ETS

Rickels et al. (2021) argue that carbon storage in building materials or long-lived chemicals could warrant inclusion in the ETS, and this could include biochar (as-per definitions in sections 1.3.1 and 1.7). Long-term climate mitigation can be achieved when compliance markets are included in the policy mix, as long as carbon prices are sufficiently high for predictable time-frames (Howard, 2018). The ETS therefore presents a powerful tool to enable scaling. The scaling of biochar could involve the development of industrial-sized pyrolysis plants, which would also achieve the economies of scale required to reduce costs of CDR deployment. Funding for these pyrolysis plants could be achieved through inclusion in the ETS along with DACCS and BECCS, implying the conceptualisation of biochar within the policy as a technological CDR method, and a carbon storage product. Inclusion in the ETS might then only benefit Denmark's agricultural emission reduction targets indirectly, through its co-benefits as a chemical fertiliser substitute or other mitigation mechanisms, rather than an agricultural CDR. Otherwise there would be a risk of double-counting.

The advantage of biochar's co-benefits when compared to CCS

Cox & Edwards (2019) note that the co-benefits of CDR methods such as biochar further allow them to be more competitive than methods such as DACCS, which provides the sole benefit of sequestering carbon. Firstly, the soil amendment properties of biochar create the potential for a *"demand pull"*. Secondly, the potential for use in agriculture exposes it to a greater variety of potential incentivising policies, as compared to technologies such as DACCS which must rely solely on high carbon pricing for incentivisation. Paul et al. (2023) argue that carbon sequestration techniques should be incentivised for their mitigation and adaptation co-benefits rather than their CDR potential. Others argue that the co-benefits of biochar are highly uncertain (P.R. Shukla et al., 2022; Thomsen, 2022), and adoption of CDR technologies such as biochar require real-world implementation at demonstration scale to provide sufficient certainty of the co-benefits (Cox & Edwards, 2019). Such demonstration projects can in-part be funded by the Innovation Fund. The fund distributes proceeds from the ETS carbon allowance auctions, and serves to finance the research and development of innovative CDR technologies among other mitigation measures (McLaughlin et al., 2023; Tamme & Beck, 2021). Depending on the carbon price, the size of the fund is estimated at 25 billion Euros, but applications for funding to the innovation fund are currently heavily over-subscribed. It has been proposed to double its capacity as part of the fit for 55 package, which will help to incentivise investment in CDR demonstration projects by de-risking capital-intensive phases of development (Tamme & Beck, 2021).

Uncertainties around the co-benefits of biochar will affect the demand-pull, and the incentivising policies available for scaling biochar as a CDR (Bach et al., 2016). The benefits of biochar in agricultural soil remain contested, with studies providing contradicting results regarding, for example, effects on crop yields and water retention (Bach et al., 2016; Fuss et al., 2018; P.R. Shukla et al., 2022; Thomsen, 2022). This creates uncertainty for the financial incentive for farmers to adopt biochar as a soil amendment (Chandran & Thomas, 2019; Pourhashem et al., 2019). Chandran & Thomas (2019) note that the high cost of biochar, including production and transportation, is a significant barrier to its use in agriculture, and one study by Vochozka et al. (2016) has shown that the financial benefit of higher crop yields do not pay back the initial investment in purchasing the biochar. Farmers will need additional incentives to use biochar as long as the effects on crop yields remain unproven, as profitability will be central to their decision-making. The value proposition of biochar as a climate mitigation tool will have to be exploited to incentivise its adoption, and this could come in the form of public subsidies (Bach et al., 2016). Markusson et al. (2020) note that CDR has further long-term benefits for climate mitigation as a hedge *"against uncertainties originating from our understanding of carbon cycle climate interactions, the participation of actors in future climate agreements, or the effectiveness of mitigation policies"*. This additional benefit can incentivise governments to introduce public subsidies (Markusson et al., 2020) for the scaling of biochar.

5.6 VCM

The VCM together with provisions in Article 6 of the Paris Agreement, have allowed essential contributions to nation's NDCs and global mitigation efforts in general (See section 1.5 for an introduction to Article 6). In doing so, VCM projects have an extended benefit of incentivising countries to commit to more ambitious climate targets within their NDCs (Howard & Greiner, 2022). However, many authors identify an increased risk of double counting when allowing credits issued for the VCM to contribute to NDCs (Gehrig-Fasel et al., 2021; Marcu, 2021; Tamme & Beck, 2021). Tamme & Beck (Tamme & Beck, 2021) highlight that multiple European CDR projects intend to fund themselves in part through the VCM, and that national governments and VCM actors will have to cooperate to mitigate risks of double-counting. With the gradual adoption of CDR in the EU for contributing to its NDC (see section 1.4), the VCM could continue to play an important role in providing a funding mechanism for the scaling-up of biochar production, and incentivising farmers to use biochar as a carbon capture technique (Paul et al., 2023). The VCM global value was $2 billion in 2021 (Donofrio et al., 2022), while the ETS value was $34 billion - (European Environment Agency, 2023). Funding through the VCM would therefore be assumed to be at a smaller scale than if biochar were regulated under the ETS, and pyrolysis would occur at a much smaller scale. Furthermore, where Denmark chooses to incentivise the scaling-up of biochar as carbon farming, initial investment through the VCM would have a knock-on effect for helping Denmark meet its targets by providing essential funding to demonstration projects. Care would have to be taken to prevent double-counting in this circumstance however.

There are challenges for the EU CRC in the VCM to overcome, before biochar can be seen as a long-term mitigation measure in the agriculture sector. As previously noted, proving permanence of carbon sequestration in soil, monitoring long-term reversal of the carbon storage, and adhering to the additionality requirement are all significant challenges (L. Jeffery et al., 2020; Jörß et al., 2022; Paul et al., 2023), and Jörß et al. (2022) suggest that for these reasons, soil-based carbon sequestration is not suitable for carbon market offsets. To exemplify a situation where proving additionality will be problematic; the forward-selling of carbon credits[2] is identified as a way to bring more funding to NBS mitigation measures (Gehrig-Fasel et al., 2021). However, claims of additionality may prove inaccurate, if they are based on current economic considerations, while future market technology and policy changes are not considered[3]. Until these challenges are overcome, biochar would contribute to agricultural emission reduction targets via its co-benefits (Paul et al., 2023).

5.6.1 Reduction vs Removal in the VCM

The integrity of the VCM has been called into question in recent years (Burrows, 2022; Guizar-Coutiño et al., 2022; L. Jeffery et al., 2020; Murun & Takahashi, 2023), and coupled with a concern that offsetting will disincentivise emission reduction, some companies are setting net-zero targets without offsetting (World Bank, 2021), which could reduce

[2]The selling of carbon credits representing sequestration that is to happen in the future (Gehrig-Fasel et al., 2021)

[3]There are numerous ways to assess additionality and one is legal additionality. A project cannot claim its mitigation activity is additional if that activity is mandated by law (COWI et al., 2020)

the funding available for biochar and other CDR innovations. However, as noted in section 1.4.2, the EU CRC has been developed to support the VCM to provide genuine additionality and transparency, and certifies only permanent CDR. Such developments in policy guidance and potential regulation at the national and EU level could indicate a gradual shift towards permanent removals in the VCM (Kujanpää et al., 2023; World Bank, 2021). The Oxford Principles for Net-Zero Aligned Carbon Offsetting for example, has argued in favour of transitioning towards CDR in the VCM, while McLaren et al. (2019) argue for separate voluntary reduction and removal markets.

Companies engaging in the VCM are beginning to buy credits from projects that are more local to their clients, and paying higher than average prices for these credits, indicating that there is a demand for projects delivering local environmental impact (Org & Kennedy, 2019). This has led to strong growth in new European standards specialising in biochar such as Puro.earth and online platforms selling biochar credits such as compensate.com and carbonfuture.earth (Thomsen, 2022). It has been suggested that credits certified by new and more stringent MRV schemes such as the EU CRC and puro.earth could be more expensive, and this cost would have to be borne by the market (Böttcher et al., 2022). This could mitigate the reduction vs removal problem by making offsetting through a removals market more costly for companies than enacting emissions reduction measures (Lackner & Jospe, 2017; G. Nemet et al., 2023).

5.7 Biochar as waste management

Some authors are suggesting that a paradigm shift in the way carbon dioxide is perceived could help CDR gain public acceptance and incentivise innovation and scale-up; that is, CDR as waste management. As noted in section 1.7.3, it is suggested that infrastructure for removing carbon dioxide could be treated as a public good (Lackner & Jospe, 2017). Moreover, the polluter pays principle is enforced, whereby carbon dioxide is treated as a "*metabolic by-product of industrial and municipal activities on which billions of people depend to survive and thrive*"(Lackner & Jospe, 2017).

Biochar can also be seen as a powerful waste management tool (Buck, 2020) as an effective way to manage municipal organic waste (Mattias Gustafsson, 2018) or agricultural waste (Elsgaard et al., 2022). Combining the waste management analogy for CDR with the central mechanism of biochar as a waste management tool could help widen the scope of application of biochar in Denmark and help it gain public acceptance as CO_2 clean-up becomes a shared problem. Meanwhile, innovation, scale-up and cost reductions of novel CDR technology is supported by government investment in management of this public good (Lackner & Jospe, 2017). Cost reductions become a necessity where management of a public good is seen as affordable to the tax payer (G. Nemet et al., 2023), and the establishment of public-owned enterprises for DACCS has already begun to happen in Norway (Kujanpää et al., 2023). Biochar as a waste management tool also introduces a circular economy perspective (Buck, 2020) where waste carbon is captured in a closed loop, with biochar being used as a soil amendment or fertiliser.

Lackner & Jospe (2017) suggest that this CDR as a public good analogy could be enacted through a transparent MRV certification scheme for a portfolio of CDR methods, audited by a trusted public institution. Certificates would be earned for negative emissions, and relinquished for storage reversal. Consumers would purchase these certificates to balance out their 'residual' or 'unavoidable' emissions (Geden & Schenuit, 2020; Lackner & Jospe, 2017) and these negative emissions would count towards the afforementioned 10% removal target proposed by Geden & Schenuit (2020). Such a scheme could be said to be already in development with the EU CRC, which, as previously stated, is aimed at building trust in the voluntary carbon market and guiding it towards removals, and opening the way to including removals in the ETS. Moreover, the EU CRC will form a key pillar of the EU's circular economy action plan in order to increase Europe's circularity of carbon (Lundberg & Fridahl, 2022).

There are concerns however, that this waste management and circular economy paradigm could cause CDR to be a short-lived pursuit, disincentivising emission reduction, and loosing the trust of the public. As Buck (2020) point out, it normalises the continued generation of carbon waste, and conceptualises it as something that needs to be managed rather than eliminated. However, separate targets have already been suggested (See section 5.3) as a policy instrument to mitigate this problem. Separate targets for reduction and removal activities would make it clearer from a policy perspective what the expectations are for industry to mitigate emissions. Meanwhile, the use of a public entity-controlled certification system for removals could mean that the cost of carbon disposal incurred by the polluter could be higher than the cost of emission reduction. If removal measures become more costly than reduction measures, then reduction measures are automatically prioritised, and business as usual is disincentivised.

5.8 Critical assessment of Danish policy

The development track

In 2020, the same year the LT-LEDS was published, The Danish Council on Climate Change (DCCC)[4] published the report; *Known paths and new tracks to 70 per cent reduction*, in-which they identify an implementation track (known, implementable climate mitigation pathways) and development track (un-proven pathways). They assess that the implementation track will achieve 60% reduction, while the development track will contribute an additional 10% reduction (representing 8 MT of CO_2 eq) to achieve the 2030 target. We assess that biochar can form part of the 10% of the development track, and the Danish government commits to sequestering 2 MT of CO_2 from just biochar alone (see section 1.8). However, the DCCC suggest that in the Development track, agriculture's share of the 8 MT CO_2 eq will be 2 MT, achieved through changing eating habits and developing new technologies to find new ways to produce food, without acknowledging biochar's possible contribution. Therefore, we see a disconnect between the DCCC as policy advisers, and the Danish Government's policy as communicated in the LT-LEDS and 2022 Klimaprogram for how to reduce emissions in agriculture. The implication is

[4] "The Danish Council on Climate Change is an independent body of experts which exists because Denmark and the rest of the EU have a political objective to reduce CO_2 emissions by 80-95% by 2050. The Danish Council on Climate Change advises on how Denmark can most effectively and cost-effectively undertake the transition to a low-carbon economy by 2050."(Danish Council on Climate Change, 2020)

that the 2 MT for biochar is potentially unrealistic from the point of view of the DCCC's analysis.

Furthermore, the DCCC warn against a focus in the government's incentivising policy on technical mitigation measures in the development track. A larger focus on biogas plants for example, could lead to technological lock-in, whereby the industry is reliant upon carbon-intensive livestock production to feed the plants, counteracting positive climate outcomes (Jette et al., 2023). Biochar could also fall into this trap, if the feedstock for biochar is from agricultural processes that are the target of emission reduction policy.

