



Mapping Multi-Level Policy Incentives for Bioenergy With Carbon Capture and Storage in Sweden

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Bioenergy with carbon capture and storage (BECCS) is considered a key mitigation technology in most 1.5–2.0°C compatible climate change mitigation scenarios. Nonetheless, examples of BECCS deployment are lacking internationally. It is widely acknowledged that widespread implementation of this technology requires strong policy enablers, and that such enablers are currently non-existent. However, the literature lacks a more structured assessment of the “incentive gap” between scenarios with substantive BECCS deployment and existing policy enablers to effectuate BECCS deployment. Sweden, a country with progressive climate policies and particularly good preconditions for BECCS, constitutes a relevant locus for such examinations. The paper asks to what extent and how existing UN, EU, and Swedish climate policy instruments incentivize BECCS research, development, demonstration, and deployment in Sweden. The analysis is followed by a tentative discussion of needs for policy reform to improve the effectiveness of climate policy in delivering BECCS. Drawing on a tripartite typology of policy instruments (economic, regulatory, and informational) and the ability of these instruments to create supply-push or demand-pull, the article finds that: (1) no instruments create a demand-pull to cover operational expenditure; (2) economic instruments provide partial support for research and the capital expenditure associated with demonstration, and; (3) regulatory instruments provide partial clarity on environmental safeguards and responsibilities. A few regulatory barriers also continue to counteract deployment. The article concludes that the existing policy mix requires considerable reform if BECCS is to contribute substantially to the Swedish target for net-zero emissions. Continued effort to dismantle regulatory barriers must be complemented with a strong demand-pull instrument that complements the current focus on supply-push incentives. If unreformed, the existing policy mix will most likely lead to substantial public expenditure on BECCS research, development, and demonstration without leading to any substantial deployment and diffusion.

Keywords: bioenergy with carbon capture and storage (BECCS), governance, incentives, negative emissions, policy instruments, regulation

