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Near-term public financing of Carbon Dioxide Removal through BECCS in Sweden

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BECCS, bio-CCS, procurement auctions, reverse auctions, state support, net-zero, carbon removal, CDR

Summary

The Swedish government has adopted a climate policy framework, including a target to achieve carbon neutrality by 2045 and net-negative emissions beyond that year. Some emission sources are quite difficult to mitigate. One option to address this challenge is to deploy measures that remove carbon dioxide (CO2) from the atmosphere to compensate for residual emissions. Removing CO2 from the atmosphere can also play a key role in achieving net-negative emissions.

This report discusses near-term options for incentives for removing CO2 from the atmosphere through the deployment of one of the most discussed so-called Negative Emission Technologies - bioenergy with carbon capture and storage (BECCS or bio-CCS).

The report first elaborates on the underlying problem that motivates incentives for BECCS deployment in the short term and then, based on a literature review, outlines general categories of policy instruments that could be implemented to provide financial support for BECCS. The current development phase of BECCS is assessed and it is concluded that the technology is in a demonstration to early commercialization phase. On this basis, two types of policy instruments are deemed to be suitable for incentivizing BECCS in the near term, namely (i) Procurement Auctions and (ii) Pre-determined, Uniform Compensation. These two policy instruments are selected for analysis against a set of criteria. The assessment indicates that Procurement Auctions may be the one more capable of delivering on current policy objectives.

Finally, the report considers some practical considerations should the Swedish state provide financial support for BECCS in the near-term, including issues related to the terms of a long-term agreement between the state and BECCS suppliers, frameworks for Monitoring, Reporting, and Verification and provisions related to Public Procurement.

The report is based on information available in the literature and a series of interviews with industry representatives and other stakeholders.

List of abbreviations

A/R	Afforestation and Reforestation
BC	Biochar
BECCS	Biomass Energy with Carbon Capture and Storage
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CDR	Carbon Dioxide Removal
CHP	Combined Heat and Power
CO2	Carbon Dioxide
CRF	Common Reporting Format
CP	Conditions Precedent
DACCS	Direct Air Carbon Capture and Storage
DD	Due Diligence
EM	Enhanced Mineralization
EOR	Enhanced Oil Recovery
EU	European Union
EU ETS	EU Emissions Trading System
EW	Enhanced Weathering
GHG	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change

IPPU	Industrial Processes and Product Use
ISO	International Organisation of Standardisation
LOU	The Public Procurement Act in Sweden ("Lagen om Offentlig Upphandling")
LULUCF	Land Use, Land-Use Change and Forestry
MRV	Monitoring, Reporting and Verification
NDC	Nationally Determined Contribution
NEPA	Negative Emission Purchase Agreement
NET	Negative Emission Technology
OF	Ocean Fertilization
R&D	Research and Development
SCS	Soil Carbon Sequestration

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1 Introduction

1.1 Background

The Swedish Environmental Protection Agency has assigned IVL Swedish Environmental Research Institute to analyze how incentives for CDR through BECCS could be designed in the short term, based on the Swedish state providing financial support for CDR. There are many other areas that are equally important to truly understand the opportunities and challenges involved in achieving BECCS deployment in Sweden, such as legal and governance issues etc., those are, however, beyond the scope of this report.

The Swedish parliament has adopted a climate policy framework for Sweden which consists of three pillars: a Climate Act, long-term climate goals and a climate policy council. According to the climate goals, Sweden shall reach net zero emissions of greenhouse gases (GHG) by 2045 and shall thereafter achieve net negative emissions.[1] The remaining territorial Swedish emissions must be at least 85 per cent lower than in 1990 (corresponding to territorial emissions of approximately 11 Mt CO2e). Remaining emissions should be compensated by “supplementary measures”, such as increased uptake of carbon dioxide by forests, investments in various climate projects abroad and Carbon Dioxide Removal (CDR), for example through Bio-Energy with Carbon Capture and Storage (BECCS). In order to reach carbon negativity, such supplementary measures will be indispensable. Supplementary measures should be accounted in accordance with internationally established rules.

In June 2018 the Swedish Government appointed a new Committee[2] with the purpose to propose an overall strategy for supplementary measures to eventually be implemented and contribute towards the long-term goal. The Committee shall analyze potentials, obstacles and opportunities in relation to the three types of additional measures and propose a strategy for Sweden to achieve negative emissions post-2045.

[1] The 2045 target assumes raised ambition in the EU ETS.
[2] ”Kompletterande åtgärder för att nå negativa utsläpp av växthusgaser”, Dir. 2018:70.

The Swedish climate policy framework sets out the implementation of the Paris Agreement in Sweden.[3] The Paris Agreement is a historic global climate agreement which was agreed by world leaders in 2015. The objective of the Paris Agreement is to stabilize the climate system at a global warming of well below 2°C above pre-industrial levels. Stabilization requires reaching a balance of sources of greenhouse gases (GHG) and sinks.[4] Current global GHG emissions projections and mitigation scenarios suggest that without removing significant amounts of CO_2 from the atmosphere through the deployment of so-called "negative emissions technologies" (NETs), such as nature-based CO_2 removals like afforestation and reforestation (A/R), Bio-Energy with Carbon Capture and Storage (BECCS) and Direct Air Capture and Storage (DACCS), these temperature goals are unlikely to be achieved. Nemet et al. (2018) provide some numbers to put the role of NETs into some perspective; the first large-scale BECCS pilot project in the world, in Decatur, IL, USA, will remove about 1 MtCO2/year (from ethanol production) once in full operation. Worldwide, no other operational projects exceed 0.3 MtCO2/year. Thus, emission scenarios compatible with the Paris Agreement involve bringing online hundreds of new plants of Decatur-scale every year between 2030 and 2050. Sweden's work towards deployment and commercialization of BECCS and achieving negative emissions after 2045 should therefore be understood in the context of Swedish commitment to the implementation of the Paris Agreement.

There is no natural demand for BECCS and current policies[5] that provide potential support for CDR through BECCS are insufficient to incentivize investment. Thus, further incentives would need to be introduced in order for the technology to be implemented.

The Swedish Environmental Protection Agency has assigned IVL Swedish Environmental Research Institute to analyze how incentives for CDR through BECCS could be designed in the short term, based on the Swedish state providing financial support for CDR. There are many other areas that are equally important to truly understand the opportunities and challenges involved in achieving BECCS deployment in Sweden, such as legal and governance issues etc., those are, however, beyond the scope of this report.

[3] https://www.government.se/495f60/contentassets/883ae8e123bc4e42aa8d59296ebe0478/the-swedish-climate-policy-framework.pdf.

[4] As noted in the Paris Agreement Article 4.

[5] Primarily grants available through the EU "NER300" and "Innovation Fund" and the Swedish "Minusutsläppsstödet" (Support for negative emissions) as of 2019. Notably, biogenic CO_2 emissions are counted as zero in the EU Emissions Trading System (EU ETS) and would therefore not be eligible for crediting if Carbon Capture and Storage (CCS) were applied. Besides, BECCS abatement costs are high and far above any projections regarding near- to mid-term price levels in the EU ETS. E.g., Luckow et al. (2010) find that a price incentive above 100 USD/tCO_2 would be required to make BECCS competitive with coal- or natural gas-based power production and that 150 USD/tCO_2 is needed to ensure that over 90 percent of biomass in the energy system is used in combination with CCS.

1.2 Objective

The objectives of the study are to:

- Elaborate on the underlying problem that justifies, or motivates, public support for BECCS in the short term.
- Given the identified problem that justifies public support, list types of policy instruments that a government could feasibly use to support BECCS.
- Select two relevant policy instruments - one with a predetermined price and one with a predetermined quantity.
- Assess the selected policy instruments against a set of relevant criteria.
- Address relevant practical considerations in relation to implementation of the selected policy instruments.

2 Methodology

The present study was carried out from June through September 2019 and included the following main data collection and analytical elements: An initial literature review, initial interviews with stakeholders and a discussion with the Swedish Environmental Protection Agency to refine the scope, a more comprehensive literature review, and a series of semi-structured interviews with stakeholders from the industry and government agencies, and analysis of the information collected.