Green Tax

As noted in section 5.4, Denmark will be forced to make new policies to balance the new emissions from its livestock that now fall under the LULUCF. The DCCC has suggested that a key policy tool to achieve the 70% reduction target is a green tax reform with a recommended carbon price of around 1,500KR ($220 USD) per ton by 2030, and a new carbon tax on the agricultural industry which is currently still omitted from the green tax policy (Danish Council on Climate Change, 2020). A tax on agricultural products such as fertilisers has been recommended for example (Verschuuren, 2022), and this could incentivise the development of biochar as a fertiliser product in Denmark as it could partially substitute the taxed chemical fertilisers. The DCCC also expect that the green tax will drive a transition from livestock farming to more plant-based farming, and that cattle farmers especially will be significantly negatively impacted (Jette et al., 2023). A green tax will therefore also raise questions of public acceptance (Batini et al., 2020), in the agricultural industry, and this could limit its scope of implementation and therefore its potential to incentivise biochar adoption.

Another disconnect between government policy and the DCCC's analysis, is in the carbon price required to bring about sufficient change. The DCCC identify that the government is likely so assign a carbon price of 750 DKK to the tax, and that this will be insufficient to deliver the 70% reduction target, suggesting that in fact, a price of 1,500 DKK will be required in 2030 to meet the targets (Danish Council on Climate Change, 2020). The potential for the green tax to incentivise biochar adoption sufficiently to meet climate targets will therefore be highly dependent on the carbon price assigned. Furthermore, the 1,500 DKK carbon price will worsen the perception of the tax in the agricultural sector, and this could lead to a more conservative and insufficient carbon price being assigned.

5.9 Sub-conclusion

The literature analysis has shown that biochar will likely require adoption of the EU CRC before it can contribute to the NDC. While the EU CRC is seen as essential to provide equivalence across CDR technologies, it is also argued that it may be inadequate for soil-based mitigation, affecting its ability to enable the scaling of biochar. Furthermore, there is a concern that it will hinder reduction efforts - whether implemented through the LULUCF, ETS or VCM - and be used as an excuse to continue business as usual. Authors recommend public policy to incorporate separate reduction and removal targets to complement the arrival of the EU CRC, however the Danish government have not done-so.

Following the implementation of the EU CRC, biochar could fall under the LULUCF and/or the VCM, or the ETS. LULUCF reform presents an opportunity for the biochar system, forcing emission reduction in agriculture while enabling land-based mitigation through the carbon farming initiative, and biochar will benefit from this reform when regulated as an NBS.

Regulation in the ETS would incentivise the supply side of a biochar system, however it would have the challenge of achieving equivalence to BECCS and DACCS, and will require amendments to the ETS directive. The timeline for these amendments is unknown as it awaits the implementation of the EU CRC. However, the requirement of the ETS to be net-negative by 2040 is an incentivising factor. The no-debit rule of the LULUCF already accommodates removals to some extent, therefore regulation of biochar under the LULUCF is regarded as the most likely scenario in the short to medium-term.

As a waste management tool, There is a concern that CDR will lead to an excuse to continue producing more CO_2 waste. However, conceptualising pyrolysis as a public good could significantly increase the government's stake in pyrolysis, and if CO_2 is seen as society's problem, giving a larger share of the carbon budget to removals through separate targets would be more politically acceptable.

There remain many uncertainties for the Danish case. Where biochar is incentivised through the carbon market - whether the ETS or VCM - it is unclear how the mitigation outcome would count towards a reduction in the agricultural sector. Furthermore, there is disagreement in the literature regarding biochar's co-benefits as an incentive for diffusion. The co-benefits should give biochar an advantage over CCS where they compete for the same pool of subsidies, and it is argued that policy should emphasise carbon farming's co-benefits rather than CDR. However, others argue that it is unlikely that the co-benefits alone would incentivise farmers to use biochar in their fields.

There also remain uncertainties as-to the role of biochar in climate mitigation in Denmark. Without separate targets, the Danish government cannot ensure that biochar is used for residual emissions only. Moreover, the 2MT biochar target is at odds with the DCCC's analysis of how to assign Denmark's overall climate mitigation potential. Lastly, the carbon price that the government is expected to assign to the green tax may be insufficient to meet targets, and may therefore be insufficient to incentivise biochar's adoption in order to meet the 2MT target.

The state of the art identified a lack of CDR literature based in the danish-context. Therefore the following chapter will analyse interviews with Danish stakeholders of potential biochar systems, supported by analysis of policy documents, in order to further explore these uncertainties to determine how they will impact biochar's technological diffusion and scaling.

Figure 5.1. Photograph taken by Olesen during the spreading of biochar on fields in Northern Jutland, Denmark for field testing of Skyclean's biochar (Interview, Olesen)

6 Analysis: The Danish Biochar System

This analysis combines knowledge from the SOTA, interview data and document data to answer sub-RQ2. The conceptual framework guides the analysis, whereby within the three subsystems, and the links between them, enabling and constraining factors can be identified, that affect biochar's potential for scaling and diffusion by 2030, to meet Danish climate targets. The conceptualisation of biochar is also a key factor to analyse. The ways in-which stakeholders of the Danish biochar system conceptualise biochar will determine how it is incentivised. Therefore enabling and constraining factors for biochar's scaling can also be found within the different conceptualisations.

We begin with an analysis of how political support for biochar is acting as an enabling or constraining factor, including by enforcing the mitigation hierarchy. This is followed by an analysis focused on the context-specific biochar technology subsystem in Denmark and the constraints and enabling factors found with the use of the technology (cost-benefits for agriculture), regulatory constraints, and the VCM. We then analyse how the conceptualization of biochar is influencing the different policy scenarios based on the different stakeholders' needs. Finally, we analyse the constraints and enabling factors that influence the social acceptance of biochar in the agricultural sector.

6.1 Political support in Denmark incentivises biochar

As noted in section 1.8, biochar is considered to be at the demonstration stage. At this stage in technological development, processes of diffusion (the integration of the technology into society through adoption by the users) and scaling (increasing production capacity) become important agenda items. However, because scalability and public acceptance are yet to be proven, investments in increasing capacity are high-risk. Political support is therefore critical to ensure the incentivisation of biochar through investments into scaling, and early adoption (L. Jeffery et al., 2020; Pourhashem et al., 2019) by the agricultural industry.

The current situation (pre-LULUCF reform), is that GHG emissions in the agricultural sector are not regulated in the EU, and it has been left to the individual Member States to determine national ESR targets. This has led to a lack of political support and therefore incentives, for the reduction of agricultural emissions across the EU (Danish Ministry of Climate Energy and Utilities, 2020). Section 1.8 shows that the Danish government has recently demonstrated a political focus on the reduction of GHG emissions within the agricultural sector, and section 5.4 indicates that this focus is likely to have been incentivised by upcoming the LULUCF legislative reform, as it will put pressure on Denmark to reduce emissions from livestock. This has led the government to assign a 2,000,000t CO_2 Eq (2MT) emission reduction target using biochar to the agriculture sector (see section 1.8).

The mitigation hierarchy in agriculture

Emission reduction in agriculture is seen as a greater challenge than in other sectors due to biological factors related to the livestock industry and the non-CO_2 emissions it produces (Interview, Frandsen). For example, the agricultural industry has always been taxed, along with other sectors, with regard to its use of fossil fuels, and emission reductions here can be achieved through electrification. However, reductions in livestock emissions are harder to achieve without reducing the size of the entire industry (Interview, Nørring). To reflect this challenge, the agricultural sector has a national emission reduction target of 55 - 65% by 2030, which is less than the national 70% target (Interview, Frandsen).

To achieve the 55% emission reduction target in agriculture, government policy is aimed at reducing livestock numbers and transitioning to plant-based food production, while simultaneously reducing demand for animal products by changing eating habits, and encouraging the use of climate-friendly production technologies. As noted in section 5.8, some of the suggested policy frameworks are a carbon tax, or a subsidy for the implementation of green technologies (Danish Council on Climate Change, 2020). Frandsen acknowledges that part of the solution to achieving the targets will be to decrease farm-level production, and dairy farms will inevitably disappear from Denmark (Interview, Frandsen). In-line with this viewpoint, Jørgensen states that the first step to achieve the targets will be to reduce the production of feedstock for animals and produce more plant-based food. Approximately 62% of Denmark's total area is dedicated to agriculture, and 80% of this is used for growing feed for animals which is regarded as a carbon-inefficient use of agricultural land (Interview, Jørgensen). The second step towards achieving the targets will be to use pyrolysis and biochar to help remove the residual emissions (Interview, Jørgensen).

6.1.1 The Danish strategy for reducing emissions using biochar

The scientific consensus in the SOTA is that the time factor is crucial - we need to develop CDR now in time for at-scale deployment by 2030 - and that EU countries do not have a strategy to achieve this. Achieving the 2MT emission reduction requires building pyrolysis facilities very soon, and if it is not possible to deliver the target, those emission reductions will have to come from somewhere else to balance the carbon budget for the 2030 55% target (Interview, Sørensen).

The Danish government is therefore relatively unique in the EU as having published a technology development track to help deliver the 70% reduction target by 2030, with a basic pyrolysis strategy within the *'roadmap for brown biorefining'* forming a part of this development track (see section 1.8). The pyrolysis strategy has been put in motion, through the Danish Ministry of Climate, Energy and Utilities' public-private partnerships in the agricultural industry. The ministry regards such partnerships as vital to enable inter-disciplinary planning and to secure sufficient funding for the development of the nascent biochar system (Danish Government Climate Partnerships, 2019). In line with this policy, the government has entered into a partnership with a pyrolysis development company Skyclean, a subsidiary of Stiesdal, to develop pyrolysis technology with the aim of increasing carbon storage while developing green energy for transport. The ministry states that 400 million DKK has been requested for the Skyclean project (Danish Government Climate Partnerships, 2019). In 2022, Skyclean completed a 2MW demonstration pyrolysis plant in Skive Northern Denmark, in order to develop the pyrolysis technology necessary to deliver agricultural emission reductions through biochar. In Vraa, Northern Denmark, they are building a 20MW pyrolysis plant in industrial symbiosis[1] with a biogas plant. This 20MW plant is planned to be completed in 2023. For this plant, Skyclean has received a grant of DKK 124 million (Interview, Lindholst) from the Next Generation EU pyrolysis pool, distributed by the Danish Energy Agency (Galacho, 2022). An additional DKK 196 million of funding is expected to be announced soon (Interview, Lindholst).

The plant has the potential to produce 15,000t biochar per year from 40,000t of dry biomass feedstock, to sequester 40,000t CO_2 eq "total climate effect"[2](Stiesdal, 2023), while the CDR effect of the biochar alone will be approximately 26,000 tonnes (Personal communication, Lindholst). The government states that the estimated CDR potential of Skyclean's biochar in 2030 is 800,000t to 900,000t CO_2 (Danish Government Climate Partnerships, 2019). Government support is therefore an important enabling condition. The 20MW plant will be critical to show if the 2MT target is achievable, however, no other partnerships with pyrolysis developers are identified by the Danish Ministry of Climate, Energy and Utilities, implying that there are no other partnerships in place to achieve the remaining 1.1MT of the 2MT target.

6.2 Biochar technology in the Danish context

An important enabling condition for the Danish biochar system is the synergy with biogas. The intensive livestock industry of Denmark noted in section 1.8 creates a need to efficiently use agricultural residues as bioresources. The Vraa Skyclean scale-up project with its biogas plant symbiosis presents an opportunity to do this. Biochar, therefore, can have a key role in Denmark in helping it manage its livestock manure residues, together with the established and growing biogas network (Interview, Jørgensen).

Figure 6.1 depicts the current skyclean pyrolysis business model planned for the scale-up project. Organic residue from the agricultural industry consisting mainly of livestock slurry (or manure) mixed with dry residues including straw (Interview, Jørgensen) is fed to a biogas plant. Biogas digestate (residue fibres from the process of anareobic digestion) are the feedstock for pyrolysis, with the primary product being carbon sequestration via biochar pellets (see figure 6.2) amended to agricultural soils. A co-product of the pyrolysis process is pyrolysis gas which can be used as an energy source to substitute fossil fuels. Pyrolysis gas cannot be readily used in the natural gas grids. Therefore Skyclean's prefered option involves supplying it back to the upgrading plant of the biogas facility to power its

[1]Industrial symbiosis involves the maximising of resources conservation through the exchange of by-products between industries,leading to emission reductions (Dou et al., 2021).

[2]Total climate effect means that it includes the CDR component, as well as avoided CO_2 emission from fossil fuel and avoided CH_4 emissions by limiting the emissions from untreated slurry (Stiesdal, 2023)

amine scrubbers [3] (Interview, Lindholst). The final step is to amend the biochar into the soil. Once this happens, Skyclean will be able to sell carbon credits on the VCM (Interview, Lindholst).

