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Towards Net Zero Emissions – Creating Incentives for BECCS and DACCS

Abstract

This policy paper examines the incentives and funding mechanisms needed for carbon dioxide removal (CDR) methods, specifically bioenergy with carbon capture and storage (BECCS) and direct air capture and carbon storage (DACCS). It begins by outlining the necessity for CDR and the scaling required over time, both in the EU and globally. The paper then provides an overview of the current state of BECCS and DACCS, comparing them to other CDR methods and addressing key risks and challenges. It also highlights existing EU policies and novel projects in the Nordic countries. In light of the insufficient current incentives for BECCS and DACCS, five models are proposed: state support programs, quota obligations, emissions trading, trade between states, and voluntary markets. The advantages and challenges of each model are discussed, alongside with the roles of the EU and Member States in driving their implementation.

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List of abbreviations and acronyms

BECCS	Bioenergy with Carbon Capture and Storage
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CRCF	Carbon Removals and Carbon Farming Certification Regulation
CDR	Carbon Dioxide Removal
DAC	Direct Air Capture
DACCS	Direct Air Carbon Capture and Storage
GHG	Greenhouse Gases
NZIA	Net Zero Industry Act

Towards Net Zero Emissions

Creating Incentives for BECCS and DACCS

1.1 Introduction: Why is carbon removal needed?

In the IPCC AR6 WGIII report (IPCC, 2022), scenarios limiting global warming to close to 1.5°C by 2100 require that net-zero carbon dioxide emissions are reached globally by mid-century. In addition to rapid and deep greenhouse gas emission reductions, all scenarios also rely on large volumes of carbon dioxide removal (CDR).

There are several carbon removal methods. These can be defined as anthropogenic activities that remove carbon dioxide from the atmosphere and store it durably in geological, terrestrial, or ocean reservoirs, or in products (IPCC, 2022).

Carbon removal is necessary to achieve the two main functions of (i) counterbalancing hard-to-abate residual emissions – a fundamental requirement to attain global net-zero emissions – and (ii) reducing historically emitted carbon dioxide ("legacy carbon removal") through achieveing global net-negative emissions and bring global temperature back down. The latter can be achieved through eventually reaching a state at which annual carbon removal exceed annual residual emissions (Obersteiner et al., 2001). In addition to these two main functions, carbon removal may enable faster lowering of net emissions in the shorter term, and to enhanced cost-effectiveness of achieving mitigation targets when carbon removal can be deployed at a cost lower than the marginal cost of reducing emissions (e.g., Azar et al., 2010).

According to 1.5 °C compatible scenarios assessed by the IPCC, requirements of carbon removal contributions until 2100 range from 200 to 1000 billion tonnes of carbon dioxide, with annual removal rates at the end of the century reaching nearly 50 percent of current global annual emissions (IPCC, 2022). Any single CDR method is very unlikely to sustainably achieve the large carbon removal rates observed in many 1.5°C and 2°C mitigation scenarios. Therefore, portfolios of multiple CDR methods need to be developed to increase the likelihood of reaching the climate goals (IPCC, 2022).

A portion of the required carbon removal can be achieved through nature-based solutions (ranging from 20 to 400 billion tonnes until 2100). However, to attain the carbon removal rates likely required later this century, significant contributions from different kinds of less mature "novel CDR methods", including the permanent CDR technologies BECCS and DACCS, will be required (ranging from 30 to 800 and 0 to 300 billion tonnes until 2100 for BECCS and DACCS, respectively).

The interest in BECCS and DACCS has seen a rapid growth due to their capacity to generate permanent carbon removal. However, despite the significant need for removals, there are few programs that provide incentives and funding for carbon removals today.

1.2 What is BECCS and DACCS?

The European Commission (2024b) divides carbon removal methods into three overall categories: 1) permanent carbon storage, 2) carbon farming (such as sink enhancement through soils and forests), and 3) carbon storage in long-lasting products and materials (for example, wood-based materials in buildings). There exist big differences among the various methods, including their technological maturity, permanence, scalability, costs, and sustainability – all of which must be considered in the regulation of carbon removal. This report focuses on the two CCS-based carbon removal methods BECCS and DACCS, which are methods that ensure that carbon that has been removed from the atmosphere will be stored for millennia.

While both BECCS and DACCS are ultimately based on the storage of carbon dioxide in geological formations, there are significant differences between them. In the case of BECCS, carbon dioxide is first removed from the atmosphere through photosynthesis by growing plants. The biomass is then converted in thermal energy plants, where the carbon dioxide is captured, transported, and finally permanently stored in deep geological formations. DACCS, on the other hand, separates carbon dioxide directly from ambient air before storing it. Significant demonstration will be required before the entire CCS value chain reaches commercial maturity (IEA, 2020).

Box 1: *Fossil CCS and carbon removals have different roles.*

Applying **carbon capture and storage (CCS)** to carbon dioxide emissions from **fossil sources** can enable deep emission cuts where alternative mitigation solutions are not feasible for technical and/or economic reasons. The applicability of CCS is limited to larger point emission sources. It is a common assumption that it is only realistic to capture up to about 90 percent of the carbon dioxide in a gas stream. Higher capture rates are theoretically possible but there will be trade-offs between increased capture rates and the marginal cost of abatement. This means that CCS applied to fossil emission sources will lead to so-called 'residual emissions' that will need to be counterbalanced in order to attain zero net emissions. Whenever discussing fossil CCS it is important to bear in mind that it should primarily be seen as a tool to manage emissions in sectors where full decarbonisation is very challenging.