3 Why are incentives for Carbon Dioxide Removal important?

Human-induced warming had reached about 1°C above pre-industrial levels in 2017 and the global mean temperature is increasing at a rate of around 0,2°C per decade. Risks to ecosystems and societies associated with global warming can be reduced considerably if global warming is limited below 2° C and even further if warming is limited to 1,5°C (IPCC, 2018). Many impacts projected for a global warming level of 2 °C relative to pre-industrial levels and above may exceed the coping capacities of particularly vulnerable countries. The Paris Agreement of 2015 committed its Contracting Parties to act towards the objectives of keeping a global temperature rise this century well below 2°C above pre-industrial levels, and to pursue efforts to further limit the temperature increase to 1.5 °C. The Contracting Parties, furthermore, pledge to "achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century".

The Contracting Parties to the Paris Agreement have submitted Nationally Determined Contributions (NDCs) outlining their post-2020 climate action. The NDCs collectively lower greenhouse gas emissions compared to where current policies stand, but still imply a median warming of 2.6–3.1 degrees Celsius by 2100 even if the nationally determined contributions are fully implemented and policies of similar strength are implemented after 2030 (Rogelj et al, 2016).

The IPCC (2014) linked the temperature increase with the cumulative total of GHG emissions since the industrial revolution, calculating carbon budgets that are compatible with a 66% chance of limiting warming to specific temperatures. According to updated calculations by the IPCC (2018) the budget necessary to limit warming to 1.5 °C appears likely to be exceeded in less than 20 years if current rates of emissions continue.

The IPCC (2018) presents scenarios (based on Integrated Assessment Model simulations) that illustrate how warming could be limited to 1.5°C. In available emission pathways that aim for no or limited overshoot of 1.5°C global CO_2 emissions are typically reduced by 45 percent by 2030 compared to 2010 levels and reach net zero around 2050. This contrasts starkly with median estimates for current unconditional NDCs suggesting a likely increase in global emissions by 2030 compared to 2017 (UNEP, 2018) albeit a reduction compared to no-policy baseline emission estimates. For a two-thirds likelihood of limiting global warming to below 2°C CO_2 emissions in scenarios typically decline by about 25 percent by 2030 and reach net zero around 2070.

Future scenarios, however, show great difficulty of reaching the long-term temperature targets only by reducing emissions. This is due to the lack of mitigation action so far as well as the inadequacy of currently planned mitigation measures, which implies cumulative emissions of GHGs exceeding the levels that are compatible with the Paris Agreement's long-term targets. Consequently, scenarios in the IPCC "Special Report on Global Warming of 1.5°C (SR15) also incorporate significant contributions from approaches that remove CO_2 from the atmosphere. In principle, Carbon Dioxide Removal (CDR) has two functions: (i) to enable a balance between global carbon emissions and removals to be reached sooner and (ii) to compensate for an over-spent carbon budget.[6]

The scale and type of CDR in 1.5°C scenarios vary widely. Typically, the 1,5°C compatible scenarios in SR15 feature global carbon emissions becoming net-negative in the second half of the century.[7] Accumulated CDR deployment over the 21st century is substantial in most of the scenarios, and deployment levels cover a wide range, on the order of 100–1000 Gt CO2 in 1.5°C pathways with no or limited overshoot. As a point of reference, the global energy-related CO_2 emissions in the year 2017 reached 32,5 Gt (IEA, 2018). The high end of the CDR deployment range appears in high overshoot pathways where very large CDR deployment contributes to returning warming to 1.5°C by 2100. In contrast, the low end is found for emission pathways with no or limited overshoot, coming entirely from afforestation/reforestation with no or small contributions from BECCS. These are pathways with very low energy demand facilitating the rapid phase-out of fossil fuels and process emissions and/or pathways with rapid shifts to sustainable food consumption freeing up sufficient land areas for afforestation/reforestation.

There is a range of approaches to achieve CDR. In the scenarios included in SR15, CDR appears mainly from afforestation, reforestation (A/R) and BECSS, only in a few cases also DACCS. In addition to these approaches, options include soil carbon sequestration (SCS), biochar as soil amendment (BC), enhanced weathering (EW), Enhanced Mineralization (EM) and ocean fertilization (OF) (IPCC, 2018; Minx, et al., 2018).

There is, however, very limited experience with NETs at significant scales and confidence in their capability to remove several billion tCO_2 annually is low. NETs' development status ranges from existing (e.g., afforestation, reforestation) to research (e.g., EW) (EASAC, 2018; Fuss et al., 2018; Haszeldine et al., 2018; IPCC, 2018). Significant side effects on broader sustainability are to be expected and a growing strand of literature is drawing attention to the importance of understanding the difference between technical potentials for CDR and the

[6] NETs are likely to be deployed to reduce atmospheric CO_2 long before fossil emissions have been reduced to near zero. Reducing fossil emissions further once they reach low levels will are projected to be very expensive and therefore methods for reduced emissions and NETs will probably be used in concert for centuries, even during a period of net negative global emissions.
[7] Should the scale of CDR eventually exceed residual emissions of GHGs, the increase in atmospheric GHG levels and thus also warming could even be reversed as originally observed by Obersteiner et al (2001).

practical feasibility (e.g., EASAC, 2018; Minx, et al., 2018; National Academies of Sciences, 2018). Lenzi et al (2018) argue that uncertainties surrounding potential side effects of NETs at vast scales even raise a question of whether it is obvious that lower temperatures are ethically preferable ("Keeping within 1.5°C could cause side effects that are as bad as those in a world that is 2°C warmer") and make the point that ethicists and social scientists should be more deeply involved in the elaboration of mitigation scenarios.

The IPCC Special Report on Climate Change and Land (IPCC, 2019) shows that many nature-based CDR strategies can be applied without competing for land (such as sustainable improved and sustainable forest management, and increased soil organic carbon content and agroforestry) and have the potential to provide multiple co-benefits. The report however also highlights that the use of land-based solutions options (such as BECCS and afforestation) when applied at large scale and in an unsustainable manner, can increase pressures on land and food security, with negative effects on adaptation and land degradation. The feasibility and sustainability of CDR use could be enhanced by a portfolio of options deployed at substantial, but lesser scales, rather than a single option at a very large scale. Feasibility and sustainability can also be strengthened through complementary measures, such as dietary change, and reduction of food waste and loss, that can reduce pressure on land while contributing to poverty eradication and improving health and sanitation.

Several authors warn that the significant contributions of NETs in climate stabilization scenarios might distract from engaging in rapid and deep mitigation policies now. Placing an unrealistic expectation on such backstop technologies could thus have irreversibly damaging consequences if NETs are unsuccessful at removing CO_2 from the atmosphere at the assumed levels (either due to failure to develop into viable, commercial technologies or due to delayed development, or both) thus locking society into a high-temperature pathway (e.g., Fuss et al, 2014; Anderson and Peters, 2016; Lenzi et al, 2018; Anderson et al., 2019).

Recent comprehensive assessments have confirmed that uncertainties surrounding the real-world potentials of NETs are significant. The European Academies Science Advisory Council (EASAC) have reviewed the scientific evidence on several possible options for CDR using NETs and concluded that the realistic potential to remove carbon from the atmosphere is limited and not at the scale envisaged in some climate scenarios (EASAC, 2018). According to a comprehensive assessment by the National Academies of Sciences (2018), the potential global uptake from current technologies is substantially lower than the negative emissions in most scenarios that would produce less than 2°C of warming. The assessments highlight the importance of concerted R&D efforts to address the constraints that currently limit deployment of both existing NETs and NETs that are in less advanced development stages and NET piloting in order to both enable scaled-up deployment and rapidly build further knowledge concerning their potentials and limitations from technical, economic, social and environmental etc. points of view.

Obersteiner et al (2018) observe a problem of a different kind with the current dominating low-temperature stabilization scenarios, namely that these typically feature very large mitigation contributions from NETs in the last decades of the century and that this raises issues related to intergenerational equity to carry the burden of mitigation. The late deployment in the scenarios is largely due to discounting over a 100-year time horizon and a related preference for deferring investments. In a recent article, Bednar et al. (2019) propose a changed perspective on the role of NETs in climate change mitigation policy that builds on two main pillars (i) earlier and more radical mitigation than current Integrated Assessment Model simulations suggest and (ii) near-term development and ramping-up of NETs to clarify the actual potential and scaling properties of specific pilot technology-options and to avoid their non-realization. As it stands increasingly clear that the phasing out of fossil fuels and the deployment of NETs is not a matter of "either/or" but rather a "yes, and" (Anderson et al., 2019), the need for mechanisms for encouraging the development and introduction of NETs is gaining more attention (e.g., Honegger and Reiner, 2018; EASAC, 2018; Bednar et al. 2019; Burke et al., 2019).