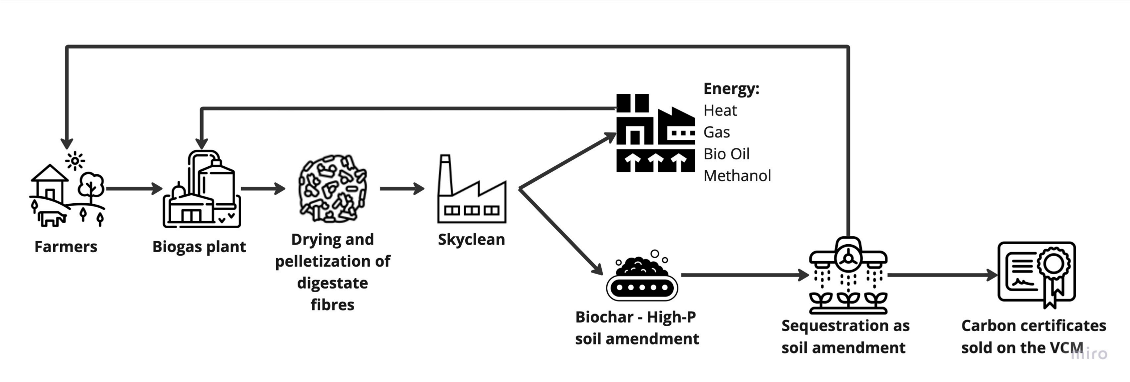

Figure 6.1. A flow diagram adapted from Stiesdal A/S 2023, showing the process flow of the Skyclean pyrolysis plant to be built in Vraa. , Northern Denmark (Interview, Lindholst)

Both the CDR product and green fuel co-product are essential to the long-term commercial viability and scalability of Skyclean's technology. Skyclean's biochar price is close to zero because the energy track delivers half their turnover. This energy co-product from pyrolysis will therefore act as a significant enabling condition for the scaling of biochar production before 2030, adding an additional revenue stream to sustain biochar production. The other half of the product value comes from the carbon market, however, Lindholst emphasises that the CDR component is not sufficient to make a viable business case alone (Interview, Lindholst). The consensus amongst Skyclean (Interview, Lindholst), the carbon market methodologies (EBC, 2020; Puro Earth, 2022) and the EU Commission (European Commission, 2020b) is that biochar must be used in the way that ensures the greatest permanence, and therefore the carbon in biochar is not considered permanently stored until it has been amended to the soil. The main constraining conditions of this value chain will then be the challenges of biochar diffusion, such that it can be amended to soil on a large scale.

6.2.1 How biochar maximises the use of Denmark's bioresources

As part of the pyrolysis strategy, the government has also launched a National Bioeconomy Panel to assess the emission reduction potential of Denmark's bio-resources:

> *Carbon from bioresources will play a major role in the green transition. Overall, the panel's message is that bioresources hold great opportunities for both agriculture and industry, climate, biodiversity and the environment, but bioresources are scarce and future demand is expected to be very high.*
> (The National Bioeconomy Panel, 2022)

[3]Amine scrubbing is a process that upgrades biogas to create a natural gas substitute (Capra et al., 2018)

The panel has identified an opportunity in the pyrolysis of a biogas digestate fibres as a means to maximise the efficiency of Denmark's carbon budget (The National Bioeconomy Panel, 2022), a process that will be put into action by Skyclean.

Through current farming practices in Denmark, Phosphorous (P) and carbon are not used efficiently, being either discarded or returned to the atmosphere. The soils in the Jutland region of Denmark have a surplus of phosphorous (P) due to the intensive livestock industry and the import of soy feed which has a high P content, and this creates a eutrophication problem. This phosphorous is retained in the biomass that is fed to the biogas plant (Interview, Thomsen). Today, biogas digestate, rather than being pyrolysed, is currently re-distributed to farmers and applied directly to fields as a slurry fertiliser and source of organic carbon. A Danish law known as the phosphorous ceiling stipulates a maximum amount of P that can be added to soils, and due to the locally already high P content of the soil, the P is removed from the slurry and discarded, before farmers can use it on their fields (Interview, Thomsen; Interview, Jørgensen). The carbon eventually breaks-down and is released back into the atmosphere, while the slurry also continues to release Methane (CH_4) (Interview, Lindholst).

Pyrolysis stores carbon (see sections 1.3.1 and 1.7) and also halts the release of CH4 from the digestate feedstock (Interview, Lindholst), however it also removes the nitrogen (N) from the original biomass feedstock, and releases it back into the atmosphere as natural atmospheric N_2. Therefore, to maximise nutrient recycling, Green Transition Denmark (RGO) have recommended a 3-step process. The first step is anaerobic digestion of biomass in a biogas plant. Second, the separation and preservation of the liquid fraction which contains the N. Third, the pyrolysis of the separated fibre fraction to preserve the P. The N-rich liquid fraction can be sprayed directly onto fields, while the P is preserved in the biochar (Interview, Jørgensen).

Pyrolysis of the digestate fibres therefore preserves and upgrades this valuable P resource. Biochar has been shown to improve the bio-availability of phosphorous to plants (Interview, Jørgensen), while increasing the mobility of phosphorous through the separation and pyrolysis of the digestate fibres, so that it can be transported and used in nutrient-deficient areas (Interview, Thomsen). Residual bioresources from agriculture can therefore be preserved and returned to sector, while also creating the potential to produce a phosphorous fertiliser soil amendment product, which could itself in the future incentivise biochar production. Skyclean's biochar is high in phosphorous, which provides the potential for Skyclean to develop a more high-value product. It is Skyclean's intention to eventually re-distribute the high-phosphorous biochar to the East of Denmark where the agricultural soils are more nutrient deficient (Interview, Thomsen; Interview, Lindholst).

From a socio-technical perspective, Biochar's ability to preserve P enables food to be produced more efficiently, and RGO see that with this sustainable 3-step biochar system, biochar technology can help address the country's needs as dictated by current food consumption and population growth trends (Interview, Jørgensen). With a political focus on reduction of emissions in the agricultural industry, the Danish government will need to de-couple GHG emissions from food production in order to continue to meet society's needs, and biochar will therefore contribute to this goal.

As previously noted, the main constraining conditions of Skyclean's value chain will then be the challenges facing the application of biochar to agricultural soil, and the local conditions in Denmark potentially constrain the ability to use biochar as a P fertiliser and source of organic carbon in Denmark. Olesen acknowledges that field testing is required to provide certainty about the impact of biochar on Danish soils, both on a crop yield basis and an environmental impact basis. However, it is his belief that the Danish soil, even in East Denmark, is too good to incentivise farmers to use biochar, and moreover, through biochar's field-testing phase, the soils may be too good be able to monitor its effect on crop yield. Olesen therefore believes that Danish farmers will be unlikely to use biochar as a fertiliser, and demand for biochar for this purpose will most likely come from other parts of the world with poorer soils. This opinion was expressed in the SOTA in section 5.5, and also by Frandsen, who stated that the willingness to buy biochar based on its co-benefits will be low (Interview, Frandsen).

Lastly, there is currently no market for biochar as a fertiliser in Denmark (Interview, Thomsen, Interview, Nørring), and Skyclean does not yet have a fertiliser product. Furthermore, Skyclean is not currently focused on developing a fertiliser product, as they are more focused on the CDR aspect of biochar as a potential incentive for farmers to adopt it (Interview, Lindholst). The potential for scaling biochar in the Danish context in order to meet the 2MT target is highly dependent on farmer's ability to adopt it in their farming practices, and Skyclean are conducting field testing as the essential next step for technological diffusion.

Figure 6.2. Pellets from Skyclean, Skive, Northern Denmark. Clockwise from top left - Straw pellets, biogas fibre residue pellets, biogas fibre biochar, straw biochar

Danish regulatory constraints for field testing of biochar

A key constraining factor for both an EU and Danish policy to incentivise biochar adoption identified in sections 1.7 and 1.8, is the uncertainty around its negative environmental impact on agricultural soils such as on soil fauna, for which it requires large-scale field tests. The standard in Denmark is for field testing of agricultural products to be conducted for three years, and therefore Olesen believes that a fertiliser product could potentially be licensed in Denmark after 2025 (Interview, Olesen). In the 2030 timeline, a fertiliser product could therefore technically incentivise scaling of biochar for the 2030 target.

Current Danish legislation requires an application for environmental exemption before any biochar can be applied to agricultural soil (Interview, Lindholst, Frandsen, Interview). Skyclean has applied for and been granted five environmental exemptions so far, and this has allowed them to begin field testing (Interview, Lindholst), starting in 2022 and continuing in 2023 (shown in figure 6.3). Testing consists of how to handle biochar, as well as its impact on crops, soil pH levels and nutrient levels (Interview, Olesen).

Figure 6.3. Photograph taken by Olesen during the spreading of biochar on fields in Northern Jutland, Denmark for field testing of Skyclean's biochar, 2022 (Interview, Olesen)

For larger-scale testing to happen, the biochar industry needs legislation to provide general approval from the Danish environmental authorities to freely use biochar in the soil, if it can be demonstrated that it is safe and sustainable. Through the demonstration plant in Skive, Skyclean has shown that their biochar is below critical EU limits of key toxic compounds - tar content and PAHs [4], and this has allowed them to gain the European Biochar Certificate (Interview, Lindholst), which *"guarantees sustainable biochar production, processing and sale"*(EBC, 2020). Both Lindholst and Frandsen believe that EBC certification fulfils the Danish requirements, however, national-level legislation is still needed (Interview, Lindholst, Frandsen, Interview).

[4]PAHs (polycyclic aromatic hydrocarbon) (Buss et al., 2022) and tar (Bolan et al., 2022) are potentially toxic organic compounds that can form on biochar from problems in the pyrolysis process including faulty temperature control (Bolan et al., 2022; Buss et al., 2022) which could have negative environmental effects in the soil (Interview, Jørgensen)

Skyclean is working with various ministries to overcome these legislative constraints. The development of the Danish biochar system requires the intersection of the work of four different ministries: The Danish Ministry for Climate, Energy and Utilities (responsible for GHG accounting)
The Ministry for the Environment (responsible for legislating the application of biochar to soil)
The Ministry for Agriculture (responsible for the end-use of the biochar)
and The Ministry of Taxation (responsible for the Green tax).
The fact that the biochar system touches upon so many branches of Danish government could be seen as a constraining condition. However Lindholst believes that Skyclean is receiving positive treatment and political support from ministers, and have engaged in constructive dialogue (Interview, Lindholst).

EU Regulations affecting biochar's use as a fertiliser

At EU-level, there exist both regulatory enabling and constraining conditions affecting the use of biochar in agricultural soils.

Biochar has been cleared in EU regulation to be used as a fertiliser for food production (Huygens et al., 2021), and similarly in organic food production (European Commission, 2021c), which shows clear EU policy support for biochar. The fertiliser regulation states:

> *(The Commission's Joint Research Centre's) assessment report furthermore concludes that there is an existing and growing market demand for pyrolysis and gasification materials, and that those materials are likely to be used to provide nutrient inputs to European agriculture. It further concludes that the use of pyrolysis and gasification materials produced following the recovery rules suggested in the assessment report does not lead to overall adverse environmental or human health impacts.* (Huygens et al., 2021)

However, before a fertiliser market in EU can be developed using biogas residue-derived biochar, the EU fertiliser directive will need to be amended. The regulation explicitly excludes biochar made from feedstock of animal origin (Huygens et al., 2021), and this therefore excludes biochar from biogas digestate, as well as from sewage sludge. The publication by The Danish National Bioeconomy Panel is at odds with the EU ruling, stating not only that the biogass/pyrolysis symbiosis should be pursued, but that biochar is important for organic food production: *"The biogas sector's recirculation of nutrients and carbon is at the same time crucial for the future fertility of the production areas, which is a particularly important prerequisite for the development of organic agricultural production"* (The National Bioeconomy Panel, 2022)

It has been shown in multiple studies that the pyrolysis process eliminates all pathogens and toxins, and following lobbying from the European Biochar Industry (EBI) (Bier, 2023), it is expected that this regulation will be soon updated to allow a certain percentage of animal feedstock for pyrolysis for fertiliser production. The new legislation has be prepared and waiting to be finalised and implemented (Interview, Thomsen; Interview, Lindholst). There is no certainty of the timeline for this legislation, and in its current form, the directive restricts the biochar industry's potential to help process and recirculate Denmark's livestock-derived bioresources.

6.2.2 The potential for technological lock-in

With the political emphasis on reducing emissions in agriculture and managing livestock residues, the current lack of public policy incentives and the lack of market for a biochar product beyond CDR, symbiosis with biogas is seen as the only viable business case for larger-scale pyrolysis and biochar. The incentive structure is effectively limiting pyrolysis to being a biogas digestate add-on (Interview, Thomsen). According to Thomsen, speaking of the stakeholders of the Danish biochar system; *"They all see pyrolysis primarily as a way to treat digestate and residues from Biogas plants. That's kind of the role that it has been given"* (Interview, Thomsen). This increases the risk of technological lock-in in the biochar system, a risk also identified by the DCCC (See section 5.8). The DCCC identify that it could lead to business as usual in the livestock industry, and Thomsen argues that the potential for biochar to treat other organic wastes may not be fully realised; *"here we have a platform that can convert many different things to many different products. I think it's too early to rule that out for just treating digestate or soil amendment."* (Interview, Thomsen).