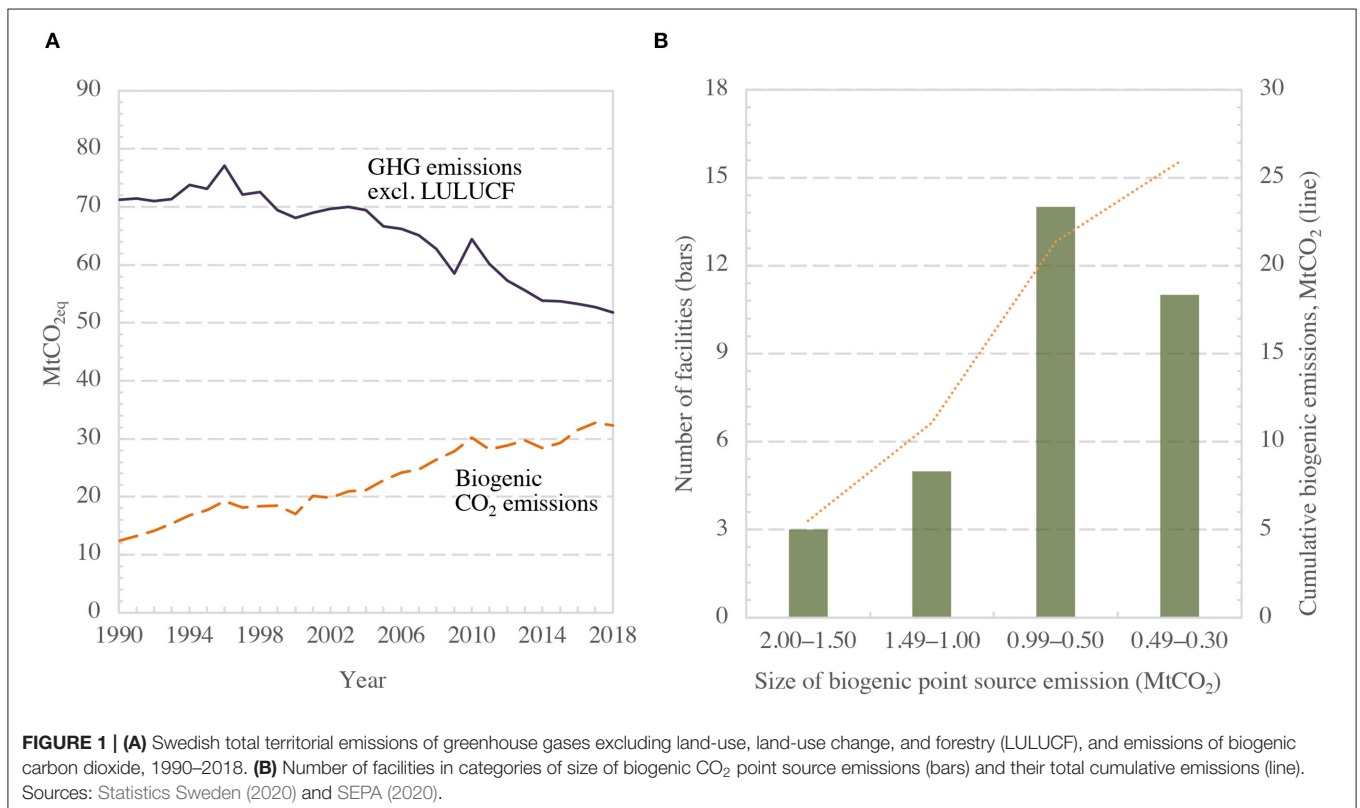
INTRODUCTION

Achieving the goal of the Paris Agreement, to limit global warming well below 2°C, will require a radical transformation of the world's fossil-fuel-dependent energy systems. In the last decade, bioenergy with carbon capture and storage (BECCS) has become a key mitigation technology in the majority of 2°C scenarios assessed by the Intergovernmental Panel on Climate Change (IPCC) (Fuss et al., 2014; IPCC, 2018). Various conceptual BECCS technology systems have been proposed. All of them capitalize on the ability of plants to absorb carbon dioxide (CO₂) from the atmosphere during growth. The biomass is then intended to be used in various operations in which the re-released CO₂ is captured, transported, and stored geologically.

While climate change mitigation scenarios deploy BECCS on a large scale, real world deployment is close to non-existent. Few countries are actively investigating the scope of BECCS deployment (Moe and Røttereng, 2018); Sweden is one of few exceptions. In 2017, a broad majority in the Swedish parliament adopted a net-zero greenhouse gas (GHG) emissions target to be achieved by 2045. Sweden shall also achieve net-negative emissions after 2045. In practice, this is specified as at least an 85% reduction of economy-wide GHG emissions by 2045, compared to 1990 levels, and offset the remaining emissions through so-called supplementary measures including the option to use BECCS. The maximum amount of supplementary measures is, thus, restricted to 15%, which translates into 10.7 million metric tons (Mt) of CO_{2eq}. Because the feasibility of

achieving negative emissions remains uncertain, the Government of Sweden appointed a committee in July 2018 to investigate the role that enhanced land-use, land-use change and forestry (LULUCF), BECCS, and verified emission reductions in other countries could play in reducing residual emissions to zero. In January 2020, the committee delivered its final report to the government in which it proposed two indicative targets for BECCS: 1.8 Mt of stored CO₂ by 2030 and 3.0–10.0 MtCO₂ by 2045. The delivery of these levels, however, is seen as dependent on reforming existing or implementing new policy instruments capable of providing adequate incentives for businesses to engage in BECCS deployment (GoS, 2020c).

Sweden, with a large modern bioeconomy, has unusually good preconditions for BECCS and is therefore a particularly relevant national case study. In 2018, Sweden emitted 32.3 MtCO₂ from biomass-based fuels. This can be compared to the total emissions of GHGs that amounted to 51.8 MtCO_{2eq}. While emissions of GHGs have fallen by 27% in the period 1990–2018, CO₂ emissions from biomass-based fuels have increased by 161% (Figure 1A). During the same period, the net removals in the Swedish LULUCF sector remained stable at a high level. Net LULUCF removals in 1990 amounted to 34.5 MtCO_{2eq}, which had increased to 42.0 MtCO_{2eq} by 2018. Although the inter-annual variation is high and in part linked to events such as storms and wildfires, the trend indicates a slight increase in Swedish net LULUCF removals (SEPA, 2020). Indeed, the share of biomass-based energy supply in Sweden is exceptional among high-income countries (Ericsson and Werner, 2016).



A substantial amount is used in the large-scale production of electricity, heat, pulp and paper, biofuels, and cement. As a rule of thumb, Swedish uses a cascade model, e.g., biomass used for energy is typically sourced from waste fractions from the forest industry (Rodríguez et al., 2020).

One example of the Swedish potential for BECCS is provided by a key basic industry in Sweden; the production of pulp. In 2019, biogenic emissions from the 10 largest pulp and paper facilities amounted to 13.0 MtCO₂ (SEPA, 2020). Several other large point sources of biogenic CO₂ exist too, such as in the energy sector (including several bioenergy and waste-to-energy facilities) and the chemical industry, including bioethanol production (see **Figure 1B**).

Some of these industries can partly recover the electricity loss for the separation of CO₂ as useful heat. This is particularly applicable to combined heat and power plants (Levihn et al., 2019). One prominent example is the biomass-dedicated boiler at Värtaverket in Stockholm with 0.9 Mt biogenic CO₂ released in 2019 (SEPA, 2020). Others, such as many pulp and paper mills, could utilize excess heat to capture CO₂ (Kuparinen et al., 2019). There are also substantial amounts of biogenic CO₂ emitted from Sweden's many waste incineration plants as well as a few larger point sources from biogas and bioethanol production (Fridahl, 2018). All of the above make Sweden an interesting case for exploring policy incentives for BECCS research, development, demonstration, and deployment (RDD&D).