In contrast, **carbon removal** through the deployment of various so-called carbon removal methods removes carbon dioxide from the atmosphere on a net basis. Importantly, the capacity of carbon removal methods to remove carbon dioxide from the atmosphere should not be seen as a tool to allow for continued emissions, but only as a complement to very aggressive emission reductions.

Other CDR methods worth mentioning include different kinds of nature-based solutions, such as afforestation, reforestation and soil-carbon sequestration, biochar carbon removal, enhanced rock weathering, and ocean alkalinization.[1] They vary significantly in cost, technological readiness, and durability of carbon sequestration etc. (Smith et al., 2024).

1.3 Status of BECCS and DACCS today

Smith et al. (2024) in their State of CDR report identify a large gap between needed and actual carbon removal. The current rate of carbon removal through conventional methods building on nature-based solutions is in the order of 2 billion tonnes carbon dioxide annually. This is around 4 per cent of the net anthropogenic carbon dioxide emissions at the global level. The estimate considers only carbon removal which is the result of direct human intervention and the associated uncertainties are significant. Moreover, implementation levels vary widely between countries and remain vulnerable to policy changes.

Meanwhile, novel carbon removal methods are still in the research and demonstration phases with contributions of around 1.4 million tonnes of carbon dioxide removed annually. The largest current contributions to novel carbon removal are from biochar (with an estimated 0.79 million tonnes carbon dioxide annually) and BECCS (0.51 million tonnes). The magnitude of future carbon removal required thus presents a remarkable scaling challenge. This implies technical, environmental, and financing challenges as well as socio-economic opportunities and risks. These need to be thoroughly assessed to attain a good understanding of their potential for implementation.

BECCS and DACCS are currently only marginally deployed in Europe. A limited number of BECCS projects are operating, notably a waste-to-energy facility in the Netherlands and small-scale carbon capture from bioethanol plants (Birk Rasmussen & Gammelgaard Bøttcher, 2023). However, there is a growing number of BECCS demonstration projects under development, not least in Denmark and Sweden (Möllersten, Zetterberg & Tynkkynen, 2023). There are currently no operational DACCS facilities in the EU, and no upcoming projects are under development (Birk Rasmussen & Gammelgaard Bøttcher, 2023). Iceland hosts small-scale and operational DACCS facilities (Möllersten, Zetterberg & Tynkkynen, 2023).

The costs associated with CCS-based carbon removal are high and uncertain and can vary significantly depending on the specific case. The IPCC indicates a future cost of abatement in the range of EUR 100-400 per tonne of carbon dioxide abated (IPCC, 2022). Current costs are, however, in many cases significantly higher. The current cost of BECCS has been estimated at up to EUR 300 per tonne of carbon dioxide abated, while corresponding estimates for DACCS range

1 Biochar carbon removal builds on the conversion of biomass into recalcitrant biochar through pyrolysis with the subsequent application as soil amendment and other applications where the carbon will be stored for long periods of time. Enhanced rock weathering refers to the spread of finely grained silicate rocks containing calcium or magnesium on land which react with carbon dioxide forming carbonate minerals. Ocean alkalinization refers to methods of increasing seawater pH to enhance the absorption of carbon dioxide from the atmosphere.

from EUR 500 to over 1000 per tonne of carbon dioxide (Fuss et al., 2018; Bednar et al., 2023). Hence, in particular for DACCS, significant cost reductions will be required before the technology can give meaningful contributions to mitigation efforts. Intensified R&D as well as piloting and demonstration will therefore be needed.

1.4 Critique and barriers facing BECCS and DACCS

Widespread optimism about the potential of carbon removal later in the century has led to concerns that the prospect of future carbon removal may lead to overreliance on CDR methods that may prove not to be scalable due to technological, environmental, and socio-economic constraints (Fuss et al., 2014; Obersteiner, et al., 2017).

Separate targets for emission reductions and carbon removal have been proposed to prevent reduced emphasis on phasing out fossil fuels, a risk known as "mitigation deterrence", due to the predicted future availability of carbon removal (McLaren, et al., 2019; Morrow, et al., 2020). Observing that policies are needed that not only drive the required decarbonization but also create sufficient incentives for large-scale demonstration and gradual scaling of carbon removal, Bednar et al. (2019) propose that an effective mitigation strategy should be built on two pillars:

i. Achieving earlier and more radical reductions in emissions than those proposed by most Paris Agreement-compliant mitigation scenarios suggest, and

ii. Accelerating near-term development and ramping-up of carbon removal methods to clarify their actual potentials and the scaling properties of specific technological options.

Analysis of performance, opportunities and risks of CDR methods are in many ways sensitive to regional context (Honegger, Michaelowa, & Roy, 2021). Here we will shortly discuss uncertainties related to BECCS and DACCS.

BECCS can require significant land and water resources, which might compete with food production and natural ecosystems (Anderson and Peters, 2016; Smith, et al., 2019; Honegger, Michaelowa, & Roy, 2021). DACCS is much less land intensive, but much more energy intensive and still prohibitive in costs (Honegger, Michaelowa, & Roy, 2021). The scalability of DACCS thus mainly hinges on the local energy supply conditions surrounding the DACCS plant. Remote places with ample supply of fossil-free energy sources and adequate infrastructure for transporting and storing carbon dioxide, are likely to see cost advantages and might be able to scale once they become cost competitive.