Denmark stands out amongst Nordic countries in terms of biochar implementation. In countries such as Finland and Sweden which have a still small-scale, but more developed biochar market, biochar production is incentivised by the need to manage forestry residues (Interview, Thomsen; Interview, Esko). In Sweden and Finland, there is more engagement in the biochar system from municipalities, with Stockholm and Helsinki municipalities developing urban soil carbon sinks with biochar, and using the energy co-product for district heating (Interview, Esko).

A technological lock-in in Denmark makes the scalability of biochar dependent upon the livestock industry. If livestock numbers are drastically reduced, this will limit the availability of feedstock for pyrolysis (Christian Ege, 2022); (Interview, Jørgensen). The negative implications being that potentially less sustainable feedstocks would potentially need to be sourced. In an example from the more established biogas industry, energy crops - especially maize - are still grown as feedstock for biogas plants. German biogas plants run on maize, and Danish farmers produce maize for these plants. Jørgensen sees a parallel in this system with the 3rd generation biofuels such as rape-seed oils used in cars, which have been outlawed due to competition with food crops (Interview, Jørgensen). In 2013, EU legislation was implemented to gradually limit the proportion of energy crops used, first to 25%, then 12%, and in summer 2023 to 6%, and RGO is lobbying for the total faze-out (Interview, Jørgensen).

The scalability and sustainability of the biochar system will therefore be limited by the availability of sustainable feedstock. If the industry grows while dependent on a particular feedstock whose supply is locally in decline or too costly, a problem could arise of eventually needing to import feedstocks. Lower-cost and less sustainable agricultural industries in countries such as Poland could then substitute Denmark in growing energy crops or providing straw for biogas and pyrolysis. Ultimately, the biochar industry should remain flexible towards different feedstocks beyond biogas digestate (Interview, Thomsen;

Interview, Sørensen).

6.2.3 The potential of other feedstocks for biogas and pyrolysis

The potential problem of constrained feedstocks from livestock will affect both the pyrolysis and biogas industries, and there is a need to diversify feedstock for both technologies. Jørgensen indicates that manure could be increasingly supplemented by dry organic matter in biogas plants (Interview, Jørgensen). Meanwhile, diversifying energy generation away from incineration plants in Denmark could increase the availability of biomass for pyrolysis (Danish Ministry of Climate Energy and Utilities, 2020), in order to reduce its dependence on biogas plants.

Municipal organic waste

The new EU law requiring municipalities to separately collect household organic waste by the end of 2023 (Council of the EU, 2022) provides a new opportunity to diversify the biochar and biogas systems to reduce their dependence on constrained feedstocks (Interview, Jørgensen). RGO see an opportunity to mix solid organic household waste with other feedstocks to achieve the correct dry matter and wet matter ratio in the biogas plant that is necessary to maximise efficiency. The dry fraction would then be pyrolysed (Interview, Jørgensen). Pyrolysis can also treat organic household waste directly. This would potentially increase the interest in municipalities to partner with Skyclean and bring an extra source of funding to the biochar system.

Straw

Straw is identified as potential pyrolysis feedstock to avoid technological lock-in to the biogas industry, while it is currently also a valued component of the biogas feedstock when mixed with manure as it increases the gas yield (Ea Energianalyse a/s, 2020). The majority of Denmark's straw is currently either ploughed directly back into the fields to increase the organic carbon content of the soil, where the carbon is gradually released back into the atmosphere (Interview, Lindholst), or it is burned by municipalities for district heating. It is estimated that between 1MT and 1.3MT of straw are burned for energy each year (Ea Energianalyse a/s, 2020; Searchinger et al., 2021).

It is the intention of the Danish government to gradually reduce the amount of biomass burned for energy (Danish Ministry of Climate Energy and Utilities, 2020), and it is assumed that it will be replaced with renewable energy and heat pumps for district heating (Interview, Lindholst) (Ea Energianalyse a/s, 2020; Searchinger et al., 2021). This therefore, in theory, frees up 1.3MT of biomass for pyrolysis. Skyclean's ratio of biomass feedstock to CO_2 eq sequestration means that the 2MT government target will require approximately 3MT of biomass, and 1.3MT of straw could therefore contribute at almost half of the government's 2MT target.

The business case for Skyclean to use a straw feedstock is dependent upon the economics: The cost of straw, the prices that can be realised for the bio-energy they produce, the price of any future fertiliser product, and the carbon price on the VCM. On top of the 1MT of straw being burned for district heating, 1MT to 2MT of straw is ploughed back into fields each year and it has high value to farmers (Interview, Thomsen). Farmers have established routines around ploughing organic crop residues back into the fields. They firmly believe in the benefit it brings to the soil in terms of adding organic carbon and nutrients (Interview, Mott; Interview, Thomsen). For this reason, straw is considered an expensive feedstock compared to the biogas digestate which is effectively free (Interview, Lindholst). According to Thomsen the biggest constraint to the availability of straw is the need to change established farming practices to accommodate the biochar system. Another challenge which adds to the cost of straw, is the work required to make it available for something other than being ploughed back into the soil. It requires drying in the field, collecting, storing and transporting, and these activities add-up to a relatively high price (Interview, Thomsen). The need for changing farmer practices is further analysed in section 6.5.1.

6.2.4 Enabling biochar's political support through production of green fuel

Another unintended effect of biochar's technological lock-in with the biogas industry is that it could constrain the potential to develop green fuels from the pyrolysis gas. As previously noted in this chapter, the preferred business model for Skyclean is that the energy co-product is supplied back to the biogas plant instead of being used for green fuels. Meanwhile, the Danish government's intention is to use pyrolysis to develop green fuels for aviation as stated in the government's climate strategies, published in the 2020 LT-LEDS (Danish Ministry of Climate Energy and Utilities, 2020) as well as in 'The Climate Partnership for the Food and Agriculture Sector' document (Danish Government Climate Partnerships, 2019).

In acknowledgement of the potential to develop pyrolysis gas into a higher-value energy product, Skyclean has a long-term plan for the upgrading of pyrolysis gas into both maritime fuel and aviation fuel, as part of a technology development roadmap[5]. Skyclean is less focussed on developing this energy track in the short-term. Lindholst emphasises that due to the strict safety regulations in the aviation industry, and competition with fossil fuels due to the un-rivalled energy density of hydrocarbons, aviation fuel is a difficult fuel to replace, particularly before 2030. The potential for this energy upgrading track to contribution to the 2030 targets is therefore limited. Although green aviation fuels may not be produced before 2030, the potential of upgrading of pyrolysis gas has still been an important incentive for the government to make the approximately 400 million DKK of funding available to Skyclean.

6.3 The role of the VCM the Danish biochar system

The SOTA analysis has shown that EU regulations do not currently incentivise supply and demand of biochar, and incentives are regarded as insufficient within Danish regulation

[5]To produce maritime fuel, pyrolysis gas can be cooled down and condensed into an oxygen-rich bio oil to be used in the marine shipping sector. Skyclean expect a strong demand from this sector for green fuels, and also a large capacity to pay for this energy. For the production of aviation fuel, Skyclean can supply methanol to refineries. To produce methanol, the pyrolysis gas, which consists of short chain and long chain hydrocarbons, can be cracked into synthesis gases consisting of is CO_2, CO and H. Methanol is produced from these elements with an input of renewable energy (Interview, Lindholst)

(Interview, Thomsen; Interview, Lindholst). This has created a situation where Skyclean are relying on the VCM during its scale-up phase. The credits can be sold internationally while the mitigation outcome can count towards the reduction of Danish agricultural emissions, and eventually the EU NDC. Lindholst states that the Vraa project will increase global biochar production by 10%, therefore it can be said that biochar currently contributes close to 0% to climate mitigation (Interview, Lindholst). Biochar is therefore a nascent industry, and Skyclean is expected to have a large impact on the global biochar carbon credit market.

The VCM therefore presents an enabling condition for the biochar system. As mentioned in the section 5.6, companies are increasingly willing to pay higher prices for higher quality credits and this will be an important source of funding. Skyclean will rely on achieving a long-term carbon price of approximately 100 Euros per ton, while the current price for NBS offset credits (N-GEO futures contracts) on the VCM is approximately US $2 (carboncredits.com, 2023), and the current price for carbon removal credits (CORCs) on the CORC index is 126.15 Euros (Puro Earth, 2023). Expert1 believes that the price premium of CORCs represents a belief of companies purchasing credits, in the role of CDR on the IPCC's net-zero strategy, and the belief that mitigation outcomes of low permanence credits do not rank equally with those of high permanence credits (Interview, Expert1).

Neverthless, The VCM also has some constraints when compared to potential alternative sources of funding such as the ETS and public subsidies. For Skyclean, the VCM represents a high-risk funding mechanism due to long-term carbon price uncertainty. Skyclean will need to secure long-term biochar off-take contracts and long-term carbon credit sales contracts in order to make final investment decisions on building plants, and to lower the overall business risk. They will look at selling credits to brokers and also selling direct to large companies like microsoft, depending on where they can achieve the contract with the highest volume and the best price (Interview, Lindholst). The limitations of the VCM are that, as also noted in the SOTA, some companies are beginning to set net-zero targets that don't involve offsetting due to the loss of credibility of the VCM, and this would reduce Skyclean's potential to scale via the VCM. This risk is also shared by the Danish government. By Skyclean relying on the VCM, it means that the Danish gov is also relying on the VCM to achieve the 2MT target, and this presents a risk for the government to reduce emissions in the agricultural sector. Support for biochar from EU legisltation, such as via the implementation of the EU CRC, will help Skyclean secure long-term contracts (Interview, Lindholst).

6.3.1 The role of the EU CRC

While there are many uncertainties around how the EU CRC will be implemented, the SOTA showed that it is expected to increase the credibility of the VCM. The core problem of the VCM has been that it assumes fungibility between reduction and removal credits - i.e. the mitigation outcome of 1 tonne of avoidance or reduction credit is equal to that of 1 tonne of removal credit. So companies buying credits can make the same carbon neutrality claims by buying reduction credits, as if they bought removal credits. Furthermore, the VCM ranks the mitigation outcome of all removal credits equally, and so lower permanence

CDR credits (e.g. NBS) rank equally with higher permanence CDR credits (e.g. biochar). This means that companies can purchase lower-quality removals credits which don't achieve the desired mitigation outcome.

The EU CRC will seek to make clear the lack of fungibility between reduction & removals credits, and also make removals credits generated across different sectors fungible so that credit buyers have the assurance that the credits they buy all achieve a similar level of climate mitigation. It will achieve this by standardising methodologies across the EU, while also raising the quality certification and MRV methodologies, and once implemented, should raise the credibility of biochar carbon credits. Demand for biochar credits would be expected to increase as a result, because credit buyers will have greater assurance that the credits will deliver the desired mitigation outcome.

Some risks from soil carbon removal for the carbon market remain however. In section 5.6, it was suggested that soil carbon removal is not suitable for offsetting due to a lack of certainty of additionality and risk of reversal. Expert1 acknowledges that the long term monitoring of biochar in the soil after the credits have been sold (ex-post monitoring) needs to be developed, to ensure that the carbon stored is not reversed. This is seen as a barrier to the adoption of biochar as a carbon farming method, and EU CRC criteria will also need to incorporate long term monitoring (Expert1, Interview).

6.3.2 The EU CRC implementation timeline

According to Expert1, the EU CRC has a very long implementation timeline, and this conflicts with the need to scale-up CDR by 2030. Its implementation has been pushed back due to the development of a lot of secondary legislation to map out its governance. The EU has chosen to develop its own methodologies rather than borrow from existing removals methodologies, and this has added to the delays. As previously mentioned, it is expected that the implementation of the CRC will lead to the standardisation of methodologies in the EU, meaning that existing certification organisations in the EU will be required to adopt the CRC methodologies. A primary agreement within the commission on the methodology and governance is expected to happen in 2023, with a political agreement made in Q1 2024, and it is hoped that the methodologies will be operational by end of 2025 or start of 2026. A use case has not been officially defined for the EU CRC, and it is not an automatic entry for CDR into any of the current EU regulatory pillars. However, as also noted in section 5.5, the ultimate goal for the ETS is to be net zero and eventually negative. It is therefore expected that the EU CRC will deliver the trust and transparency necessary to aid the wider inclusion of CDR in the ETS after 2026 to achieve net-zero (Interview, Expert1). The EU CRC is also expected to allow for increased CDR (including potential CDR market) inside the LULUCF, and EU-level policy backing of CDR will increase the level of funding available to CDR projects such as through CAP payments. The CRC not being implemented until 2026 delays the EU support of biochar, but also delays the EU support of the VCM, thereby creating a higher-risk policy environment for the government and Danish biochar producers such as Skyclean to scale-up by 2030.

6.4 The conceptualisation of biochar as carbon farming Vs an industrial CDR technology

The conceptualisation of biochar in EU policy will have a significant impact on the funding mechanisms available to the Danish biochar system. As previously noted in this report, biochar sits in a difficult position for policy design. It requires industrial engineering for at-scale production, while it must be amended into agricultural soil, or stored as a product, to achieve its CDR potential (See section 1.7).