Against this background, and since there is no natural demand for BECCS, incentives would need to be introduced in order for demonstration to commence and ensure that learning and commercialization will take place at a sufficient rate. The existence of so-called "knowledge spillovers" (that competitor firms can observe the result from demonstration projects and learn from them without having to make the required investments themselves) creates a hesitance among companies to fund demonstrations. This free-rider situation creates weak incentives for companies to fund demonstration, thus motivating government intervention and designing demonstration programs aimed primarily at knowledge generation (Nemet, et al., 2018).

Under any circumstances, mankind's capacity to remove very large quantities of atmospheric CO_2 in this century is of crucial importance for the global effort to achieve temperature goals in line with the Paris Agreement. Sweden's work towards climate neutrality in 2045 and achieving negative emissions thereafter and any potential future policies that provide for industrial NETs should thus be seen in a global perspective. Sweden is well-positioned to deploy BECCS at scale (Johnsson and Kjärstad, 2019) in the near-term. By taking a role as an early mover in incentivizing and deploying BECCS, Sweden can show the kind of global leadership in the development of NETs that the world urgently needs from many nations.

A final point that should be made is that the case for the development and commercialization of NETs does not rest solely on the adoption of a well below 2°C climate target. As pointed out by Grönkvist et al. (2006), NETs can potentially reduce the cost of regional or national programs to limit GHG emissions by reducing the need to eliminate emissions from more challenging sources of GHGs (such as those from agriculture, transportation, some emissions from land-use change, or aviation fuels.

4 The development status of BECCS

Technology for CO_2 capture from gas streams is well-established in some applications. Similarly, technologies for CO_2 compression, transportation and geological storage are also available (Johnson and Kjärstad, 2019). Yet, there are ample opportunities to further develop the individual technologies, through research, development and demonstration, in particular CO_2 capture technologies.

Globally just a few facilities are actively using BECCS technologies[8], e.g.:

- In Illinois, USA 1 MtCO2/year is captured from corn-based ethanol production. The CO_2 is stored in a dedicated geological storage site deep underneath the facility.
- In Kansas, USA 200 000 tCO_2/year is captured from an ethanol plant in Kansas and transported in pipelines to Texas for enhanced oil recovery (EOR).
- Also in Kansas, USA 100,000 tCO_2/year was captured from an ethanol plant and transported in pipeline to a nearby oil field for EOR.
- In Saskatchewan, Canada, 250 tCO_2/day is captured from the fermentation process in an ethanol plant and transported by truck to nearby oil fields for EOR.

Notably, these early BECCS projects sequester CO_2 from the fermentation process of ethanol production where a stream of high CO_2 concentration and purity is generated thus making the capture relatively easy.

Furthermore, a number of projects going beyond capture from ethanol production are in the planning phase, including in North America, Japan, and the EU, e.g.:

- The Drax power station in the UK converted four of its six generating units from coal to wood pellets. A pilot project commissioned in February 2019 that captures one tCO_2/day is planned to be operated throughout 2019. Drax's stated objective (subject to the right policy is to fully convert the first of its four biomass units to BECCS by the mid-2020s, with the other units being converted on a modular basis in the following years (IOGP, 2019).
- In the autumn of 2019 Stockholm Exergi installed a test facility to capture and store CO_2 emissions from a biomass-fed CHP plant in Stockholm. During a testing period up to 700 $kgCO_2$/day will be captured. After the test is completed (tentatively in June 2020), it will be evaluated. Experiences from the trial will be useful for a decision regarding a possible pilot or full-

[8] https://co2re.co/FacilityData

scale plant. Stockholm Exergi estimates that there is a potential to capture 800,000 tCO_2/year if full-scale BECCS is deployed at the CHP plant.[9]

Separating CO_2 from power plants (or combined heat and power plants) is still at demonstration or early commercialization stages of identifying and overcoming technical problems (in particular, the loss of efficiency in the overall conversion of fuel to electricity) (EASAC, 2018, NAS, 2019). For BECCS more generally, integrating the entire value chain from CO_2 capture to geological storage (e.g., Johnsson and Kjärstad, 2019) needs demonstration at large-scale.

Benefits of demonstration, which can be defined as "an operational step in a real-world environment at, or near, commercial scale to show technical and commercial viability" (IEA, 2019), include that they provide information on costs and performance to manufacturers, potential buyers and policymakers. At this stage, investors typically face the highest risks, and according to the IEA (2019), the need for government support is at its highest.

The current development phase of BECCS means that project developers face multiple barriers and uncertainties ranging from technical, economical to legal, regulatory and perception/acceptance etc. (e.g., EASAC, 2018; NAS, 2019; CSLF, 2019). This implies that policy instruments are required that substantially reduce project developers' risks.

[9] https://news.cision.com/se/stockholm-exergi/r/stockholm-exergis-teknik-att-fanga-in-koldioxid-far-stod-av-energimyndigheten,c2893909.

5 Policy instruments to incentivize negative emissions through BECCS in the near term

BECCS (as well as other NETs) can be incentivized if CDR is attributed with an economic value. However, conventional carbon pricing - a penalty on positive emissions alone - is not enough (Burke, 2019; Fridahl M, 2019; Zetterberg L, et al, 2019). A price on (positive) emissions discourages the release of carbon dioxide of fossil origin but does not encourage CDR given the current approach in carbon accounting whereby biomass exploitation is recorded as land-use change and emissions from biomass combustion as zero.[10] This principle could in theory be abandoned in favor of an accounting system where CO_2 emissions from biomass combustion were treated the same way as emissions from fossil fuels. Then a penalty on positive emissions would incentivize BECCS in the same way as it would incentivize CCS applied to emissions from fossil fuels. Such a change would, however, be a very large step and would require a revision of the principles for Land Use, Land Use-Change, and Forestry (LULUC) reporting/accounting in order to avoid double counting of CO_2 of emissions biogenic origin.

An alternative, and more feasible, way of incentivizing BECCS would be to set up a complementary price mechanism to encourage the development and use of NETs. The way CDR is rewarded will have implications for the performance of the mechanism.
A number of generic ways in which CDR through BECCS may be attributed with an economic value through public intervention are listed below, based on (Burke, 2019; Zetterberg L, et al, 2019; Fridahl M, 2019). Note that all the options would require a governance system that secures environmental integrity, including rules for robust Monitoring, Reporting and Verification (MRV) and certification that, in the end, leads to the issuance of certified CDR units.[11] A practical approach would

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[10] There are several ways in which anthropogenic CO_2 emissions can be caused. For instance, carbon-containing materials – with either a biomass or a fossil origin – can deliberately be chemically or biologically degraded or be combusted and in these processes, the CO_2 will normally reach the atmosphere. National reporting of fossil CO_2 emissions is based on atmospheric flows, which means that the CO_2 flux from the carbon pool to the atmosphere is estimated in the country where decomposition takes place. On the other hand, the reporting framework in the Land Use, Land-Use Change and Forestry (LULUCF) sector is based on estimating net carbon stock changes in biomass in a number of broadly defined carbon pools of the reporting country. Any net decrease in carbon stocks in the included pools is reported as the equivalent CO_2 emission and any net increase is reported as the equivalent CO_2 removal. Emissions from the combustion of biomass are generally considered "climate neutral" and only reflected indirectly, through biomass harvesting which influences the balance of the carbon pools considered in the reporting framework (Grönkvist et al., 2006.

[11] Generally speaking, robust principles for establishing baselines and "additionality" is an important prerequisite for environmental integrity when mitigation outcomes are to be used to offset other emission sources. In the case of BECCS in the near term, additionality can be easily established in many cases due to the relatively high abatement costs involved. One exception would be the combination of geological CO_2 storage with so-called Enhanced Oil Recovery (EOR). EOR is the process of increasing the amount of oil that can be recovered from an oil reservoir, usually by injecting a substance into an existing oil well to increase pressure

be that any verified CDR units would accrue to accounts of the project developers that capture biogenic CO_2 in Sweden. They would, therefore, be eligible for payments from the support system. The indirect funding of CO_2 transport and/or geological storage managed by other actors would require contractual arrangements with the project developers that capture CO_2 in Sweden.