Both DACCS and BECCS face a common challenge: scaling up CCS requires that the different components along the value chain be developed and incentivized jointly to avoid cross-chain risks and the associated potential for "hold-up" or "commitment" issues (Möllersten, Marklew, & Ahonen, 2023, Zetterberg, Johnsson & Möllersten, 2023). A given industrial actor is unlikely to want to invest heavily in capture equipment before knowing that sufficient storage capacity will be available. Conversely, a storage operator is unlikely to invest heavily in carbon dioxide injection and storage capacities without knowing that capture plants are prepared to deliver carbon dioxide and pay for its storage. Therefore, strategic coordination of infrastructure development, including solutions for carbon dioxide transportation, will be crucial for achieving the massive carbon removal capacities needed. Here, public sector institutions could play an important role (Rootzén et al., 2018).

Birk Rasmussen & Gammelgaard Bøttcher (2023) observe that the EU potential of BECCS and DACCS towards reaching net-zero emissions and net-negative emissions thereafter remains unclear and depends on residual emissions, technology costs, infrastructure development, availability of sustainable biomass as well as political and social acceptance.

1.5 EU CDR policy – state of play

According to the European Commission's communication of February 6th, 2024 (European Commission, 2024a), residual emissions in the EU economy could reach up to 850 million tons CO_2e by 2040. These emissions are expected to come from agriculture, aviation, shipping, and industry. To meet the climate target of -90 % GHG emissions by 2040 and net zero by 2050, a significant amount of carbon removals will be needed. The Commission estimates that carbon removals should reach up to 400 million tons CO_2e by 2040.

There are, however, no specific targets for emission reductions and carbon removals (the communication states that carbon removals "should reach up to 400 million tons", which in principle can be anything from zero to 400 million tons). The Commission is also unclear on how much carbon removals should be provided by nature-based solutions (mainly carbon sequestration in forests, harvested wood products and biochar) and how much should come from permanent technologies such as BECCS and DACCS. According to the Commission, the potential for BECCS in 2050 ranges from 5 to 276 million tons, while the potential for DACCS in 2050 ranges from 83 to 264 million tons (European Commission, 2022). These wide ranges reflect the considerable uncertainty surrounding factors such as technology costs, infrastructure development, and the availability of sustainable biomass.

Other outstanding issues are how these carbon removals are to be incentivized or funded, and at what level they should be implemented (at EU or Member State levels). Some potential funding models for BECCS and DACCS are presented in chapter 2.

In March 2023, the Commission presented its Green Deal Industrial Plan. The plan contains two bills – the Raw Materials Act and Net Zero Industry Act (NZIA). The NZIA aims to foster the conditions for development of green technology in the EU (EU Commission, 2023). One issue highlighted in the NZIA is the coordination problem surrounding CCS. Plant owners face a significant risk of not having access to geological storage, while investors in storage locations risk insufficient demand for storage capacity. To address this, the NZIA proposes that storage capacity corresponding to 50 million tons CCS in the EU must be secured by 2030. This would be achieved by requiring oil and gas producers to fund storage sites in proportion to their licensed production capacity. It can be noted that there are some oil extraction sites nearing the end of their production life that could be repurposed for geological storage of carbon dioxide. Although 50 million tonnes are far from the future expected need, this could be an important contribution and provide valuable experience for subsequent installations.

In February 2024, the Commission adopted an industrial carbon management strategy, with the objective to scale up carbon management (European Commission, 2024c). It consists of three technical pathways: 1) Carbon capture and storage (CCS); 2) Carbon Capture and Utilization (CCU); and 3) Carbon removals (illustrated by panels e-g in Figure 1).