Biochar's difficulty in categorisation will be a constraining factor for scaling. As the EU Commission notes in the accompanying impact assessment (IA) for the EU CRC proposal:

> *Some carbon removal solutions belong to different categories depending on the context of their deployment. This is the case for biochar that can be used as a soil amendment contributing to the enhancement of soil properties (carbon farming), as a construction material with the partial replacement of GHG intensive material (carbon storage in products) or can be stored in suitable geological formations (permanent storage).* (European Commission, 2022a)

The IA indicates that due to differences in end-uses of the biochar, and differences in permanence and risk of reversibility for each category, different methodologies will have to be developed for biochar depending on its end-use. The IA further notes that due to the difficulties in making assurances on permanence and risk of reversal, the development of methodologies for carbon farming could be delayed (European Commission, 2022a). Expert1 acknowledges that the CRC will likely initially operationalise only CCS methodologies as CCS already has EU legislative support through the CCS Directive (Expert1, Interview).

The SOTA showed that if conceptualised as an industrial CDR technology it could be included in the ETS (see section 5.5), while if conceptualised as carbon farming it would be regulated in the LULUCF (see section 5.4). Although it is not yet regulated in EU policy, biochar is frequently referenced in relation to carbon farming and LULUCF regulation in EU policy documents and policy briefs (COWI et al., 2020; Elkerbout & Bryhn, 2022; European Commission, 2022a; Margaras et al., 2022) and the Danish government also currently regards biochar as a carbon farming CDR method (interview, Sørensen). Reflecting this current consensus of biochar as a carbon farming methodology, VCM methodologies currently also regulate biochar as a carbon farming and therefore an NBS.

From Lindholst's perspective, regulating biochar as carbon farming is a mistake, and will constrain the potential to scale biochar production: *"If it's considered a carbon farming practice, there is a risk that the associated value of the credit is so low that the business case doesn't fly"* (Interview, Lindholst). NBS carbon prices are lower due to their higher risks, and therefore pyrolysis development will be more expensive and this will delay scale-up. This could mean that the Danish government will no longer be able to depend on biochar to meet reduction targets. Furthermore, institutional investors in the carbon market may be less willing to invest in lower permanence carbon credits due to risks of greenwashing, particularly since the loss of credibility of the VCM, and in particular, the recent negative press concerning Verra NBS crediting (see (Lawson & Greenfield, 2023)) (Interview, Lindholst). As Lindholst emphasises; *"it can be very harmful ending up in the wrong category"(Interview, Lindholst).*

The SOTA showed that the inclusion of biochar in the ETS is the more uncertain pathway for EU regulation, however, Skyclean are lobbying for the European Commission to eventually include biochar in the ETS (Interview, Lindholst). It is a critical enabling factor for Skyclean's scaling, as it would reduce the business risk overall by opening up the biochar carbon market to institutional investors, while also providing lower price volatility (Interview, Lindholst). To achieve entry into the ETS, Skyclean is campaigning for equivalence with CCS, and this idea has also been championed by authors in the SOTA, section 5.5).

The biggest challenge to entering the ETS and achieving equivalence with CCS is that the MRV requirements are much higher compared to the VCM, and as previously discussed, the unique characteristics of biochar make the MRV frameworks more complicated than for CCS. One example is Ex-post monitoring. The EU CCS directive makes provisions for ex-post monitoring while it will be more difficult to achieve the same for biochar (Interview, Expert1). For biochar, it will require the development of new IT systems that track all biochar system inputs and outputs including sequestration tracking for where the biochar is spread together with pyrolysis feedstock inputs, and details of the carbon market transactions (Interview, Lindholst). The registry would be used to protect the sequestration against human-induced CO_2 reversal to achieve a guaranteed permanence of a minimum number of years, thereby achieving similar levels of assurance of permanence as for CCS. Lindholst adds that Denmark already maintains records on many aspects of land management, so it would not be a significant additional burden to achieve this kind of national-level registry for biochar (Personal communication, Lindholst).

Lindholst highlights another significant MRV complication unique to biochar, being that it is technically a fuel, and if the biochar were burned after carbon credits were sold, this would amount to fraud. Through engagement with the farming community, Skyclean has learned that some farmers already consider biochar a potential fuel to heat their homes (Interview, Lindholst). Biochar MRV frameworks would have to prove that the biochar has been amended to the soil rather than burned (Interview, Lindholst), and when trying to achieve equivalence with CCS, MRV safeguards against fraud will be important to preserve the integrity and therefore carbon price of the ETS (Interview, Expert1).

By achieving equivalence with CCS, Skyclean hopes that it will also make more Danish national subsidies available to scale biochar production. Lindholst argues that if they can ensure and document the permanent storage of CO_2 in the form of biochar, they should receive the same government subsidies as CCS. 14 billion DKK have been put aside to support CCS, while a fraction of this has been put aside to support biochar (Interview, Lindholst). Lindholst states; *"What we do has the same effect (...) If we achieve the same thing we should receive the same benefit"*(Interview, Lindholst). The Danish government is currently aware of the campaign for equivalence, and it has recently been discussed in parliament:

> *The government wants methodologies to be developed under the certification framework certification of pyrolysis and biochar plowing on an equal footing with other carbon removal activities. It appears from the memorandum that has been sent to the Folketing that (it) is easier to certify technological uptake than carbon farming. The intention here is a desire that the development of methodologies for technological uptake be given high priority, but this should not be understood as a downgrading of pyrolysis and biochar.* (Lars Aagaard, 2023)

This quote enforces the idea that biochar is regarded by the Danish government as an NBS, and that CCS will be prioritised in CDR policy, however the Danish government will still promote biochar methodologies to bring it to equivalence with CCS.

6.4.1 Implications for the agricultural industry of biochar's inclusion the ETS

Nørring argues that if the agricultural industry provide the biomass feedstock to the pyrolysis process, and the biochar returned to agricultural soils, they should receive the benefits of the emission reduction (Interview, Nørring). Where biochar is placed in EU policy will have implications for whether the agricultural industry will ultimately receive the credit for the carbon removal so that it contributes to agricultural emission reductions. This is critical because as previously noted, biochar's co-benefits will offer limited incentive, and so biochar's technological diffusion relies on policy. However, as Thomsen notes;

> *I think the biggest barrier for pyrolysis is that there is not really an incentive structure in place for end users of the biochar, especially within agriculture and especially within Denmark.* (Interview, Thomsen)

Skyclean is depending upon the CDR potential to incentivise its adoption, and if farmers are not rewarded for the CDR, there will be little incentive for them to adopt it.

If regulated under the ETS, the emission reductions achieved by biochar production would be accounted-for within the ETS, and the effective emission reduction would not be attributed to the agricultural industry. This therefore creates a conflict with the dominant Danish political agenda to reduce agricultural emissions, and the biochar industry could lose political support. In this case, Nørring states that the emission reduction targets for agriculture will have to be reduced by the 2MT CO_2 eq that is allocated to biochar (Interview, Nørring). The farmers would also not be able to sell credits on the VCM for the production of biochar as this would be double-counting. Skyclean would therefore rely on the green tax to incentivise the adoption of biochar by farmers. It is hoped that farmers will be rewarded for spreading biochar on their fields by receiving a tax deduction that corresponds to the tonnes of biochar used, the carbon sequestered by Skyclean's pyrolysis process, and the price of carbon designated by the policy (Interview, Lindholst), which is expected to be approximately 750 DKK / ton (Jette et al., 2023). Lindholst states that because the green tax and UNFCCC carbon accounting are separate systems, it will be possible to both sell carbon credits, either in the ETS or the VCM, and achieve tax deductions via the green tax without double-counting (Personal communication, Lindholst).

For Skyclean to rely on the green tax brings more uncertainties for their scaling strategy. As identified in section 5.8, the DCCC concludes that the 750 DKK carbon price will be insufficient to deliver the national 70% reduction target, and has calculated that a price of 1,500 DKK will be required in 2030 to meet the targets (Danish Council on Climate Change, 2020), and this will have negative implications for public acceptance of the tax. Stakeholders of the biochar system strongly oppose the tax, believing that it will cause many farms to close down (Interview, Nørring; Interview, Frandsen; Interview, Mott), and the Food and Agriculture Organisation of Denmark (Landbrug & Fødewarer) are actively lobbying against the tax (Interview, Nørring). So while a higher carbon tax would also translate to a greater tax-related subsidy per ton of biochar used, public opposition could lead to a more conservative and insufficient carbon price being assigned. Relying on the green tax for biochar's scaling could therefore itself be a constraint for a successful diffusion of the technology.

6.4.2 Implications for the agricultural industry of biochar's inclusion the LULUCF

As noted in the SOTA, the regulation under the LULUCF is the most likely scenario, and any possible regulation under the ETS should not be expected before 2040. Once the EU regulates biochar, for biochar to contribute to agriculture's reduction targets, emission reductions from biochar will have to be accounted for under LULUCF. The implications of this, are that Skyclean will still rely on the VCM for scaling[6], while the government will also be relying on the VCM to meet the 2MT target. For farmers to be incentivised to use biochar, they will either be able to sell carbon credits themselves, or be incentivised by the Danish government through public subsidies and green tax, or a combination of these. As stated in section 5.4, by being regulated under the LULUCF, farmers could also have access to direct CAP payments or subsidies, which could serve to specifically incentivise their use of biochar.

For farmers to generate carbon credits themselves, the expense of developing a pyrolysis

[6] When CDR projects sell carbon credits internationally to private organisations for the buyer's marketing purposes, the emissions reduction will be accounted for in the host country national registry, and it will not lead to double-counting (Gehrig-Fasel et al., 2021). Therefore the carbon credit will still contribute to the Danish national targets, as noted in the SOTA, and by Lindholst (Personal communication, Lindholst)

plant will be a constraint, and one solution will be to partner with Skyclean. Skyclean's viable business case lies in building and selling pyrolysis plants, rather than owning and operating the plants. For their long-term business model, they prefer partnering with public or private entities through part-ownership in the plants, to show belief in and commitment to the technology. Lindholst states that due to the synergies with the biogas plants, the most likely pathway to scaling will be partnering with the biogas industry, where they become both biochar and energy producers (Interview, Lindholst).

EU regulations:	**ETS**	**LULUCF**
Conceptualisation as a CDR	**Industrial CDR:** biochar depends on an industrial process to be produced	**Carbon farming**: biochar has to be applied in the soil to achieve necessary CDR permanence
Who get the credit?	The ETS sectors	The agricultural sector
Enabling factors	• Lower business risk • Lower price volatility • Long-term carbon contracts • Institutional investors • Potential partnerships between pyrolysis developers and agricultural sector to incentivise biochar demand	• Credit goes to the agricultural sector = political support • EU CAP and Danish public incentives • Potential partnerships between pyrolysis developers and agricultural sector to incentivise biochar demand
Constrain factors	• Difficulty achieving CCS equivalence, • Difficulties incentivising demand, • Credit doesn't go to the agricultural sector = Loss of political support • Re-allocation of the 2MT target	• Uncertainty of the business case due to risk of reversal. • Uncertain carbon price on the VCM. • Higher-cost scale up. • Government must subsidise both supply and demand

Figure 6.4. The table shows the implication that biochar has when regulated under each EU regulation

Partnerships to ensure removals count towards the agricultural sector's targets

Arla currently own and operate biogas plants (Interview, Frandsen), and this could, in the future, be the case for pyrolysis as well. By entering into a partnership with Skyclean, the agricultural sector would share the benefits of the sale of carbon credits on the ETS or the VCM, and the energy co-product.

Arla is committed to a science-based target of 30% reduction by 2030 compared to 2015, at scope 3 level, (i.e. farm level), and they see that biochar can contribute to this target. Frandsen states that 80% of the carbon footprint of their milk comes from the farm level, so they are developing and implementing farm-level measures to achieve reduction targets. Carbon removal is necessary for Arla's net-zero targets, and biochar is a potential tool that can contribute to the 30% reduction. Arla is therefore trying to support the overall spread of biochar in their business model thereby enabling the diffusion of biochar through the development of the pyrolysis technology, the business development around pyrolysis, and application of biochar. Frandsen states that they need more data about the effect of biochar in the fields and the benefit of applying biochar to the soil before they can incorporate biochar into their incentive model (Interview, Frandsen). Some of their farmers are taking part in the Skyclean field trial this year, using biochar made from biogas digestate in Skive, and applying it to fields of mace cattle-feed crops (Interview, Frandsen).

To achieve science-based scope 3 reductions, Arla could implement biochar as an insetting project[7], and Arla's incentive model provides a platform for this.

Arla's incentive model

Arla's incentive model allocates points to farmers who improve environmental sustainability. Farmers who implement emission reduction measures, for example, receive a slightly higher price for their milk, and the worst-performing farmers receive a lower price. Funds are therefore re-allocated from poorly performing farms to well-performing farms, rather than passing the cost on to the consumer. Currently, there is no incentive for Arla farmers to apply biochar, however, Frandsen expects biochar to be incorporated within Arla's incentives model within the next 2 to 3 years. Farmers would report how much biochar they applied, and an emission factor would be applied to represent that in tonnes CO_2 sequestered (Interview, Frandsen). The EU CRC is expected to support scope 3 initiatives such as Arla's incentive model. The EU Commission expect that it could help farmers quantify their mitigation impact and help companies like Arla credibly document the carbon footprint of their products (European Commission, 2022e).