- A predetermined, uniform compensation (a long-term guaranteed price) for CDR where the Government would reward all producers with a fixed price for each ton of verified CDR unit (similar to feed-in tariffs).
- Government-led CDR auctions. The government would procure specified quantities of verified CDR units. Price bids from producers would be obtained through reverse auctions and contracts are awarded to the bidder(s) that submit the lowest bid(s).
- A quota obligation where the Government creates a demand for CDR by introducing a quota obligation for sectors with significant residual GHG emissions. Emitters in the concerned sectors would be obliged to purchase CDR units in proportion to the GHG they emit. Producers of CDR would be able to sell CDR units they receive from the state on the basis of MRV.
- A carbon fee where emitters of GHG above certain thresholds would pay a fee and the revenue would be allocated to producers of CDR.
- A negative tax on CO_2, i.e., a subsidy for CDR on par with the level of the CO_2 tax.
- CDR credits that can be generated and traded in the EU-ETS. A CDR credit would be a unit representing the removal of 1 ton of CO_2 and issued by the state or an appointed entity. In order to not inflate supply emittance of CDR credits would need to be accompanied by a corresponding cancellation of units elsewhere in the system.

A main objective of this study was to analyze two policy instruments - one of which with a predetermined price and one with a predetermined quantity. The study will thus consider the following two options for further analysis:

(i) A uniform and pre-determined long-term guaranteed compensation level per verified CDR unit delivered. The price is paid for a fixed number of years. This increases the stability and allows for long-term planning ("Pre-determined, Uniform Compensation"), and

(ii) Government-led auctions and long-term Negative Emissions Purchase Agreements (NEPAs) between the winning bidders (suppliers) and the state ("Procurement Auctions").

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and reduce the viscosity of the oil. In such cases the revenues from incremental oil production would have to be considered in additionality assessment. Furthermore, the incremental oil production would have to be considered in the determination of the decrease of emissions between the baseline scenario and the project scenario. These considerations are complex and there may be public acceptance issues in relation to EOR. It may, therefore, be worth considering whether BECCS activities should be made ineligible for state support in case captured CO_2 is used for EOR.

In the next section, they are subject to a qualitative assessment against a set of criteria.

6 Assessment of selected policy instruments against criteria

In this section, the two policy instruments selected for further evaluation in the previous section are characterized and evaluated against a set of criteria. The evaluation is based on information available in the literature, which to a large degree is based on experiences from government initiatives to promote renewable energy (Lucas, et al., 2013; Grau, 2014; Naturvårdsverket, 2014; Passey, et al., 2014; Cerda and del Rio, 2015; Wuester, 2016; Zuraidah and Radzi, 2016; Dobrotkova, et al., 2018; Fridahl, 2019; Kitzing, et al., 2019) as well as on the results from the interviews carried out for this study. It remains to be seen to what extent the experience-base from renewable energy promotion is relevant for BECCS. Some significant differences between the two cases as well as possible implications are outlined below.

6.1 General description of the policy instruments

Below, the main features of Procurement Auctions and Predetermined, Uniform Compensation are outlined:

General features of Procurement Auctions
• In a "Procurement auction" the government will specify the quantity which is up for auction and other evaluation criteria. • Project developers can then submit a bid to the auction, outlining their project proposal and stating the price per unit delivered at which they will be able to realize their project. • The government then evaluates the different offers, ranking them based on their price and other criteria. • The best candidates are then selected, and the government signs a long-term purchase agreement with the successful bidders. • Auctions are flexible and can be organized in many ways.

General features of Pre-determined, Uniform Compensation
• A pre-determined and uniform compensation level is guaranteed for suppliers (or a premium tariff which adds a bonus to the wholesale market price, however, this is not applicable to BECCS where there is no natural demand). • The supplier signs a contract that entitles it to sell its commodity. The compensation is paid from state budgets. • The total quantity may be unregulated or capped (either by limiting the quantity supplied or total payments that may be awarded. • The compensation is paid for a fixed number of years. There is often a tradeoff between duration and magnitude of compensation per unit commodity. • Policies may have a built-in digression rate, a mechanism for gradually reducing the compensation paid according to the number of years after policy enactment the contract is signed to slowly adjust the incentive provided and to adapt to increasing economic viability.

Based on a literature review (see introduction to this section) the following main strengths and weaknesses of Procurement Auctions and Pre-determined, Uniform Compensation have been identified:

Strengths and weaknesses of Procurement Auctions	
Strengths	Weaknesses
• High competition results in cost-effectiveness and can provide price discovery of different technologies. • Limits can be set by the authorities for the quantity and the budget. • High investor security if auctions are linked to long-term purchase agreements. • Guaranteed purchase at a fixed price, leads to favorable financing options and potentially lower prices.	• Discontinuous market development (stop-and-go cycles). • Difficult for bidding companies due to the high transaction costs (project proposals need planning, feasibility study, risk assessments) and the risk of not getting a return on investment in case a bid is not chosen. • High administrative costs.

Strengths and weaknesses of Procurement Auctions	
• Bids can be selected according to specific criteria in addition to price. This allows for multiple country-level priorities to be considered, e.g., related to innovation.	• High competition can lead to underbidding which results in low financial returns, contract failure or attempted post-auction price raises by successful bidders. • Insufficient competition can lead to unjustifiably high bids. • In open auctions there is a risk of collusive behavior between bidders to drive up prices.

Strengths and weaknesses of Pre-determined, Uniform Compensation	
Strengths	Weaknesses
• Simple policy model. • Long-term security drives technological development. • Facilitates the entry of new players in the market. • Long-term investment security offered drives industrial innovation/development. • Often funded by consumers and not exposed to public budget cuts. • Because it is output-based it provides an incentive to maximize production.	• Tariff setting and tariff adjustment process is challenging and complex, finding the best compensation level (and digression mechanism, as applicable) for each country is difficult. • There is less control over the quantity generated. Large budget spending when high deployment rates are achieved. • When funded through a budget the stability of the policy is linked to the budget reliability.

6.2 Evaluation against criteria

6.2.1 Cost-effectiveness

Cost-effectiveness can be discussed from a static (short-term) perspective or a dynamic (long-term) perspective (Söderholm and Hammar, 2005). Cost-effectiveness from a static perspective measures how society can fulfill an environmental goal at the lowest possible cost at a given time. However, it is possible to think of measures that are relatively expensive in a short-term perspective but, if implemented early would promote cost-effectiveness in the long term. The underlying cause is that investing in a measure provides opportunities for producers and users to learn from the experience and thus to lower the cost of the technology. Investments in new wind turbines, e.g., give rise to learning effects in turbine manufacturing, which favors (in principle) all future wind power investors in the form of lower costs. This justifies, among other things, the introduction of, e.g. certificate markets, that ensure a given market share for renewables electrical power sources. Dynamic cost-effectiveness takes into account when in time different measures should be taken to minimize future costs. The literature reviewed primarily discusses cost-effectiveness from a static point of view (the generation of a certain volume at the lowest possible cost. Impacts related to learning and technology development are discussed in sections below.

Importantly, the main difference between Procurement Auctions and Pre-determined, Uniform Compensation is the price discovery mechanism. For the former, project developers determine the price through competitive bidding between the bidders. For the latter, on the other hand, the compensation rate is pre-determined by the policymakers. Therefore, Pre-determined, Uniform Compensation requires considerable 'guesswork' concerning current and future market conditions, the rates of technological development, etc. Once the compensation is set, all actors who choose to implement measures to receive compensation are likely to have lower costs (below the pre-determined price level) than those who do not implement measures. However, there is likely to be a large uncertainty regarding the corresponding quantity that will be delivered, and therefore also with respect to the required government budget spending. On the other hand, if the quantity is capped in order to remediate budget uncertainty the cost-effectiveness will be undermined since compensation will be based on a first-come, first-served basis and some project developers with higher production costs are likely to win the race to deliver within the cap before some developers with a lower cost.

If a country does not have much experience with setting prices for a certain technology and data are scarce, then auctions are a useful way of discovering the true cost of the technology. For Procurement Auctions, underbidding (i.e., project developers with higher costs place bids with a lower markup in an effort to establish large market shares) or unjustifiably high bids (project developers aiming for a high markup) may lead to cost-inefficient combinations of producers winning an auction. This effect is likely to be most significant in a first-tranche auction and then diminish with consecutive tranches as the market actors gain knowledge about competitors' costs. According to theory, Procurement Auctions can help reduce the overall public budget spending since the compensation can be limited to the individual level necessary for each project developer.

Consequently, for auctions to be successful they need to be competitive. This means that there needs to be enough interest amongst project developers in the country to invest in the technology. The auction should be oversubscribed so that the generation capacity offered by all of the bidders (suppliers) is higher than the demand from the state. The interviews carried out suggest that there is considerable interest among potential project developers in taking part in the demonstration of BECCS. BECCS has clearly been up for discussion in companies and there are several examples of pre-feasibility studies and feasibility studies etc that have been made.