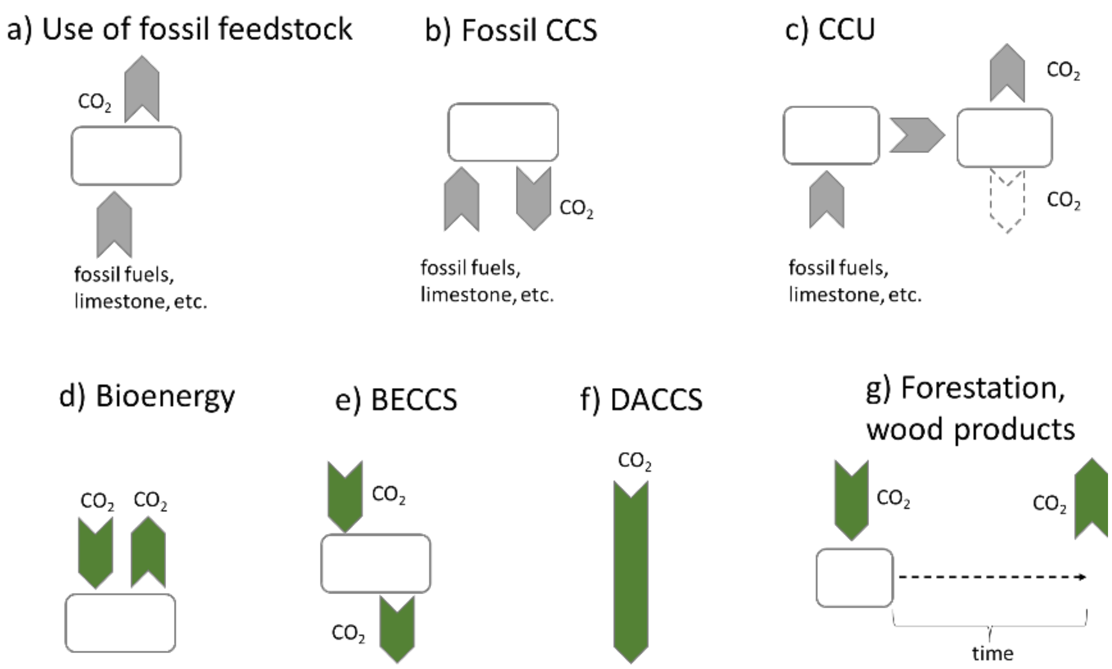

Figure 1. *Schematic description of different carbon management pathways.*

In Figure 1, panel (a) illustrates the use of fossil fuels and other fossil feedstocks in industrial processes, for instance power plants, blast furnaces, cement kilns, waste incineration, and refineries. These processes result in CO2 being released to the atmosphere and increasing atmospheric CO2 concentrations. Panel (b) illustrates carbon capture and storage (CCS) where fossil CO2 is captured and permanently stored. Panel (c) illustrates carbon capture and utilization (CCU) where captured fossil CO2 is used in other applications, for instance as fuels in the transport sector. As in pathway (a), CCU also contributes to increased atmospheric CO2 concentrations but has the advantage that the same fossil carbon atoms provide two services (each box in the figure represents one service) before being released to the atmosphere as CO2. There are CCU-applications where part of the CO2 is captured and stored, illustrated by the dotted arrow.

Panel (d) illustrates bioenergy. First, through photosynthesis CO2 is removed from the atmosphere and sequestered in growing plants and then combusted to produce energy. In the combustion process CO2 returns to the atmosphere with no net increase of atmospheric CO2. Panels (e), (f) and (g) represent carbon removals. Panel (e) illustrates bioenergy and carbon capture and storage (BECCS), where, after bioenergy combustion, the CO2 is captured and permanently stored. Panel (f) illustrates direct atmospheric carbon capture and storage (DACCS) where CO2 is extracted directly from the atmosphere and stored without providing other services (in contrast to the other pathways). Panel (g) illustrates non-permanent carbon removals such as forestation or the use of harvested wood in products. They are considered non-permanent since the captured CO2 may return to the atmosphere, although this could potentially be many years after capture. Forestation could potentially be permanent, but the final outcome of forestation, in terms of carbon storage, is uncertain due to the risks of future fires, mortality and cuttings.

The NZIA carbon management strategy confirms the target of deploying a storage capacity of at least 50 million tons of carbon dioxide per year, together with related transport infrastructure consisting of pipelines, ships, rail, and road.

The strategy does not specify sectors for applying carbon capture for permanent storage or utilization but leaves it to Member States to determine the best applications. However, according to the submitted National Energy and Climate Plans, the main applications for capturing carbon dioxide identified by Member States are in industrial processes, such as cement, steel and natural gas processing sectors, as well as in electricity production (especially from biomass) and low carbon hydrogen, refining processes, waste incineration and thermal heat production.

1.6 An EU common framework for CDR certificates

In 2024, the European Parliament adopted the provisional agreement on the Carbon Removals and Carbon Farming (CRCF) Regulation (EU Commission, 2022), which created the first EU-wide framework for certifying carbon removals, carbon farming and carbon storage in products across Europe. For the time being, the framework is voluntary. The CRCF framework is meant to safeguard the quality and integrity of CDR outcomes, which would facilitate investment in carbon removal technologies and address greenwashing. The framework distinguishes between 1) permanent carbon removals, such as BECCS and DACCS, 2) carbon farming and soil emission reductions, and 3) carbon storage in long-lasting buildings.

In our eyes, carbon removal units corresponding to one ton of carbon dioxide removed from the atmosphere, is a useful concept. A possible development is that a regulator, upon verification, issues carbon removal units to producers of carbon removals. These units can then be traded and used for compliance against targets by companies or states. This way, the units can be seen as a common currency in carbon management. The integrity of the system will of course depend on the quality and integrity of the units.

1.7 Developing a pilot ecosystem for CCS-based carbon removal in the Nordics

The Nordic region has taken a global lead in developing CCS-based CDR (Möllersten et al., 2021; Möllersten, Zetterberg & Tynkkynen, 2023). The Nordic countries have been proactive in developing a more permissive regulatory environment for CCS, both nationally and internationally. They continue working actively to eliminate remaining regulatory gaps and lower barriers to facilitate the deployment of CCS technologies. Additionally, all Nordic countries are making significant investments in CCS-related R&D.

Norway has been an early mover in using a carbon tax and regulatory instruments to deploy CCS. Today, over 25 years of experience in CCS has been accumulated, including geological storage of carbon dioxide under the seabed outside the coast of Norway. Denmark, Sweden and Norway are currently developing some of the world's first support systems to incentivise BECCS and DACCS.

With the Longship and Northern Lights projects, Norway is taking steps to develop geological storage of carbon dioxide as a service. In 2021, Denmark adopted a roadmap for CCS, which includes several initiatives. Overall goals include building an entire CCS value chain and positioning Denmark as a European hub for carbon storage.

In Iceland, a unique technology called the "Carbfix method" is being deployed, which builds on dissolving carbon dioxide in water and injecting it into basaltic layers. There it solidifies through mineralisation in less than two years. A storage hub for carbon dioxide is also planned, with a terminal that would enable the import of carbon dioxide to Iceland via ships, e.g., from European industry.