Farmers are free to implement reduction measures such as manure treatment, feed efficiency, or carbon farming in their own way (Interview, Frandsen), and so increasing awareness and education on the benefits of biochar could be important in helping farmers decide which measures to implement. As Verde & Chiaramonte (2021) states, farmers would need dedicated training to maximise the potential benefits of biochar.

6.5 Public Acceptance

The successful incentivization of technology will not only require technology innovation and policy support but also requires an understanding of the functionality from the demand side (Geels, 2004). Diffusion is the process of allowing technology to be understood and correctly used by society. In other words, diffusion leads technologies to jump from just innovation to fulfilling society's needs (Geels, 2004). The diffusion of biochar in the Danish

[7]Insetting involves investing in mitigating activities with an organisation's own value chain, as opposed to offsetting, which involves investments outside of the value chain (Insettingplatform.com, 2023)

context involves bringing knowledge and awareness on what are the benefits of biochar to farmers. In section 4, the importance of building networks with farmers to build awareness of the technology was noted, and Farmers are already part of agricultural networks that can enable the diffusion of biochar (Otte & Vik, 2017). Raising awareness through community engagement is important for Skyclean, because for successful implementation of a biochar system in farming communities, neighbouring communities will also need to be involved in the planning stages and potentially have some financial stake in the plant to ensure whole community support (Interview, Lindholst).

6.5.1 The awareness of biochar within farming communities

Skyclean has visited at least 20 communities of farmers across Denmark in order to build awareness of biochar. Through these interactions, they have learned that farmers are motivated to use biochar as a CDR, because of the pressure to meet the emission targets and the impending green tax, and they are not currently receiving any financial help from the government to reduce emissions (Interview, Lindholst). Mott notes that there is some awareness of biochar in his community, and he understands that it is part of the future where binding emissions reductions will have to be achieved.

Interreg North Sea Carbon Farming Program survey report

In a recent report from the Interreg North Sea Carbon Farming Program, the need for awareness amongst farmers was emphasised:

> *Carbon sequestration in soils and protection of soil organic carbon (SOC) is seen as a promising approach to counteract (global warming) and to maintain soil fertility (Minasny et al. 2017). It is therefore important to increase the knowledge and activity amongst farmers*
> (Paulsen et al., 2022)

Two surveys were conducted, one in 2019 and one in 2021, as part of this project, across Norway, Belgium and the Netherlands. From the results, it is evident that there is a general awareness of carbon farming practices in these regions (Paulsen et al., 2022). Figure 6.5 below, shows which carbon farming practices the respondents use:

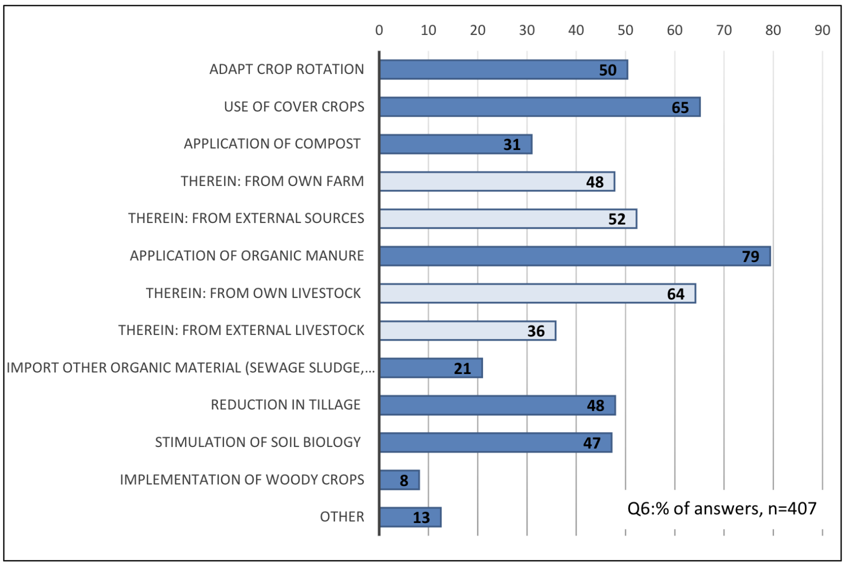

Figure 7: **Carbon Farming Survey 2019: Answers to question: Which techniques to increase the carbon level in your soils do you use? (percentage of answers, mutiple answers were possible)**

Figure 6.5. Interreg North Sea Carbon Farming Program survey - "Answers to question: Which techniques to increase the carbon level in your soils do you use? (percentage of answers, multiple answers were possible"(Paulsen et al., 2022)

Some respondents also showed that they associated biochar with carbon farming. Four respondents used biochar to increase carbon levels in their soil, four respondents used biochar to stimulate soil biology, and 13 respondents identified that they could be paid to store carbon using biochar (Paulsen et al., 2022).

Figure 6.6 shows why farmers used carbon farming practices. From an n-number of 321, 34% used carbon farming to store CO2, while 85% used it to improve soil structure, and 81% answered that it contributed to soil fertility (Paulsen et al., 2022).

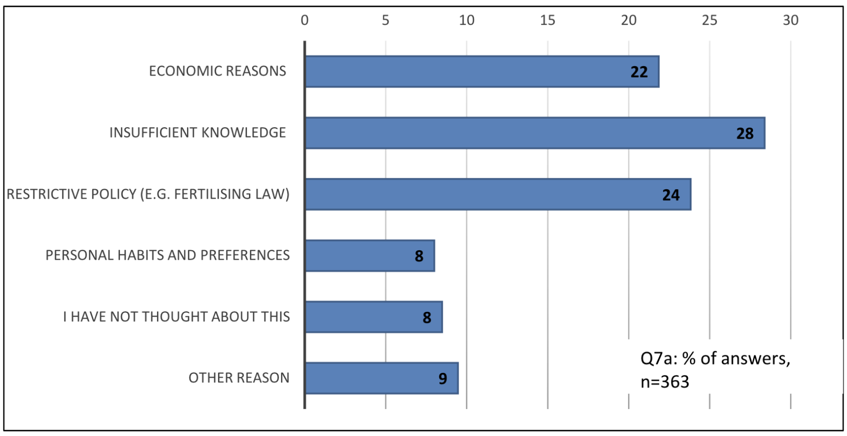

Figure 6.6. Interreg North Sea Carbon Farming Program survey - "Answers to questions on motivation for introduction of Carbon Farming measures: Have you considered to use techniques to increase or protect the carbon level in your soils? If yes, please indicate the reason below. (percentage of answers, multiple answers were possible)"(Paulsen et al., 2022)

The results show that (in the tested regions at least) farmers' appreciation of the benefits of carbon farming for their soils should not be underestimated. The report also identified that there is relatively low awareness of the potential to store, verify and be paid for soil carbon storage (Paulsen et al., 2022). Work should therefore be done to increase awareness in these communities in order to prepare them for early adoption of biochar. However, the Danish Agriculture and Food Organisation say that they have not yet begun engaging with farmers as part of their work to develop the Danish biochar system, and that they are waiting for the aforementioned legislative barriers to be removed before they do so (Interview, Nørring). Olesen also expresses that through his work, he has not begun spreading knowledge and awareness of biochar, largely because full-scale production of biochar has not started, and they are waiting to see the results of the testing. For scale-up by 2030, there is an urgent need to engage fully with communities to increase public acceptance for the diffusion of biochar technology.

Changing user practices

From a socio-technical perspective, the requirement of farmers to change their practices will be a constraint for the diffusion of biochar as a technology. Sarewitz & Nelson (2008) identifies that:

> *When knowledge is not largely embodied in an effective technology, but must instead be applied to practice through, say, training, institutional incentives, organisational structures or public policies, the difficulty of improving outcomes is greatly amplified.*

Biochar could be seen by stakeholders as a technology which does not have knowledge embodied within it, requiring additional training and awareness for its adoption. Olesen identified unexpected challenges with regards to the application of biochar during field tests. Biochar is a new material for-which no large-scale solutions (approximately 5t biochar per hectar) currently exist in Denmark for its application to soils. This is evidenced in figures 6.7 and 6.8, which show biochar being spread on fields as part of the field testing program, either by hand or from a tractor bucket. New methods will therefore have to be developed to efficiently apply biochar in the future (Interview, Olesen).

Figure 6.7. Photograph taken by Olesen during the spreading of biochar on fields in Northern Jutland, Denmark for field testing of Skyclean's biochar (Olesen, 2022)

Figure 6.8. Photograph taken by Olesen during the spreading of biochar on fields in Northern Jutland, Denmark for field testing of Skyclean's biochar (Olesen, 2022)

Moreover, in section 5.3, it was noted that the application of biochar could conflict with no-till practices. In Denmark, no-till farming practices are relatively common, however the extent to which this could be a constraint for biochar depends on individual farm practices. It would conflict with farms where the soil surface is not touched at all, however this is less common. It is thought that biochar could be sufficiently amended to the soil at a depth of 10cm by method of harrowing only[8] and so it could be used where farmers refrain from

[8]Harrowing rakes the surface of the soil to a depth of around 15cm, and is sufficient for biochar, because

ploughing (Interview, Olesen).

Finally, in places with soils depleted in phosphorous, biochar may also have to compete with the digestate slurry that is applied directly to the fields. Mott states that this is a popular way of fertilising because farmers believe that it is good for the soil, and it is extremely cost-effective (Interview, Mott). However, the separation of fibres from the slurry in preparation for pyrolysis may in-fact create a better product for farmers. Compared to separated liquid slurry, the nutrients in high-fibre slurry are less immediately available to crops, while it is also more difficult to distribute on the fields. Olesen therefore believes that the symbiosis with pyrolysis will help the digestate slurry from the Vraa biogas plant be more attractive to farmers (Interview, Olesen). In this case, pyrolysis may offer an incentive to farmers beyond CDR, and the need to change user practices may be less of a constraint.

Biochar therefore requires new ways of distributing the nutrients held within it to be developed, and where farmers currently use digestate slurry as a phosphorous fertiliser, the use of biochar instead will also require changes in practices. Moreover, as noted in section 6.2.3, the use of straw as a primary feedstock of pyrolysis may require farmers to no-longer amend the straw directly into their fields, requiring further changes in farming practice. Sarewitz & Nelson (2008) continues; *"Now the task involves moulding, coordinating and governing the activities of practitioners, who themselves must acquire judgement and skill that may not be easily translatable from one context to another."*, reflecting the challenges above.

Sarewitz & Nelson (2008) identifies a further constraint in the context of changing practices being the requirement of new policy instruments that are not *"directly related to the actual technology deployment"* (Sarewitz & Nelson, 2008). Sarewitz & Nelson (2008) concludes; *"Interpreting the results of management or policy innovations is difficult because of the many variables involved"*. In this case, biochar will be constrained by the influence of additional government policies such as those related to diverting straw away from incineration plants, or policies related to the export of energy crops.

6.6 Sub-conclusion

Emission reductions in agriculture are seen as a greater challenge than in other sectors because of intensive livestock farming. Biochar synergy with biogas has been found to provide a solution to reduce agricultural emissions, and maximise the use of bioresources, which is key in the Danish context to maintain political support. Moreover, the synergy allows pyrolysis to provide clean energy to biogas plants, which has been found to be a key enabling factor. However, potential lock-in with biogas plans could constrain biochar scale-up, as it exposes the system to being dependent upon a constrained feedstock while not being flexible to receive other feedstocks.

The VCM provides an enabling condition for scaling biochar in the absence of government incentives, while VCM methodologies require that biochar be amended to soil before

phosphorous molecules are immobile in the soil. Therefore for a plant to absorb phosphorous the root has to grow around the phosphorous molecule, and a burial depth of 10cm would be sufficient (Interview, Olesen) credits can be sold. Therefore scaling is entirely dependent upon farmer's willingness to use biochar, and therefore having the right demand incentive structure, and this is a risk due to the expected lack of demand for a fertiliser product.

The inclusion in the ETS is considered an essential step in Skyclean's scale-up strategy. However, it will require conceptualisation of biochar as an industrial CDR, and achieving equivalence with CCS will constitute a considerable constraining condition. Furthermore, the agricultural sector would not receive the mitigation outcome, and biochar could lose the all important political support. Due to this, the 2Mt target may have to be reallocated to an other sector or technology. Furthermore, incentivisation of demand would depend on the green tax, for-which there is great uncertainty as-to its implementation.

Regulation under the LULUCF would guarantee the credit going to the agricultural sector, while it is seen as a mistake by Skyclean as it would be a higher-risk business environment. Public incentives for farmers using biochar, would come from an EU level through the CAP, and the green tax. The political support for agricultural emission reduction would also increase the availability of government subsidies. Moreover, partnerships between Skyclean and farmers could be an enabling factor since revenue from the carbon credit sales in the VCM and the energy sold to the biogas plant could shared.

Finally, there is an urgent need to bring awareness and knowledge of biochar technology to the farming community, as farmers' willingness to change their practices to adopt biochar will have a significant impact on the scalability of biochar.