Finally, according to literature transaction costs for buyers and sellers are generally higher for Procurement Auctions compared to a policy based on Pre-determined, Uniform Compensation due to the relatively higher administrative burden of Procurement Auctions. This needs to be considered in the overall assessment of cost-effectiveness and public budget spending.

6.2.2 Target achievement

In this section target achievement is primarily discussed in relation to technology development. Furthermore, the policy instruments' ability to achieve pre-determined CDR volume targets is also discussed.

6.2.2.1 Contribution to technological development

A definition of technological change in the context of climate change has been proposed by Nemet (2013): 'a process typically involving stages of invention, innovation, and diffusion, whereby users can produce more or better outputs from the same amount of input.' One can think of innovation in NETs as generating more CDR, fewer adverse side effects, and more societal acceptance. Describing innovation as a progression from early stages to later ones has been criticized as a simplistic model that oversees important features, such as networks of actors or innovation systems (Geels, 2004). However, the notion that there is an essential sequence to them remains useful (Balconi et al., 2010). The literature is also consistent in describing that the mechanisms at work, capital required, level of risk, and actors involved are distinct across stages and that, as technologies pass through each stage, the level of risk taken by investors is successively reduced and likewise the need for public support (IEA, 2019).

The way innovation happens may also change over time. E.g., innovation in emerging areas such as digitalization and distributed energy is very different from traditional, capital-intensive hardware innovation. New technologies for software and digital-based products have shorter innovation cycles and can be brought to the market quicker (IEA, 2019).

As noted in section 4 of this report, BECCS can be regarded as being in a demonstration and early commercialization stage. As technologies progress from R&D to the demonstration stage, they need to prove that their performance is adequate and that they can function reliably in non-laboratory environments. At this stage there is a need to reduce uncertainties/risks by building one or more examples. One problem that emerges, known as "knowledge spillovers", is that competitor firms, or countries, can observe these demonstrations and learn from them without having to make the required investments themselves (Nemet, 2018). This creates a hesitance among companies to fund demonstrations. Governments are also often hesitant due to, amongst others, the magnitude of investment required, a mixed track record of success, and to some extent perceptions that they will be 'picking winners '. Research assessing this hurdle provides several useful insights that should apply to BECCS (Nemet, 2018). Above all demonstration programs should be designed as a portfolio of projects so that the program is robust to failure in a single project and knowledge generation should be a higher priority than production. The scope of this study is limited to establishing incentives for the deployment of BECCS. One could, however, consider creating a broader portfolio of NET demonstration projects. The feasibility of including several NETs under one incentive scheme is discussed in section 5.2.5.

Reiner (2016) discusses learning through demonstration efforts and identifies two chief values in either revealing technology performance relative to expectations or relative to other technologies (learning from diversity) or demonstrating potential cost reductions at later stages (learning from replication). The author notes that replication has been (and is) particularly important for technologies such as solar photovoltaics or wind but also that CCS projects are 'lumpy' (fewer and large-scale) and recommends that in the near-term, therefore, priority in demonstration should be on learning from diversity.

It seems likely that of the two policy options Procurement Auctions and Pre-determined, Uniform Compensation, the former alternative would have greater potential to be used as an instrument to promote technological development. Procurement Auctions are inherently more flexible, can be organized in auction cycles, quantities can be easily capped, and bids be selected according to specific criteria in addition to price. These aspects taken together, Procurement Auctions are likely to be more capable of facilitating the design of a portfolio of projects that is useful for learning by diversity.

6.2.2.2 Achieving pre-determined CDR volume targets

When knowledge of producers' costs is scarce, e.g., due to a lack of previous experience, Procurement Auctions have a clear advantage concerning achieving specified quantities. The authorities can clearly define the quantity to be procured (in this case tons of geologically stored biogenic CO_2) and/or budget limits. For Pre-determined, Uniform Compensation, on the other hand, the lack of information for predicting BECCS project developers' costs means that it is difficult for authorities to determine a compensation level that will lead to a desired volume.

Some respondents argued that policies that incentivize investments in BECCS would be likely to crowd out other investments[12], including investments that increase production. This could potentially reduce the CO_2 being sequestered in forests and woody building materials and other types of long-lived forest industry products. It goes beyond the scope of this study to analyze whether this could materially reduce the CO_2 mitigation impact of project activities. However, one remark is that it seems plausible that investment support for BECCS, e.g., through grants or advance payments for verified CDR units, could be a way to reduce the risk of BECCS support leading to the diversion of other investments that mitigate CO_2 emissions (since additional up-front finance would become available).

[12] In capital-intensive industries investment options are usually characterized by intensive internal competition for capital (Möllersten and Sandberg, 2004; Swedish Energy Agency, 2007). In principle, projects are ranked by (i) financial return and (ii) whether they contribute to improved competitiveness, and then funded from best to worst. When capital is allocated to investments in BECC projects, less capital will be available for other investments.

6.2.3 Legal compliance

Provisions for state aid in the Treaty on the Functioning of the European Union (TFEU) have implications for public payments (from states or regional or local authorities) to companies. State aid is defined as an advantage in any form whatsoever conferred on a selective basis to undertakings by national public authorities. Since a company that receives state aid gains an advantage over its competitors the treaty generally prohibits state aid unless it is justified by reasons of general economic development. The treaty leaves room for a number of policy objectives for which state aid can be considered compatible.[13] The EU legislation makes CCS projects (applied to emissions from fossil fuels or biomass) exempt from the general prohibition in the TFEU.[14] The term of the exemption is 2014 to 2020 and the Commission has expressed that the term of the exemption will be extended two years. An analysis of the provisions provided by the Commission suggests that both Procurement Auctions and Pre-defined, Uniform Compensation should be compliant with the exemption for CCS projects.[15]

Public payments for CDR units from BECCS should therefore be compatible with the EU provisions with respect to state aid at least until 2022. It may be reasonable to assume that the term of the exemption will be extended further given the urgent need to commercialize CCS to achieve EU and global GHG mitigation targets.

6.2.4 Acceptance

From an acceptance point of view, it is an important observation that Pre-determined, Uniform Compensation features a weakness in relation to control over the quantity generated. This leads to large uncertainties with respect to the associated costs for the state (i.e., payments for CDR units at the pre-determined unit price) and potentially large budget spending. Using Procurement Auctions allows more effective ex-ante control over quantities and costs, which implies less significant acceptance challenges.

Respondents in the interviews generally expressed a positive interest in incentives for BECCS. However, a serious concern raised by some respondents, in particular by representatives of the forest industry, is related to the general treatment of

[13] Article 107(3)(c), which allows aid to facilitate the development of certain economic activities, provided it does not adversely affect trading conditions to an extent contrary to the common interest.
[14] Communication from the Commission. Guidelines on State aid for environmental protection and energy. (2014-20202014/C 200/01).

biogenic CO_2 emissions. The concern is that policies that reward BECCS could be the first step in a process that would lead to a deviation from the current principle in carbon accounting rules that record biomass exploitation as land-use change and emissions from biomass combustion as zero. Hence, there is possibly a reluctance to develop BECCS projects and generate CDR should it not be made quite clear that CO_2 emissions from biomass combustion will be counted as zero also in the future. This is an important aspect as policy credibility is an important issue in climate policy in general and will likely become central to the success of NETs (Nemet et al., 2017; Nemet, 2018).

6.2.5 Flexibility to include other NETs than BECCS in the future

Multiple NETs have been proposed that differ amongst others in the mechanism of CO_2 fixation (biological versus chemical) and the final repository for carbon. CCS-based NETs target CO_2 sequestration in geological reservoirs (BECCS and Direct Air Capture with CCS - DACCS). "Nature-based" approaches capitalize on the ability to manage ecosystems for increased carbon sequestration and aim to strengthen the carbon sink either on land or coastal regions (Afforestation/Reforestation - A/R; Soil Carbon Sequestration– SCS; BioChar – BC; Enhanced Weathering – EW; Wetlands Restoration– WR) or in the ocean (EW; Ocean Alkalinization - OA; Ocean Fertilization – OF). Some NETs can also be combined, e.g., different combinations of EW, BC, SCS, and A/R are possible.