2 Creating incentives for BECCS and DACCS

There are, to our knowledge, almost no specific policies that create incentives for producing BECCS and DACCS. The exception is Denmark and Sweden, which we describe below.

A common way to create incentives for reducing the environmental impact of emissions is the so-called Polluter Pays Principle, PPP (Organisation for Economic Co-operation and development, 2021). Polluter Pays Principle includes pricing carbon dioxide emissions and other pollutants in the form of a tax or a trading system, such as the EU Emissions Trading Scheme, EU ETS (European Commission, 2003). However, with negative emissions, PPP is not applicable, since there is no pollution, but instead a common benefit (or a positive externality).

Since carbon removal results in a common benefit, it can be argued that funding should be drawn from the state budget (although for global common benefits there are no corresponding global "state budgets"). If one wants to use a principle analogous to PPP, one could use the Beneficiary Pays Principle, BPP.

On the other hand, one could argue that those who emit fossil carbon dioxide (and other GHG) should contribute to funding BECCS and DACCS. Sectors that could be targeted are those that emit considerable amounts of carbon dioxide today and in the future. There is an ongoing discussion with demands on the fossil industry to "take back" carbon dioxide emissions (The Guardian, 2023).

Guided by these two principles, i.e., i) that the government should pay for a positive externality; and/or ii) that greenhouse gas emitters should be responsible for capturing or paying for the capture of carbon dioxide, we have identified five models to create incentives for and financing of BECCS and DACCS.

2.1 Model 1. State guarantees

With this model, the state (i.e., the taxpayers) buys BECCS or DACCS outcomes. This can be done through long-term agreements with BECCS or DACCS producers, whereby the state guarantees to buy a certain level of carbon removal over a certain time. To minimize costs to the state, the contracts can be auctioned off in lots to the lowest bidder.

The Swedish inquiry for supplementary measures (SOU 2020:4) proposed a model of this kind in form of a reverse auction system for BECCS. Reversed in the sense that there is one buyer of the credits – the Swedish state – and many potential sellers of carbon removal in the form of companies that could invest in BECCS or DACCS. The proposal set a target of capturing 1.8 million tons carbon dioxide per year until 2030. Since the proposal was presented, the Swedish government has allocated SEK 36 billion (approximately EUR 3.2 billion) to support BECCS in Sweden. The initial auctioning round opened in Q3 2024 and will close on November 21 the same year. The winners of the auction will receive support for a maximum of 15 years at a level of their respective bid for each ton of verified geologically stored biogenic carbon dioxide.

Denmark has introduced a subsidy system for carbon dioxide capture, use and storage (CCUS) with the aim of achieving 3.2 million tons captured carbon dioxide per year until 2030 (Möllersten et al., 2023). The subsidies are financed through three separate funds with a total budget of 38 billion DKK (2023 prices; approximately EUR 5.1 billion). Qualified techniques include CCS applied to fossil and biogenic carbon dioxide, and direct capture of atmospheric carbon dioxide (DACCS). The support is planned to be paid out from 2025/6 with contract durations for individual projects ranging from 8 to 20 years. In the first procurement, initiated in 2022 and finalized 2023, a BECCS project was awarded a contract (Energistyrelsen, 2023). The same project has sold negative emission credits to Microsoft for climate compensation. These negative emissions are thus counted both against the Danish national climate target and against Microsoft's own neutrality goal, which has been criticized due to double counting (Romm, 2023).

An alternative to auctioning is for the state to buy BECCS or DACCS outcomes "per verified stored ton" at a fixed tariff. The main difference between this and auctioning is that the state decides the price per ton but then has limited control over how many tons will be purchased. The system can be compared to a negative tax, in the sense that the producer is paid for each ton of separated and stored carbon dioxide. A fixed storage tariff has the advantage of payment upon delivery for the benefit performed, albeit with the disadvantage that it is difficult for the state to determine the appropriate price level. With a too-low price, no volumes may be produced at all. And with a too high price it could become very costly for the state.

A challenge with a model based on government guarantees is that costs risk being high for the state. The one proposed by the Swedish government with a budget of SEK 36 billion will be enough to finance 1–1.5 million tons of BECCS per year for 20 years, given a price of SEK 1,200–1,800 per ton. If the entire maximum Swedish allowance for supplementary measures of 10 million tons by 2045 (SOU 2020:4) were financed this way, it would cost taxpayers approximately SEK 12–18 billion per year (the state's total budget is SEK 1,200–1,300 billion). The final cost is likely lower because you can count on a certain technological development and price decline in the future (Lindman & Söderholm, 2012).

With such high costs, the state's role as financier is most interesting at the beginning, to help create favorable prerequisites for the first BECCS or DACCS facilities. These experiences can then become useful for the next generation of facilities. Another potential source of early funding, other than the state, is the EU's innovation fund, which is financed through the sale of emission rights. In the long run, however, other actors will need to contribute to the financing, not least greenhouse gas emitters.

2.2 Model 2. Quota obligation on sectors that emit greenhouse gases

In sectors or operations where it is difficult to reduce emissions, the state (or the EU) could impose a quota obligation, which would require companies to purchase credits representing carbon removals equivalent to a certain percentage of their emissions. Such a quota obligation could be implemented on a 1-to-1 basis, meaning that for every ton of carbon dioxide emitted, companies would need to purchase one ton of carbon dioxide removal through BECCS, DACCS or another CDR method. Initially, however, one could start at a lower level, such as 10%, and then ramp it up at a certain pace. This system resembles the Swedish-Norwegian electricity certificate system that requires electricity traders to buy renewable electricity certificates corresponding to a share of the electricity sold (The Swedish Energy Agency, 2023).