Discussion 7

The SOTA identified that clarity must be sought on how the Danish government will use biochar to contribute to its 2030 targets, as this will impact whether the 2MT target is achievable. It has also been recommended by CONCITO that the government define CDR and how they intend to use it to contribute to climate targets (CONCITO, 2023). The following chapter will discuss how biochar falls under the external influence of the mitigation hierarchy, and how biochar's role in society will impact its use by the government as a CDR. Finally, it is discussed whether the 2MT target is realistic, and what an alternative pathway to scaling could be for the Danish biochar system.

7.1 How the mitigation hierarchy applies to biochar

To be clear on how biochar will contribute to agricultural emission reductions, clarity must first be sought on the meaning of the targets themselves. Biochar is both a proven reduction tool through its potential to substitute fossil fuels and its potential to reduce non-CO_2 emissions from manure, and a CDR. Beyond this, it also has reduction potential as a substitute for chemical fertiliser. The policy speaks of both reduction and removal benefits while using biochar to contribute a 2MT reduction of emissions from an overall target for agriculture (Danish Ministry for Climate Energy and Utilities, 2022). In addition, Thomsen and Lindholst have indicated that the 2MT target for biochar represents strictly CDR.

This represents a problem of policy definition. It remains uncertain how biochar will be used for residual emissions only, and so the mitigation hierarchy cannot be enforced. In the current policy space, this could be considered acceptable because while biochar is conceptualised as an NBS, it falls under the LULUCF regulation. Under LULUCF's no-debit rule, nature-based removals are balanced against human-induced emissions over a certain commitment period, and so the system is designed to use removals as reduction measures. The enforcement of the mitigation hierarchy is therefore less relevant when compared to a carbon market, which is an entirely different system of climate mitigation. This will not be the case in the future. With the gradual adoption of CDR in EU policy following the implementation of the EU CRC, Danish policy will need clarity as-to how biochar as a CDR will contribute to removing residual emissions only. This will require the development of separate removal and reduction targets for the agricultural sector.

7.1.1 The role of biochar in society

The next challenge for the Danish government will be to define what residual emissions are, and therefore what biochar will be used for in climate mitigation. The Danish government needs to reduce agricultural emissions. It will seek to do this by reducing animal production, together with changing diets to reduce demand for animal products, and using CDR technology such as biochar.

The question of how to define residual emissions becomes even more relevant for the biochar system and the agricultural sector. This is because the incentivisation of biochar supply and demand will require public subsidies, and as Sørensen argues, the public will expect that taxes are being spent only to remove residual emissions, rather than helping businesses avoid reducing emissions. In the SOTA, public subsidies were argued as being instrumental in the scale-up phase of CDR technology. Furthermore, the government acknowledges that public subsidies were necessary to establish the wind energy sector for it to eventually become an un-subsidised technology, and they wish to do the same for other green technologies (Danish Ministry of Climate Energy and Utilities, 2020). Finally, the analysis showed that biochar scale-up will largely rely on the green tax on agriculture. It is not known how this tax will be implemented and by what mechanism it will incentivise biochar adoption (Interview, Olesen). As previously noted, Lindholst hopes for a tax deduction for the farmers. Sørensen meanwhile, expects that biochar could be incentivised through a negative tax (effectively a subsidy), based on the carbon price assigned by the policy. In this case, the taxpayer would be responsible for these subsidies (Interview, Sørensen).

The public will therefore expect separate targets, and the challenge remains how to define what a residual emission in agriculture is. The difficulty is that food production meets a societal need. Reducing emissions in agriculture will require reducing livestock production, while animal products are still in demand. Meanwhile, it is highly uncertain whether the Danish government will be successful in changing Danish diets in order to reduce the demand for animal products. This risk is acknowledged by Lindholst who believes that due to the difficulties in changing consumer behaviour, the government will have to rely on technology (Interview, Lindholst). Furthermore, the government would rely on changing diets internationally as Denmark exports approximately 90 percent of its pork and 50 percent of its dairy (Searchinger et al., 2021). Frandsen notes that Arla sells milk products in Europe, USA, Middle-East and Asia. In some of their markets, especially the Middle-East and Asia, milk consumption and demand are increasing, and Frandsen believes that on a global level, milk production will stay the same or increase (Interview, Frandsen).

It is feared that the forced reduction of livestock in Denmark will therefore lead to leakage, where production moves to another part of the world to continue to meet demand. Global emissions can then actually increase because Denmark produces food more efficiently than most other countries (Interview, Frandsen; Interview, Olesen) (Searchinger et al., 2021). Olesen expresses that Denmark is in fact blessed with good farmland, and it has an important role in supplying food with lower emissions to the rest of the world (Interview, Olesen).

Following the mitigation hierarchy is therefore, not straight-forward for the agricultural industry due to the leakage problem and the need to feed a growing population. As Gehrig-Fasel et al. (2021) state, *"NbS are now regarded as a solution to achieving ambitious social and environmental goals on a mass scale. Besides climate impact, the focus is on food and water security"*(Gehrig-Fasel et al., 2021). It is possible then, that biochar as a CDR could be used to help the agricultural industry balance their emissions while meeting demand in

Denmark and other countries, while fulfilling Denmark's role of efficiently supplying food to the rest of the world. The Government will have to take these issues into account when defining residual emissions for mitigation by biochar.

7.2 Biochar in the waste management paradigm

The above discussion concluded that the public has an inherent stake in biochar through the fact that it could be used as a hedge against a lack of changing diets, and this will serve to increase the public's acceptance of the use of government subsidies to scale biochar. This fits into the waste management paradigm introduced in section 5.7 whereby the infrastructure required to manage CO_2 waste is seen as a public good that is the public's responsibility, and that biochar can constitute a part of this infrastructure. This paradigm was seen in the literature as potentially being a powerful incentive to increase the government's role in CDR. Where CDR is seen as a public good, this could result in socially acceptable, larger removals targets, once separate targets are established, as it would be easier to justify assigning a greater percentage of emissions as *residual emissions*, i.e. emissions resulting from a lack of changing diets. The analysis (see section 6.2.3) showed that biochar could soon serve to manage household organic waste, and so in this way, it becomes a public waste management tool. This could potentially open the biochar system to partnerships with municipalities, which would incentivise both the scaling and diffusion of biochar by increasing public acceptance of CDR, and the use of public money for subsidies. Furthermore, section 5.7 identified that the EU Commission intends to implement CDR to improve the circularity of carbon through the Circular Economy Action Plan. Biochar's strengths are in its ability to store carbon and return it to soils as a soil amendment, and therefore the Circular Economy Action Plan could serve as a driver for policy makers to conceptualise biochar within this waste management paradigm.

7.3 Is the 2MT target using biochar for Denmark achievable?

Biochar's diffusion will be most successful where it meets societal needs while requiring the least changes in user practices. As Sarewitz & Nelson (2008) argues:

> *Indeed, one of the key elements of a successful technological fix is that it helps to solve the problem while allowing people to maintain the diversity of values and interests that impede other paths to effective action. Recognizing when such opportunities for rapid progress are available should be a central part of innovation policy, and should guide investment choices.*
> (Sarewitz & Nelson, 2008)

The analysis meanwhile, identified that the diffusion of biochar technology in Denmark faces many uncertainties, including constraints for a scaled-up biochar system to meet the needs of farmers and the agricultural industry's climate policy. It was also noted in section 5.8 of the SOTA, that when compared to an analysis by the DCCC, the government's 2MT target for biochar may be too ambitious. This, coupled with the challenges identified, suggests that the government may need to re-assign biochar's 2MT to a different technology or sector if the challenges are too difficult to overcome by 2030, and continue to develop it for transitioning to climate neutrality by 2050 (see figure 1.7). This could involve the use of the mechanism made available through the EU's post-2030 plan to make LULUCF sinks fungible between sectors, as mentioned in section 5.4 - using a net-negative LULUCF balance to offset other sectors.

Focus should then be directed towards where biochar can contribute most to societal needs. Exporting biochar internationally will enable biochar to solve societal problems where the adoption climate mitigation methods are more important, and soils are drier and more nutrient deficient. User practices may still need to be changed, however, by increasing the size of the biochar market to an international one, it could be assumed that the impact of one community resisting changes to their practices on the overall mitigation potential of biochar, would be minimised. The need for climate mitigation tools in drier countries was noted in an EU parliament research briefing:

> *"It is estimated that there will be a clear geographical north–south divide, with countries in southern Europe impacted more by global warming than those in northern Europe (JRC report). In southern Europe, yields may be expected to decline as a result of increased temperatures and reduced precipitation affecting soil water availability to plants."*
> (Mceldowney, 2020)

Biochar should therefore be marketed for its mitigation co-benefits as much as its CDR potential, while the mitigation outcome would still count towards Denmark's national targets. Furthermore, Jørgensen highlights the fact that P is currently extracted in environmentally destructive open-pit mining. Not only could biochar as a P fertiliser contribute to reducing the negative environmental effects of this mining, but also alleviates any P supply issues related to P being a constrained natural resource in the future (Christian Ege, 2022). Lindholst indicated that Skyclean's scale-up plan ultimately involves developing biochar technology for an international market (Interview, Lindholst), and, as Searchinger et al. (2021) state; *"Danish agricultural mitigation efforts are most valuable if they develop the technology, business, and policy innovations to drive mitigation globally."* (Searchinger et al., 2021). From a CDR perspective, however, protecting against fraud, ex-post monitoring, and recording of biochar application will all be a much bigger challenge.

Biochar's potential use as a hedge against the uncertainty of changes in demand for animal products, and as an important waste management tool to manage both municipal CO_2 and organic waste, give it an important role in society. This could open it up to public funding to achieve full-scale deployment, and lead to its permanent diffusion in Denmark. Meanwhile, scale-up will still be constrained by the need to put biochar in soil, and exporting biochar internationally as a climate mitigation product could alleviate this constraint.

Reflections 8

The purpose of this section is to assess whether the project is successful in carrying out its original goal as stated in section 1.10. This is done by critically reviewing our use of the methods and conceptual framework, and how these affected the outcome of the analysis. Additionally, the wider ramifications of the findings of the project are reflected-upon and how they contribute to knowledge gaps in the literature.

8.1 Reflection on the conceptual framework

The choice of ST-system theory in this study was based on need for a context-specific analysis. Therefore it was decided to create a framework that would allow for an analysis of the conditions unique to the Danish biochar system. A potential alternative model to use would have been the multilevel perspective model (MLP). While the socio-technical systems framework focuses on the interaction between sub-systems and elements within the systems, the multilevel perspective model provides for an analysis of interactions between the landscape, regime and niche levels, to determine the potential for a niche technology to be established in the regime (Geels, 2004). Authors such as Lefvert et al. (2022) have used this model to analyse CDR technologies in a context-specific study to understand how CDR is breaking through the policy regime. This model was deemed inappropriate in our case because Danish policy's inclusion of biochar in its climate strategy means that it could be argued that it is already becoming established in the regime. For this reason, it is a different set of enabling and constraining conditions that need to be analysed. It is then more relevant to analyse the re-arrangement of the socio-technical system of Denmark when biochar needs to be scaled up. Furthermore, in using MLP, examination of the influence of the landscape level is especially relevant from the point of view of a discourse analysis (Geels, 2004), which was not the purpose of this project.

The applications of an ST-systems model are highly diverse and require strict delimitation. We delimited the scope of the project to exclude an analysis of MRV methodologies, however this would have been relevant to our conceptual framework, and research question. Furthermore, our framework could imply an analysis of carbon pricing, and indeed, Geels includes economics as an element of the production sub-system. While it would also have been relevant to the research question, particularly as an influence on the enforcement of the mitigation hierarchy (Howard, 2018; Org & Kennedy, 2019), it was outside the scope of this project.

8.2 Reflection on the analysis

ST-system theory provides a valuable framework for understanding how biochar can be incentivised since an holistic approach is required that addresses technological, social, and political factors in a specific context. This broader perspective allowed for a more comprehensive understanding of the system's elements, and allowed the identification of constraints and enabling factors for the scaling and diffusion of biochar by looking at the interactions of the elements. However, through the application of the framework, not all the interactions and conditions were fully represented in the analysis, and therefore there is the need to reflect on these limitations that could contributed to a more comprehensiveness analysis.

The analysis focused on national-level interactions and did not analyse the potential for local-level interactions between biochar producers and municipalities. Biochar as a waste management tool can be used to treat sewage sludge and with would act as an enabling condition for the system. Moreover, in regard to the technology sub-system, a key limiting factor for biochar was determined to be the lack of need for P fertiliser or soil conditioner in Denmark. This argument was based on the opinions of three subject-matter experts, and it would warrant a full analysis of the potential demand for P fertiliser in Denmark based on the Danish soil characteristics and needs.

Lastly, the analysis of social acceptance would have had more weight on the overall analysis if more data from potential biochar users could have been gathered. To enhance the results, conducting a survey specifically tailored to the Danish context, similar to the INTERREG survey, would have been highly beneficial. Therefore conducting a similar survey is highly recommended for stakeholders to understand how the incentives can be applied for the agricultural sector to start using biochar.