There are significant differences between NETs on different levels. E.g., the mechanisms by which carbon is sequestered vary which has crucial implications for permanence, there are large variations in abatement cost, and there is a significant variation with respect to the technological readiness level of NETs (ranging from research (e.g., EW) to commercial (A/R). Due to these differences, combining BECCS with other NETs under the same policy (be it auctioning or a pre-determined, uniform compensation) could not be done without challenges.

BECCS and DACCS could be addressed within the same incentive scheme since the two NETs use an identical approach to CO_2 sequestration. However, DACCS is currently limited by high cost and would simply not be competitive compared to BECCS in the near term.

Combining BECCS and A/R or BC under one incentive scheme could decrease the cost of CDR. However, since the lower abatement costs of A/R would render

BECCS not competitive the push for technological development of BECCS would be much reduced. Moreover, the fact that the permanence of carbon sequestration varies (carbon sequestration through A/R can be reversed caused by natural or anthropogenic disturbances) would make the setting of rules for a common incentive scheme complex.

One example of an incentive scheme that includes permanent emission reductions (e.g. decreased emissions from fossil fuel combustion through energy efficiency or fuel switch) and reversible carbon sequestration through A/R, and that recognizes differences in permanence between methods, can be found in the Clean Development Mechanism (CDM). CDM A/R projects address reversals by issuing expiring (temporary) credits (Olschewski and Benítez, 2005).[16] Upon expiration, these credits must be replaced. Expiring credits are not directly fungible with other CDM credits and their replacement requirement raises the cost to the buyer of using them relative to a full-price permanent credit, thereby reducing the monetary value of the credit. The use of expiring credits has not been successful in the CDM - A/R projects account for less than one percent of all CDM projects to date (Galik et al., 2016). To guarantee that any reversal of stored carbon is duly accounted for, it is important to ensure that the implementing country properly monitors and accounts for any potential reversal across time, including across consecutive NDCs. Therefore, it is important to ensure that implementing countries have in place robust systems for monitoring, reporting and verification (MRV), and for accounting for potential reversals across time. The permanence of stored carbon is also linked to the benefit-sharing and the recognition of co-benefits: if lands are providing many co-benefits, then it will be in the country's interest to protect these lands and to take appropriate governance decisions to avoid reversals.

7 Practical considerations with respect to implementation and administration

The previous section assessed two policy options – Procurement Auctions and Pre-determined, Uniform Compensation – against a set of criteria. This section

[16] The CDM Modalities and Procedures feature two type of expiring A/R credits, so-called long-term Certified Emission Reductins and temporary Certified Emission Reductions.

discusses a number of areas that are general to the policy instruments and the aim is not to compare or identify differences between the policy options.

7.1 Interaction with other relevant policy instruments

A short description of other available relevant funding sources is provided below. Finally, it is considered how they could be coordinated with support through Procurement Auctions or Pre-defined, Uniform Compensation.

The Innovation Fund

The Innovation Fund is one of the funding instruments supporting the European Commission's strategic vision for a climate-neutral Europe by 2050 as outlined in its communication "A Clean Planet for All"17 of 28 November 2018. The EU Emissions Trading System (EU ETS) is providing the revenues for the Innovation Fund from the auctioning of 450 million allowances from 2020 to 2030, as well as any unspent funds from the NER300 program. The European Commission has announced that it aims to launch the first call for proposals already in 2020, followed by regular calls until 2030.

The Fund will support the demonstration of, amongst others, low-carbon technologies and processes in energy-intensive industries, including carbon CCS applied to emissions from fossil fuels or biomass. The projects need to be sufficiently mature in terms of planning, business model, financial and legal structure and technologies need to be at advanced technology readiness levels.

The Innovation Fund support will be provided through pre-defined milestones, with clear criteria for withdrawing funding in case of failure in order to make funds available to other projects as quickly as possible. The selection procedure is also simplified and takes into account the economic viability of projects, their compliance with EU and national climate and energy policy priorities, and the existence of a firm commitment from member states vis-à-vis the project.

The Fund will support up to 60% of the additional capital and operational costs linked to innovation mainly via grants. The grants will be disbursed flexibly based on the needs of the market and the concrete project, taking into account the milestones achieved during the project's lifetime. Up to 40% of the grant can be given based on pre-defined milestones before the whole project is fully up and running.

[17] COM(2018) 773

Swedish support for CDR

As of 2019 the Swedish government allocated 100 M SEK support for CDR. A call for proposals from the Swedish Energy Agency clarified that the support should go towards BECCS and that eligible activities include investments, feasibility studies, and R&D. Companies, institutes, universities, and the public sector are listed as eligible to apply for support.

The Connecting Europe Facility

The Connecting Europe Facility (CEF) is an EU funding instrument that supports the development of high-performing, sustainable, and efficiently interconnected trans-European networks in the fields of transport, energy, and digital services. CEF investments fill the missing links in Europe's energy, transport, and digital backbone. For CCS pipeline infrastructure could be funded. CEF has supported LNG terminals, hence also infrastructure that facilitates cross-border ship transport of CO_2 should be eligible.

Coordination of support

Depending on the project design, project developers could potentially seek funding from one or more of the above support facilities. Project developers could seek to combine up-front and operational support obtained this way with payments either through Procurement Auctions or Pre-determined, Uniform Compensation. Coordination, from the authorities' point of view, would be significantly more feasible in the case of Procurement Auctions due to the flexibility to include case-specific provisions in NEPAs.

One question that has been raised when the scope of this study was determined concerns the possibility to require that successful bidders in an auction seek support from other possible funding sources. This way the resulting government payments could potentially be reduced by an amount that corresponds to support received from other funding sources. It has been suggested that such a requirement could potentially create a significant barrier to project developers' interest in participating in auctions. Applying for funding, in particular from EU funds, can be perceived as cumbersome and associated with high transaction costs. The interviews performed in this study indicate that this should not be the case. The respondents generally regard applying for funding from relevant EU funds etc. as a regular part of a process that involves investment in pre-commercial technologies. A practical way to solve this situation could be to include so-called conditions precedent[18] (CP) in NEPAs stating that the project developer should be able to demonstrate that it has made a reasonable effort to apply for funding from one or more specified support facilities in according with certain milestones. In this way, project developers would be guaranteed (via the NEPA) compensation at the agreed price for future verified CDR units delivered when initiating the work to apply for additional funding, and the state could ensure that the project developer would make a reasonable effort to receive additional alternative funding that could reduce the cost of the state.

7.2 Terms of NEPAs (Negative Emission Purchase Agreements)

There is no clear-cut answer to how long the term of a NEPA should or needs to be. Respondents generally argued that the term over which the state would commit to paying for annually verified CDR units has to be sufficiently long to allow for the required return on investment. Generally, respondents considered 10 years to be at the lower end of what would be necessary and that any term less than 20 years would imply a risk premium on the unit price of contracted CDR units. Some respondents highlighted that limiting the term of the contract could also bring opportunities due to the future growing demand for CDR units in markets that are likely to emerge.

Since the contract period is anticipated to be rather long, NEPAs would have to legally regulate risks and the Contracting Parties' respective obligations and responsibilities (e.g., in case of underperforming technologies and unanticipated disruptions related to the access to geological storage beyond either party's control). How to handle such division of responsibilities and obligations can be guided by standard contracts and clauses used in commercial law.

The competitive character of Procurement Auctions may also pose challenges in relation to target achievement. Investors may issue bids of unrealistically low prices that cannot recover their development and running costs and consequently fail to deliver their projects. Such failures will result in delivery shortfalls compared to agreed quantities in NEPAs and thus risk underachievement of policy

[18] In contract law, a condition precedent is an event which must occur, unless its non-occurrence is excused, before performance under a contract becomes due, i.e., before any contractual duty exists.

targets. This risk can be reduced if the authorities conduct a rigid counterparty Due Diligence[19] (DD) as part of the contracting process.

7.3 Auction volumes

Feasibility studies for BECCS projects in Sweden are in the range from slightly below 1 MtCO_2 down to a few hundred thousand tCO_2 annually per project. Technology choices are case-specific depending on the nature of CO_2-containing gas streams and costs of CO_2 capture vary widely depending on technology.

There are significant economies of scale in BECCS. This is mainly due to the specific cost of CO_2 capture decreasing rapidly as the volume (tons per second) increases (Garðarsdóttir et al., 2018) but also due to economies of scale in CO_2 transport and geological storage. At the same time, there are certain point sources of CO_2 that are pure and concentrated where the CO_2 capture can be done at a relatively low cost even at a smaller scale.