It is not obvious which sectors should be subject to a quota obligation system. But it seems reasonable to target "hard-to-abate" sectors such as transport (heavy road transport, aviation, and shipping), waste incineration (the fossil share) and agriculture (fossil carbon dioxide, methane, and nitrous oxide). In these sectors, there will most likely be residual emissions in 2040 and beyond. For the transport sector and fuel use in agriculture, it is reasonable to impose the quota obligation on producers or importers of fossil fuels, as it would be impractical to put it on every vehicle owner and farmer. The quota obligation would then complement the new emissions trading system, ETS2 (to be introduced in 2027), and other taxes, thereby strengthening the incentives to reduce emissions.

For waste incineration, the quota obligation could be imposed on the incineration plants. They would then, most likely, forward the fee to the waste producers. For agricultural emissions of methane and nitrous oxide, however, it is more complicated, because unlike carbon dioxide it is difficult to quantify emissions of methane and nitrous oxide, which are often site-specific. Therefore, it is reasonable to initially impose a quota obligation solely on carbon dioxide from the use of fossil fuels.

The advantages of a quota obligation model, compared to model 1, is that it widens the financing basis and reduces costs for the state. It would also increase the incentives for reducing the use of fossil fuels in the transport and agricultural sectors and to reduce the burning of plastics. A potential disadvantage, however, is that the cost may be forwarded to the consumers.

2.3 Model 3. Allow participants in the EU ETS to use CDR credits for compliance

As part of EU's Fit-for-55 climate package, the EU Emissions Trading System (EU ETS) was reformed. The total amount of emission allowances, called the "cap", will be reduced by 4.3-4.4 % per year. If the reduction factor continues at the same pace the cap will reach zero in 2039, meaning that no more emission allowances will be issued after the year 2039. However, as this year approaches, there will most likely be residual emissions which are expensive and/or technically difficult to reduce to zero. Some examples include CO2-leakage from carbon capture and storage (CCS) of fossil emissions, since the capture rate is lower than 100%. It will probably be challenging to completely phase out fossil fuels in aviation by 2040, but even if this is possible, aviation will continue to produce contrails which have a significant climate impact. Carbon removals will be needed to balance these residual emissions in the EU ETS. This could be implemented by allowing credits, representing carbon removals, to be used in the EU ETS instead of regular emission allowances.

The challenge with this model is that the EU ETS does not allow credits that represent carbon removals (EU Parliament and EU Council, 2009). But if there will be no more emission allowances issued after 2039, credits will be needed to compensate for remaining emissions. It is therefore likely that the EU ETS Directive will be revised to either continue the allocation of allowances beyond 2039 or allow credits representing carbon removals to be used instead of emission allowances.

An advantage of this funding model is that it would broaden the funding base and could lead to significant demand for negative emissions.

A risk with allowing credits in the EU ETS is, as mentioned earlier, that it can lead to mitigation deterrence – that companies buy credits instead of reducing their emissions. Therefore, it will be important to ensure that credits are only used when emissions reductions are highly difficult technically or very expensive. To avoid an overuse of carbon removals, a control mechanism will be needed that manages how many credits enter the EU ETS market. One way to avoid the overuse of credits in the EU ETS is to apply an exchange rate, for instance two-for-one, meaning that one ton of emissions needs to be compensated by two tons of negative emissions. This would create stronger incentives for emissions abatement than for compensation.

Today, the high costs associated with BECCS and DACCS minimize the risk of overuse. However, this may change as the costs of these technologies are likely to go down while the price of allowances is likely to go up. In 2026, the Commission will report to the European Parliament and to the Council on how carbon removals, for example through DACCS, could potentially be covered by emissions trading, without offsetting necessary emission reductions (European Parliament and the Council, 2023).

2.4 Model 4. Other states as buyers

Under Article 6 of the Paris Agreement, countries can cooperate on a voluntary basis to reach their respective national commitments for emission reductions. The goal of this cooperation is to increase overall ambition, i.e., to create greater mitigation (i.e., both reducing emissions and increasing removals) than would be the case without cooperation. Article 6 is expected to be a key instrument to create demand for negative emissions (Michaelowa et al., 2023).

The rules in Article 6 may therefore be relevant in situation where a country finances projects like BECCS in Sweden and wants to claim (full or parts of) the carbon removals towards their national target. Countries aiming for net zero emissions may create a demand for carbon removals from Swedish BECCS to offset their remaining emissions. Such international transactions must be in line with the provisions of Article 6. In the event of such a transaction, Sweden must adjust its reporting of greenhouse gases to ensure that the same negative emissions are not counted against its national' target (Ahonen et al., 2021). Under current EU regulations, such adjustments are not possible (Laininen, et al., 2022). This gives reason to review which adjustments to laws and regulations that are necessary at both the national and EU levels to enable such transactions in the future.

It is, nevertheless, uncertain how big the international demand will be for credits produced in the EU. This will ultimately depend on the costs for BECCS/DACCS in relation to what alternatives exist in other countries.

2.5 Model 5. Voluntary carbon markets

Voluntary carbon markets started to emerge in the early 2000's in parallel with the development of the regulated carbon market under the Kyoto Protocol (Hermwille and Kreibich, 2016). Demand for carbon credits on the voluntary market is primarily created by companies and individuals that wish to offset all or part of their carbon footprint without having legal requirements (Leonard, 2009; Hyams and Fawcett, 2013).