8.2.1 Applicability of the results

The project's results are highly specific to the Danish context. The applicability of the results to other countries may be limited as the enabling and constraining conditions related to political support, societal needs, technological application, user practices, and awareness of the technology are strongly embedded in the Danish biochar system. However, countries with similar intensive livestock industries, and a biogas industry could potentially benefit from the results. Furthermore, This study is, to our knowledge, the first biochar-specific socio-technical analysis. Therefore, any EU country wanting to adopt biochar to contribute to national climate mitigation targets could benefit from the state of the art and the analysis of how EU legislation impacts the biochar system.

9 Conclusion and Recommendations

The following chapter will summarise the main conclusions from the two analyses - the SOTA to answer sub-RQ1, and the analysis of the Danish biochar system to answer sub-RQ2, thereby directly answering the main research question - *How can the diffusion and scaling of biochar technology in Denmark be incentivised to fulfil the Danish government's 2030 emission reduction target?*.

Scaling happens when actions are taken to increase the production capacity of biochar. This can be through policy incentivising production, and requires the climate mitigation potential of biochar being proven at scale, and acknowledged and understood by the agricultural industry. The policy also contributes to lowering the costs of the technology to enable both production and demand. The diffusion of biochar technology is enabled by the exploitation of biochar's potential to solve societal problems. This can be through understanding the needs of the users, the removal of legislative barriers to its use in agricultural soils, and the spreading of the awareness and building of knowledge in the agricultural community.

The upcoming LULUCF reform will take non-CO2 emissions from the ESR and put them under the LULUCF, thereby forcing the danish gov to reduce emissions from the livestock industry at national level, and biochar will be an important mechanism for enabling these reductions. The Danish gov is therefore politically supporting biochar, and using it as a CDR to meet 2030 targets.

In the Danish biochar system, biochar's synergy with the biogas industry is an important enabling factor for biochar's diffusion as it helps to solve the problem of needing to manage livestock residues, whilst maximising use of bioresources. The Biochar system cannot fully rely on the biogas system to scale due to the constrained nature of the feedstocks, and will need to remain flexible to other feedstocks to prevent technological lock-in. Biochar developers can do this through partnerships with municipalities to use household organic waste, and by diverting straw from incineration plants to pyrolysis.

The scaling strategy of biochar developer Skyclean, involves inclusion in the ETS. The ETS presents an opportunity to scale by lowering business risk and allowing access to funding from institutional investors. ETS support of biochar as a CDR is possible with the ambition to make the ETS net-negative, and it already makes provisions for CCS as a reduction method. But inclusion of CDR will require an update to the ETS directive, as well as the development of stringent MRV processes to allow it to be considered equivalent to CCS. This will be a challenge due to biochar's inherently greater risk of reversal and challenge to prove CDR permanence.

This identifies the unique problem of biochar among CDR technologies, whereby its industrial processing can be seen as equivalent to CCS, while the requirement to use in agricultural soils place it naturally under LULUCF as carbon farming. Its requirement to be in soil to ensure permanence of carbon storage, is a significant constraining factor for technological diffusion compared to CCS. Due to pressure to reduce emissions, farmers will be most-incentivised to adopt biochar if the mitigation outcome is attributed to the agricultural sector, and this would not happen under the ETS.

For EU policy to incentivise biochar under ETS or LULUCF, it will require the implementation of the EU CRC. However, this won't happen until at least 2026 for the easier-to-legislate CDRs such as CCS, and even later for biochar. Therefore, the Danish biochar system will likely not be able to rely on EU legislation to incentivise biochar to meet the 2030 targets. This creates a higher-risk environment for biochar's scaling, where producers and the Danish government rely on the VCM for funding, and the government will have to be prepared to subsidise biochar to a greater extent.

Post 2026, biochar will most likely be regulated under the LULUCF. Production will be incentivised by the VCM and the mitigation outcome can go to the agricultural industry. The adoption of biochar by farmers will potentially be incentivised by being able to accept CAP payments or subsidies. Biochar's diffusion can be further incentivised through partnerships between biochar technology developers, and co-operatives of potential biochar users such as Arla, similar to the current model of co-ownership of biogas plants. Farmers would then share the profits from sales of carbon credits.

Whether under the ETS or the LULUCF, the incentivisation of adoption of biochar by farmers is also relying on Danish green tax policy. However, the agricultural industry is lobbying against the tax, and the carbon price assigned by the government may be insufficient to enable the scaling and diffusion of biochar by 2030. The implementation of the tax will have to be such that it maintains public support while sufficiently incentivising emission reduction. Furthermore, incentivisation of biochar through government subsidies or negative tax will require the societal acceptance of the use of biochar for residual emissions. These residual emissions must therefore be clearly defined by the government policy through using separate targets for removal and reduction. The conceptualisation of biochar as a waste management tool and public good would increase public acceptance for the use of subsidies to incentivise biochar's scaling and diffusion.

The willingness of farmers to use biochar is limited by the already high-quality of Danish soils. Furthermore, some stakeholders are not yet spreading awareness of biochar technology. The knowledge of biochar users is an important factor for the diffusion of biochar as it will require changes in user practices, and all stakeholders of the biochar system who are actively advancing the diffusion of biochar in Denmark should work to increase knowledge and awareness in farming communities during the early stages of development. Furthermore, biochar producers should acknowledge the importance of developing a product that farmers will want to use, and focus on developing a fertiliser or soil conditioner product to incentivise its adoption. A focus on public acceptance would be warranted both in Denmark, and internationally, to minimise the constraints of the potential for a lack of demand for biochar in Denmark.

Due to the uncertainties around the willingness of farmers to use biochar, the lack of supply and demand incentives, and the high-risk of existing supply incentives, scaling in-time for the 2030 targets seems unlikely. The Danish government may have to reassign the 2MT to another technology or sector, and scaling may be slower as a result, without the political support for the reduction of agricultural emissions. Biochar producers should seek to develop biochar fertiliser products for international markets where its mitigation co-benefits can be exploited. Following the removal of legislative barriers for using biochar from livestock residue feedstock as a fertiliser, biochar may gain political support in countries of Southern Europe for its co-benefits and experience less public acceptance constraints there.

Further research is required to fully determine the awareness of biochar in the agricultural industry in Denmark and Southern Europe, to gauge its potential for public acceptance. In support of this, research should also be done into the mitigation potential of the substitution of chemical P fertilisers by biochar.

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Appendix A

A.1 Table of Grey Literature

	Full Citation
1	Batini, N., Parry, I., Wingender, P., Segoviano, M., Birch Sørensen, P., Blatt Bendtsen, U.,Chami, R., Hillier, C., Krogstrup, S., Pedersen, L. H., Smidt, E., & Thakoor, V.(2020). Climate Mitigation Policy in Denmark: A Prototype for Other Countries (tekn. rapp.). International Monetary Fund
2	Burrows, D. (2022). Offsetting: carbon con or net-zero necessity? Just - Food Global News. https://www.proquest.com/wire-feeds/offsetting-carbon-con-net-zero-necessity/ docview/2632087863/se-2?accountid=8144
3	Böttcher, H., Gores, S., Hennenberg, K., Reise, J., Graf, A., & Energiewende, A. (2022). Analysis of the European Commission proposal for revising the EU LULUCF Regulation-Commissioned by Agora Energiewende (tekn. rapp.). Öko-Institut. Berlin. www.oeko.de
4	COWI, Ecological Institute & IEEP. (2020). Analytical Support for the Operationalisation of an EU Carbon Farming Initiative: Lessons learned from existing result-based carbon farming schemes and barriers and solutions for implementation within the EU. Report to the European Commission, DG Climate Action under Contract No. CLIMA/C.3/ETU/2018/007 (tekn. rapp.). http://ec.europa.eu
5	Danish Council on Climate Change. (2020). Known paths and new tracks to 70 per cent reduction (tekn. rapp.).
6	Donofrio, S., Maguire, P., Daley, C., Calderon, C., & Lin, K. (2022). The Art of Integrity; State of the Voluntary Carbon Markets 2022 Q3 August 2022 (tekn. rapp.). Ecosystem Marketplace.
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9	Geden, O., & Schenuit, F. (2020). Unconventional Mitigation Carbon Dioxide Removal as a New Approach in EU Climate Policy (tekn. rapp.). Stiftung Wissenschaft und Politik German Institute for International & Security Affairs. Berlin.
10	Gehrig-Fasel, D. J., Gehrig, D. M., & Hewlet, O. (2021). Nature-based Solutions in Carbon Markets (tekn. rapp.). The Foundation Future of the Carbon Market(Stiftung Zukunft des Kohlenstoffmarktes). http://www.carbonmarket
11	Howard, A. (2018). Incentivizing mitigation: Using international carbon markets to raise ambition (tekn. rapp.). Koru Climate. https://www.koruclimate.com
12	Howard, A., & Greiner, S. (2022). Accounting Approaches for the Voluntary Carbon Market (tekn. rapp.). VCM Global Dialogue
13	Jeffery, L., Höhne, N., Moisio, M., Day, T., & Lawless, B. (2020). Options for supporting Carbon Dioxide Removal Discussion paper (tekn. rapp.). www.c2g2.net
14	Jette, P. M., Jacobsen, B., Buus, N., Jorgen, K., Bente, E., Per, H., Marie, H., Knudsen, T., Morthorst, P. E., & Richardson, K. (2023). Adaptation of the Danish Farm Sector to a Tax on Greenhouse Gas Emissions. Effects of a carbon tax on Danish farms and their greenhouse gas emissions (tekn. rapp.). Danish Council on Climate Change. Copenhagen

Figure A.1. Table of grey literature used to contribute to the state of the art analysis (1 of 2)

	Full Citation
15	Jörß, W., Emele, L., Moosmann, L., & Graichen, J. (2022). Challenges for the accounting of emerging negative and zero/low emission technologies (tekn. rapp.). www.oeko.de
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17	Lo, V., Qi, J., & Jang, N. (2022). Seeking Clarity on Nature-Based Climate Solutions for Adaptation (tekn. rapp.). IISD. Winnipeg
18	Mattias Gustafsson. (2018). Stockholm Biochar Project (tekn. rapp.). https://nordregio. org/sustainable_cities/stockholm-biochar-project/
19	Mcdonald, H., Siemons, A., Bodle, R., Hobeika, M., Scheid, A., Schneider, L., & Mcdonald, H. ; (2023). QU.A.L.ITY soil carbon removals? Assessing the EU Framework for Carbon Removal Certification from a climate-friendly soil management perspective Ecologic Institute (tekn. rapp.). Oko-Institut e.V. Berlin. www.ecologic.eu
20	Meyer-Ohlendorf, N., & Spasova, D. (2022). Carbon Dioxide Removals in EU Member States National frameworks for Carbon Dioxide Removals: State of play and how to improve it (tekn. rapp.). Ecologic Institute. Berlin. www.ecologic.eu
21	Murun, T., & Takahashi, K. (2023). Elements related to carbon credit credibility - A brief guide for offset credit buyers (tekn. rapp.). https://about.jstor.org/terms
22	Møllgaard, P., Bredahl Jacobsen, J., Buus Kristensen, N., Bente Elmeskov, J., Halkier, Heiselberg, P., Trydeman Knudsen, M., Morthorst, P. E., & Richardson, K. (2023). Status Outlook 2023, Denmark's national climate targets and international obligations (tekn. rapp.). The Danish Council on Climate Change. https : / / klimaraadet.dk/da/rapport/statusrapport-2023
23	Nemet, G., Deich, N., Cohen Brown, N., & Fransen, T. (2023). Carbon Removal at Scale, A Call to Action from the IPCC Report. https://www.wri.org/events/2023/3/ carbon-removal-scale-call-action-ipcc-report - Conference Proceeding
24	Org, W., & Kennedy, K. M. (2019). Putting a Price on Carbon: Evaluating A Carbon Price and Complementary Policies for a 1.5◦ World (tekn. rapp.). World Resources Institute. Washington DC.
25	P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz & J. Malley. (2022). IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (tekn. rapp.). Cambridge University Press. Cambridge, UK, New York, USA. https : / / doi . org / doi : 10 . 1017 / 9781009157926
26	Scheid, A., McDonald, H., Bognar, J., & Tremblay, L.-L. (2023). Carbon farming cobenefits. Approaches to enhance and safeguuard biodiversity (tekn. rapp.). Ecologic Institute. Berlin. www.ieep.eu
27	Thomsen, T. (2022). Introduction to Production and Use of Biochar 2022 working towards a more circular and bio-based Danish economy (tekn. rapp.). Roskilde University
28	Verde, S. F., & Chiaramonte, D. (2021). The biochar system in the EU, the Pieces are Falling Into Place, but Key Policy Questions Remain (tekn. rapp.). Florence School of Regulation. European University Institute. https://doi.org/10.2870/40598
29	World Bank. (2021). State and Trends of Carbon Pricing 2021 (tekn. rapp.). World Bank. Washington DC. https://doi.org/10.1596/978-1-4648

Figure A.2. Table of grey literature used to contribute to the state of the art analysis (2 of 2)