An initial auction taking in bids for projects up to 1 MtCO_2 per year would allow for project sizes that take significant advantage of economies of scale. If an initial auction were followed by 1-2 further tranches a target volume of 2-3 MtCO_2 per year would allow for 3-4 BECCS projects of significant scale.

Potentially, auction tranches succeeding the initial auction could lower the maximum size in order to enable smaller projects to compete and create a diverse portfolio of projects. It is difficult to predict participation and the level of competition should a Procurement Auction be initiated. However, authorities would be able to learn from experiences in an initial tranche and could adapt terms in any succeeding tranches depending on experiences from earlier tranches.

7.4 Payment on delivery only or in combination with investment support?

The view regarding the need for investment support varied among respondents in the interviews. Some potential project developers are prepared to invest in BECCS only on the basis of guaranteed future payments on delivery of verified CDR

[19] Due diligence is the investigation or exercise of care that a reasonable business or person is expected to take before entering into an agreement or contract with another party.

units[20] (provided a sufficiently high unit price). For others, however, the availability of investment support would strengthen incentives to invest. Thus, it is likely that including a possibility in Procurement Auctions to place bids that are based on a combination of investment support and payment on delivery would increase competition.

Obviously, advance payments for CDR units would imply a risk premium on the side of the state and would, furthermore, require contractual arrangements that regulate risks related to project non-realization, etc.

7.5 Methodologies/protocols for MRV and accounting

Concerning MRV, the geological storage of CO_2 requires special attention. To ensure that sequestration projects are safe and effective, it is necessary to track the location of the plume of sequestered CO_2, measure the pressure buildup in and above the storage reservoir, confirm that the injection wells or other wells penetrating the storage formation are not leaking, and look for leakage into groundwater (IPCC, 2005). Requirements or guidelines for monitoring are a key part of government regulations for CO_2 sequestration projects (e.g., the EU CCS directive[21]). Numerous pilot tests and commercial operations have demonstrated a wide range of monitoring techniques.[22]

A range of GHG MRV and accounting protocols and guidelines currently exist for CCS activities, and various activities continue in this area. Such guidelines exist at the project-, entity-, state-, country- and international-level, and work is ongoing to develop common accounting approaches, including an ISO standard under development.[23]

In terms of GHG accounting, some key requirements apply to all BECCS projects (Cook et al., 2016):

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[20] As already mentioned in section 4, a practical approach would be that any verified CDR units would accrue to an account held by project developer that capture biogenic CO_2 in Sweden. They would, therefore, be eligible for payments through the support system.

[21] Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide.
[22] https://co2re.co/FacilityData
[23] ISO/TC 265.

- Recognition of "negative emissions" from BECCS. GHG accounting schemes and associated MRV rules need to adequately evaluate, attribute, and reward any negative emissions associated with BECCS activities.
- System boundaries and inter-temporal consistency:
  - Including transport and storage within the accounting rules. MRV rules need to be developed also for monitoring of transport and storage.
  - A mechanism to address permanence. Appropriate accounting and MRV rules must provide assurances that the injected CO_2 remains in the intended geological formation and isolated from the atmosphere over the long term and quantify any leaks that occur. Permanence typically requires provisions in relation to storage site selection, storage operation and closure, and short-, medium- and long-term responsibility of the stored CO_2.[24]
- Any scheme that provides incentives for CDR also needs to make sure that any CDR rewarded are verifiable, and additional and that double counting is avoided (i.e., not accounting for the same CDR twice). A reference case, or baseline, needs to be employed against which the emission reduction outcome is measured.

Existing GHG accounting and MRV frameworks generally allow for the inclusion of transport and storage within the scheme accounting rules, thereby allowing for attribution of emissions and reduction across the BECCS chain, and permanence is addressed primarily through the use of risk-based management approaches, or the setting of detailed, site-specific requirements for site characterization and selection, monitoring requirements for injection and storage, and quantification of any leaks (IPCC Guidelines).

According to Cook et al. (2016), the IPCC Guidelines allow for the recognition of negative emissions from BECCS in national GHG inventories. Kindbom et al. (2018) however note that there are inconsistencies in the 2006 IPCC Guidelines. The possibilities to report the origin (fossil or biogenic) and different destinies of captured CO2 are not consistent between sectors (e.g., between the Energy sector and Industrial Processes and Product Use (IPPU)). While it is possible to report biogenic CO2 (both emissions and capture) in the Energy sector, biogenic CO2 emissions or removals cannot be reported for the IPPU sector. According to the study, emissions from black liquor combustion in the pulp and paper industry are

[24] Contractual arrangements would be necessary to clearly define the division of responsibilities between the project developers that capture CO_2 in Sweden and the entity in charge of geological storage (and any other actors involved), taking applicable legislation into consideration.

reported in the IPPU sector in the Swedish inventory reported to the UNFCCC. This means that biogenic CO2 emissions from this source are not, and cannot be, reported. One way of enabling the reporting of biogenic CO2 emissions would be to report this source in the Energy sector (CRF 1)[25] instead. For the case of captured biogenic CO2 from black liquor it could then be reported in the CRF 1.[26]

Kindbom et al (2018) recommend changes to the CRF tables[27] in order to enable accounting for negative emissions and reporting transparently on biogenic CO_2 emissions, any capture and subsequent storage of biogenic CO_2.

Finally, for any mechanism that is introduced to reward BECCS, e.g., through a crediting approach, there should be provisions that can handle seepage in cases of non-permanence, e.g., by reversing issued credits.

7.6 Public procurement

Public procurement is done when a public authority or company[28] needs to renew a service or product and the total value of this purchase exceeds the threshold according to the Public Procurement Act in Sweden (LOU).[29] Any Procurement Auction for BECCS would exceed the threshold value.

Public procurements have to be carried out by the following principles: The principle of equal treatment, the non-discrimination principle, the principles of transparency, the principles of mutual recognition, and the proportionality principle.

There are different ways to go about public procurement:
- In an Open Procedure any operator may submit a tender and all tenders that meet the pass/fail conditions are assessed. This will result in the maximum choice

[25] CRF: Common Reporting Format
[26] Finland reports emissions from black liquor in the Energy sector. Reallocating emissions from black liquor currently reported in the IPPU sector in the Swedish emission inventory, to be reported in the Energy sector instead would increase the comparability with the Finnish inventory in this respect.
[27] (i) It must be possible to report biogenic CO2 in the IPPU sector, both emissions and capture (recovery). (ii) There needs to be a separate sum for captured biogenic CO_2 for long-term storage, as well as a sum for fossil CO2 captured for long-term storage. (iii) Summary tables and table 10 in CRF should include stored CO_2 from other sectors than Energy (CRF 1).

[28] The State, regional or local authorities, bodies governed by public law or associations formed by one or more such authorities or one or more such bodies governed by public law.
[29] https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/lag-20161145-om-offentlig-upphandling_sfs-2016-1145

potential, but there won't be a possibility to select who to invite based on i.e., their technical capacity.
- In a Restricted Procedure e.g., technical capacity can be assessed in a prior stage, and the number of operators invited to leave tenders could be limited (with a minimum number of five invitations). This staged procedure may help determine the appropriate level of performance requirements to aim for later in the specifications.
- The Competitive Procedure with Negotiation and Competitive Dialogue, respectively, are used when there is some need for adaption in already existing solutions, design, or innovation. It allows elements of flexibility that are not available in the previously mentioned procedures.
- Innovative Partnership could be used when there is a need for goods or services that are not yet on the market. The partnership's aim is the development and subsequent procurement of the good or service in question. Only operators with separate R&D activities are allowed to enter such partnerships.

There are separate provisions for each approach described above that govern under what provisions they can be applied and the approaches' respective procedures. Generally, the further down the list, the greater the elements of flexibility. It is beyond the scope of this study to determine which procedure(s) would be eligible to apply for Procurement Auctions of BECCS in Sweden.

A solicitation document is made public by advertisement and the advertisement is done according to the procurement method chosen. The advertisements shall include information about the product or service that is the object of the procurement.

A procuring authority may include certain requirements related to suppliers' qualifications in order to ensure that suppliers will be able to fulfill contracts. Criteria that are allowed in this respect relate to the eligibility to operate a certain activity, financial standing, and technical and professional capacity. The main reason for this is that the procurement process is costly both for the authority and the society. All criteria must stand in proportion to the procurement.

Furthermore, technical specifications shall be made with respect to the goods' or services' performance or function requirements, in terms of certain established standards and assessments, or a combination of the two. As it is important to describe and limit the object for procurement, these criteria shall be as precise as possible.