The voluntary carbon market has contributed to financing various types of carbon dioxide removal, above all through afforestation and reforestation in tropical countries, but also to a limited extent by storing carbon in long-lived wood products and biochar carbon removal as well as through DACCS (Michaelowa et al., 2023). However, the vast majority of carbon credits retired on the voluntary carbon markets relate to projects that reduce emissions, rather than remove carbon. In 2023, carbon removal credits accounted for less than 10 per cent of total credits sold on the voluntary carbon markets (Smith et al., 2024).

The last two to three years have seen some significant growth of BECCS and DACCS carbon credits in the voluntary carbon markets, led by large purchases by big enterprises such as Microsoft, Airbus, and Equinor. In October 2024, the world's two largest sellers of durable carbon removal credits were the BECCS developers Ørsted (Denmark) and Stockholm Exergi (Sweden), having sold credits corresponding to 4 and 3.3 million tonnes carbon dioxide removed, respectively (CDR.fyi, 2024).

Markets for the use of carbon credits towards voluntary climate targets could play an important role in contributing to funding of BECCS and DACCS. Voluntary markets can also contribute to emission reductions or carbon removals which goes beyond national commitments, reducing the gap that exists between the national commitments and what is needed to reach the 1.5-degree target. However, this requires that the mitigation outcome underlying the carbon credits used for voluntary offsetting are not also counted toward existing national goals – so-called double claiming, a form of double counting.

Double claiming occurs if a company in a particular country (e.g., USA) pays to carry out carbon removals in another country (e.g., Sweden), and the same carbon removals are used by the US company to compensate for its emissions while also being counted toward Sweden's mitigation target. The issue is whether a company's climate compensation can be seen as contributing to additional mitigation beyond existing national commitments, or in other words, whether the climate compensation contributes to an increase in global ambition or not.

Of course, there is nothing wrong if a company contributes to what a country already has committed to, but it can be questioned whether the company can legitimately call itself climate neutral. To avoid double claims, it is necessary for Sweden to adjust its reporting of greenhouse gases so that credits sold to firms for compensation are not also counted towards Sweden's climate targets; however, this is currently not possible under existing regulations (Dufour, Möllersten and Zetterberg, 2024) With such a "proportional attribution" approach, mitigation outcomes would be attributed to government support and to carbon markets in proportion to their financial contribution to the abatement costs of the mitigation activity. Despite these challenges, it is commendable that companies want to be involved and contribute to reducing net emissions, for example by paying for BECCS or DACCS.

Table 1. Summary of the five funding models described in this paper.

Model	Primary financer	Motivation	Challenges and risks
1. State guarantees	States.	Favorable conditions can be created for establishing the first BECCS/DACCS facilities.	Expensive for states. Risk for biomass resource depletion if applied in isolation from other policies.
2. Quota obligation	Sectors that emit GHGs, for instance transportation, waste, and agriculture.	Broadens the financing basis. Reduced costs for the state compared to Model 1, which may translate into increased public acceptability. Increased incentives for reducing fossil fuel use in transports, for reducing combustion of plastics and for reducing GHG emissions in the agricultural sector.	As emissions from the transport sector are expected to be reduced, so will the revenues from a transport-based quota system. Thus, in the longer term, a quota obligation should target sectors with residual emissions, such as those from waste, agriculture, and aviation.

3. Allowing participants of the EU ETS to use negative emission credits	EU ETS participants.	Broadens the financing basis. Could lead to a significant demand for BECCS/DACCS. Eventually will bring down costs for participants in the EU ETS.	Would require a reform or amendment of the EU ETS Directive, since credits are currently not allowed in the EU ETS. Mitigation deterrence risk.
4. Other states as buyers	Other states.	There will be a need for credits, representing carbon removals, so that the EU and other states can achieve their emission targets.	As of today, the EU does not provide the option to make corresponding adjustments. It is uncertain how big the international demand will be for credits produced in the EU. This will ultimately depend on the costs for BECCS/DACCS in relation to what alternatives exist in other countries.
5. Private entities for voluntary compensation	Private companies, e.g., travel agencies.	There is a growing interest from firms and individuals to voluntarily compensate for emissions.	There is a risk for double claiming. To avoid this, Member States' GHG reporting needs to be adjusted, which is not possible with today's rules.

2.6 The funding models complement each other.

The funding models above should not be seen as mutually exclusive but may well complement each other. Given the pros and cons of the different models, one can imagine that they can be sequenced. State guarantees (model 1) can be introduced first to facilitate the establishment of the first plants and to gather experience, which will be important for the development of second-generation facilities. Quota obligation (model 2) can be introduced subsequently to increase volumes and broaden the funding base. Allowing credits in the EU ETS (model 3) would require a reform of the EU ETS and can probably only come into question after 2030, since the rules for the fourth trading phase (2021-2030) are already set. The importance of other states as buyers of BECCS and DACCS outcomes (model 4) is difficult to estimate, as it ultimately depends on international demand and the costs for BECCS and DACCS compared to the costs and availability of alternative options. Finally, while voluntary markets (model 5) can provide a significant demand, it is difficult to estimate both the potential volumes and timing.

2.7 Delegating responsibility for achieving negative emissions to the Member States

If the EU CDR targets were to be delegated to the Member States, it would then be up to each Member State to implement appropriate CDR programs to reach their targets. Distributing CDR targets across Member States, similar to the Effort Sharing Regulation, would require some kind of distribution key. Effort sharing in relation to CDR can be done following different principles, for instance:

A) Based on emissions. Each Member State would be required to produce or purchase a volume of carbon removals that correspond to a share of their emissions. This target volume would increase over time. The sum of these efforts over all Member States would correspond to the total volume of CDRs that the EU will need to reach its overall net-GHG target for each given year.

B) Based on differentiated capabilities. Each Member State would be required to produce CDR outcomes based on their technical potential and financial capability (i.e., relative to GDP per capita). Furthermore, the sum of these efforts would correspond to the volume of CDRs that the EU needs for each given year. This option corresponds to how the Effort Sharing framework has operated since 2013 to share the burden of non-ETS emissions reductions.

Regardless of how the responsibility is delegated, flexibility can be provided by allowing Member States to trade CDR outcomes, so that Member States with surplus CDR outcomes can sell them to Member States that have a shortage. This flexibility would decrease the overall costs and increase the effectiveness of the system.

The way in which the responsibility is delegated to member states is likely to prove contentious, as it will have significant implications for how the costs for CDR are distributed across Member States. Therefore, effort sharing will be subject to political negotiations. However, if Model 3 (Allow credits in the EU ETS) is implemented, there would be no need to delegate the responsibility to Member States.

3 Conclusions

All global emission scenarios that reach the targets of the Paris agreement rely on large emission reductions and on significant volumes of carbon removals. These removals are needed to balance remaining emissions that are economically and technically hard to mitigate, and to remove historically emitted carbon dioxide from the atmosphere. These removals include afforestation, reforestation and other nature-based solutions, and permanent removals from BECCS, DACCS and other novel carbon removal methods.

The possibility to compensate emissions with carbon removals has led to concerns that carbon removals will be used instead of reducing emissions (known as "mitigation deterrence"), while both significant emission reduction and carbon removals will be needed to reach the targets of the Paris agreement. There is also a risk that identified carbon removal methods may not turn out to be scalable due to technological, environmental, and socio-economic constraints. Therefore, in order to mitigate the risk of over-reliance on future carbon removal, and to push the testing and commercialisation of novel carbon removal methods, separate targets for emission reductions and carbon removal need to be adopted.

The European Commission's impact assessment suggests that carbon removals should reach up to 400 million tons CO_2e in 2040. However, the Commission is unclear on how much carbon removals should be provided by nature-based solutions (mainly carbon sequestration in forests, harvested wood products and biochar) and how much should come from permanent technologies such as BECCS and DACCS. To provide clarity, target relevant sectors, and develop appropriate policies, it is important that the EU first develops separate targets for emission reductions and carbon removals and specifies how large part of the removals should be based on nature-based solutions and how much should come from BECCS, DACCS, and other durable carbon removals.

Despite the need for significant volumes of carbon removals, there are few policies and programs that provide incentives and funding for carbon removals today. We present five models for creating incentives and funding for permanent carbon removals:

State guarantees (Model 1). With this model, the state (i.e., the taxpayers) buys BECCS or DACCS outcomes. This can be done through long-term agreements with the producers of BECCS and DACCS, whereby the state guarantees to buy a certain level of carbon removal over a certain time. An advantage with this model is that favorable conditions can be created for establishing the first carbon capture facilities. A challenge with a model based on government guarantees is that costs risk being high for the state.

Quota obligation (Model 2). In sectors where it is difficult to reduce emissions, for instance in the transport sector, agriculture and waste incineration, the state (or the EU) imposes a quota obligation, requiring companies to purchase BECCS/DACCS credits equivalent to a certain percentage of their emissions. The advantages of a quota obligation model, compared to model 1, is that it widens the financing basis and reduces costs for the state. However, it is possible that the cost is forwarded to the consumers.

Allow credits in the EU ETS (Model 3). The financing basis would be widened further if participants of the EU ETS were allowed to use CDR-credits as an alternative to reducing emissions. This would also reduce costs for participants in the EU ETS. A risk with allowing credits in the EU ETS is that it can lead to mitigation deterrence – that companies buy credits instead of reducing their emissions. To avoid an overuse of carbon removals, a control mechanism will be needed that manages how many credits enter the EU ETS market.

Other states as buyers (Model 4). Under Article 6 of the Paris Agreement, countries can cooperate on a voluntary basis to reach their respective national commitments for emission reductions. The goal of this cooperation is to increase overall ambition, i.e., to create greater net emission reductions than would be the case without cooperation

Private entities for voluntary compensation (Model 5). Companies and individuals can, on a voluntary basis, compensate for their climate impact by buying credits that represent carbon removals. There is a risk for double claiming if both the company/individual and the country that produces the removals claim these removals as part of reaching their targets. To avoid this, Member States' emissions reporting needs to be adjusted, which is not possible with today's rules.

The funding models differ regarding the timing of implementation and which actors are affected. State support (Model 1) can be important at an early stage to gain experience while other models (especially Models 2 and 3) are needed to broaden the financing basis and increase volumes. Model 4 builds on Article 6 of the Paris agreement that allows nations to meet their emission targets by purchasing removals from other nations. Model 5 builds on the growing interest of companies and individuals to compensate for their emissions. This can provide significant funding for scaling up BECCS and DACCS. But the risk of double claiming needs to be addressed in order to maintain the integrity of the market.

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