Specifications may also address the process or method used to produce or deliver the good or service in question.

The procuring authority should award a contract to the supplier with the economically most advantageous tender based on: the best price-quality ratio, or cost or price. In case of best price-quality ratio is used, other award criteria will be evaluated than just price (it could be criteria for productivity, quality, or environmental performance).

Finally, all actions taken in connection to the procurement must stand in proportion to the goal of the procurement. Criteria and requirements the good or service must be in proportion to the subject in terms of relevance, suitability, and efficiency.

8 Concluding discussion

This report considers options for introducing near-term incentives for BECCS deployment in Sweden. The Swedish target to achieve carbon neutrality by 2045 and net-negative emissions beyond that year makes this topic relevant. Due to emissions that are particularly challenging to mitigate, BECCS and other options for offsetting residual emissions will be necessary to reach carbon neutrality in the target year. Importantly, beyond the Swedish case, BECCS and other GHG removal options, most of which are largely untested, will be necessary to attain global climate targets in line with the Paris Agreement. The report also considers that, in fulfilling its national climate targets, Sweden can make important contributions to early demonstration and de-risking of BECCS to verify and build confidence in the technology. Such contributions would be valuable in the context of managing Swedish as well as global goals to manage climate risk.

The report produced a list covering general categories of policy instruments that could be implemented to provide financial support for BECCS and shortlisted two policy options that are considered to be appropriate for near-term incentivization given the current development phase of BECCS. The two shortlisted policy instruments are:

(i) Procurement Auctions and
(ii) a Pre-determined, Uniform Compensation (akin to a feed-in tariff).

The two shortlisted policy options were assessed against a set of criteria. Strengths and weaknesses can be identified for both options. However, there are a number of reasons that speak in favor of Procurement Auctions:

- Currently and in the near term, authorities lack information concerning producers’ costs for generating CDR through BECCS and if a country does not have much experience with setting prices for a certain technology and data are scarce, then auctions are a useful way of price discovery.
- Procurement Auctions have an advantage with respect to controlling the quantity procured and therefore also for budget control. This advantage is particularly pronounced in a situation of cost uncertainty.
- The current development status of BECCS speaks in favor of taking steps to develop a portfolio of diverse BECCS demonstration projects in order to optimize contributions to technological learning. For Procurement Auctions, different policy objectives (e.g., related to particular technologies) can be reflected in the auction and bids can be selected according to specific criteria in addition to price.

- Access to up-front finance would likely increase the number of parties interested in developing BECCS projects. Advance payments could be more easily combined with Procurement Auctions.

Thus, the analysis points towards Procurement Auctions as the most suitable policy instruments for providing incentives to deploy BECCS in Sweden in the near term. Organizing Procurement Auctions in several consecutive tranches would probably be instrumental in achieving policy objectives as it would allow for gradual learning, gauging cost/volume, and the development of a technologically diverse portfolio of demonstration projects.

Acceptance

The interviews carried out with respondents representing the industry revealed an interest in exploring the potential of BECCS as a climate change mitigation measure. BECCS has clearly been up for discussion in companies and there are several examples of pre-feasibility studies and feasibility studies etc that have been made. At the same time, however, several respondents also expressed a concern that the introduction of BECCS could lead to fundamental changes with respect to how biogenic CO_2 emissions are treated by policy. The currently generally accepted approach in carbon accounting is that biomass exploitation is recorded as land-use change and emissions from biomass combustion as zero. The interviews revealed that there is a hesitance among some actors to engage in BECCS due to a perceived risk that payments for CDR through BECCS could be a first step away from the current approach of counting emissions from biomass combustion as zero. Thus, building confidence among industry that CO_2 emissions from biomass combustion will be counted as zero also in the future could potentially increase the interest in participating in Procurement Auctions (or other incentive schemes).

Infrastructure for CO_2 transport and storage

After capture, CO_2 generally needs to be transported to a site suitable for geological CO_2 storage (or in some cases, usage). This can be done through mobile options, such as trucks or ships, or with fixed pipeline infrastructure. Public support for such infrastructure is generally considered important including economic support and coordination of actors (EASAC, 2018). Supporting the deployment of CCS infrastructure will entail a number of political choices. Which locations to target is one. It makes sense to develop infrastructure for industrial clusters where it can be intensively used by several industries responsible for a significant volume of emissions. However, not all large emitters will be part of such clusters. Therefore, flexible modes of CO_2 transport (and, as applicable, openly accessible storage sites) should be pursued as well. Risks and barriers related to transport and storage infrastructure were addressed by several respondents in the interviews. There is currently a storage project under development in Norway[30] that plans to include flexibility to accept CO_2 from European sources. Respondents expressed concerns that relying on one partner's infrastructure for CO_2 storage places BECCS project developers in a vulnerable position of dependence. It was widely expressed that any initiatives from the Swedish government to support and coordinate transport and storage infrastructure and reduce risk across the whole value chain would be welcomed.

Timing issues

In the interviews, lead times for BECCS projects were addressed, and, based on the answers, an estimate of the time from a decision to invest until a project could be operational would be approximately 3 years and upwards. The abovementioned storage project under development in Norway that will accept CO_2 from European sources is planned to be operational in 2024. Hence, from the point of view of access to geological storage, an initial Procurement Auction could in principle be held in 2020, provided, of course, that the Norwegian project is developed according to the current time plan. If one of either capture, transport, or storage is not moving ahead it risks the success of the entire value chain. This underlines the importance of coordination in which the Swedish government can take an important role in reducing risks for project developers.

Further studies

This study has aimed to analyze and discuss near-term financing of early BECCS demonstration projects. BECCS technology is regarded by many to be an essential technological component in strategies to meet climate mitigation targets on a national Swedish level as well as globally. Deploying BECCS will first require a portfolio of large-scale demonstration projects that should assist learning, de-risking the technologies and take initial steps towards developing viable business models. Procurement Auctions and Predetermined, Uniform Compensation were identified as policy instruments that could be used by governments to provide sufficient certainty for investors with respect to return on investment and were, therefore, selected for further analysis. Burke et al. (2019) suggest that an auctioning mechanism could be used initially to build technological confidence and drive down costs before a private market is established. On a private but regulated offset market participants from sectors with significant residual

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[30] https://northernlightsccs.eu/en

emissions would buy negative emissions in place of paying the carbon price.[31] Trading within sectors could also be envisaged, such as in agriculture that are capable of producing negative emissions but that have residual emissions of their own (Burke et al., 2019). An alternative policy design would entail that purchasing negative emission offsets could qualify for a carbon tax deduction. It is important to further analyze premises for market-based solutions to incentivize BECCS and ways in which a gradual transition from incentive schemes based on government payments towards market-based solutions could be implemented.

Another important area for further analysis is the detailed design of MRV and accounting frameworks. Environmental integrity needs to be ensured in the capture, transportation, and storage of CO_2 to safeguard real and permanent CDR. This raises important considerations for regulation and governance including legal clarity with respect to potential liabilities. Many existing accounting frameworks that are part of schemes to provide private investors with incentives to reduce GHG emissions do not allow for the recognition of negative emissions. Detailed work to design credible and functioning MRV and accounting frameworks will therefore need to be initiated.

A final area of interest for further work identified here relates to the general need to redirect private capital to activities that can provide substantial emissions reductions and a significant transformational potential. Various initiatives are taken, by governments and private actors, to make finance flows consistent with long-term decarbonization objectives. Some of these initiatives will determine to what extent BECCS will be eligible for "green finance" and it is important to understand the implications of existing and emerging policies and frameworks in this area. Depending on the outcome of such an analysis, initiatives to ensure the eligibility of BECCS (and potentially other NETs) may be called for, given the significant role BECCS has to play in enabling the transition to net-zero GHG emissions and carbon negativity.

[31] The emitters of greenhouse gases would then face the following compliance choices: (i) abate remaining emissions, (ii) pay the carbon price or (iii) purchase negative emissions offsets.

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Appendix 1

Interviews in this study were carried out between June and September 2019. Below, the categories of respondents are listed:

Representatives of four forest industry companies:

2 corporate level Energy Coordinators
1 corporate-level Sustainability Manager
1 mill level Head of Sustainability Manager
1 corporate-level Director of Communication

Representatives of two utility companies:

1 corporate-level Director of R&D
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This report has been reviewed and approved in accordance with IVL's audit and approval management system.