Thus, with the large Swedish bioeconomy including substantial point sources of biogenic CO₂, it seems feasible that BECCS can be utilized to deliver on making Sweden a net-zero emitter by 2045 and net-negative thereafter. Nevertheless, the character and the extent of the incentive gap between tentative targets for deployment and existing policy enablers remain unclear. This paper, therefore, seeks to systematically map and characterize the incentive gap between a scenario in which BECCS contributes significantly to fulfilling Swedish climate objectives and the extent to which existing UN, EU, and Swedish climate policy instruments are likely to spur BECCS deployment.

It should be noted that Sweden has not committed to a specific level of BECCS or even to BECCS as such. At the time of writing, the proposed intermediary BECCS target for 2030 (GoS, 2020c; SOU, 2020) has not been adopted by Swedish Parliament. The Swedish Government has, however, dedicated funding to the Swedish Energy Agency in the budget bill for 2021, to administer an economic incentive for BECCS. The budget bill, which is currently under deliberation in Parliament, specifies that “[t]he ambition shall be to establish the program for support of operational costs during 2022, to speed up BECCS deployment” (GoS, 2020a: UO21, p. 32). It should also be noted that there is no scientific consensus on what would constitute adequate commitment by Sweden under the Paris Agreement. The incentive gap explored herein, thus, should be understood as a gap between current policy and a *scenario* in which BECCS plays a significant role in fulfilling Swedish climate targets, such as the levels proposed by the public inquiry (GoS, 2020c). The scenario has not been adopted by Parliament and hereinafter is referred to as tentative. If the scenario were to be adopted, it could still be argued to represent an inadequate level of ambition (see, for example, Anderson et al., 2020). This article is

relevant against the backdrop of such a scenario. The analysis and conclusions provide a starting point for redesigning the policy instrument mix if and when a policy commitment to BECCS is agreed on.

The article proceeds as follows. The next section provides a background to BECCS in general and our case study country Sweden, outlines the analytical framework applied, and describes the method for data collection. The Findings section maps and discusses incentive structures of international, supranational, and national policy instruments of relevance to BECCS in Sweden. Finally, Concluding discussion section discusses emerging patterns in the existing policy mix and offers a number of recommendations for more effective policymaking in terms of giving BECCS a significant role in fulfilling Swedish climate targets.

ANALYTICAL FOCUS AND METHOD

Analytical Focus

The need for negative emissions provides a new context for policy development. Previous literature on this topic has acknowledged that current policy instruments are often unfit for the delivery of carbon removals. Since CCS installed at a biomass-based operation increases capital and operational expenditure without producing any benefits beyond mitigation, Gough and Upham (2011) have noted that its deployment “depends on clearly regulated limits to CO₂ emissions or on a carbon price” (p. 329). Cost-optimal climate change mitigation scenarios mainly drive the deployment of specific technologies through assumptions on the technologies' mitigation potential, marginal abatement cost curves, and carbon price levels (Keith et al., 2006; van Vliet et al., 2014). This speaks to the issue of the carbon price levels at which BECCS can be incentivized, but not to the issue of the types of policy instruments that can achieve such price levels or what other types of instruments can incentivize BECCS in the absence of a high carbon price. Most low-carbon energy industries face significant market barriers due to the entrenched power of incumbents (Bonvillian and Van Atta, 2011), and the time horizon of venture capital is ill-suited for developing clean-techs that typically require longer periods of trial and error before being able to compete on the market (Gaddy et al., 2017). Thus, given that BECCS provides no added value to end-users, it is unlikely that a state of technological maturity through the prevailing market structure will be reached.

It should be emphasized, as pointed out by Tanzer and Ramírez (2019), that the effectiveness of BECCS in generating negative emissions, from a system-perspective, requires a full accounting of emissions and removals from “cradle-to-grave” (p. 1216). To maximize the climate benefits of BECCS, policy instruments need to minimize climate impact across all steps of technological systems, i.e., from the *production of biomass* as the primary energy source via efficient *capture* technologies, to safe and effective *geological storage*. Effects should even be factored in, e.g., on feedbacks and changed albedo (Tanzer and Ramírez, 2019; Fridahl et al., 2020). Policy making can target all of these aspects. Policy instruments for the sustainable production of biomass-based energy supply have been analyzed at length in the literature (Henders and Ostwald, 2012; Cambero and Sowlati,

2014; Su et al., 2015). Such an analysis will not be reproduced here. This article instead focusses on a substantial gap in the literature: policies for directly incentivizing the capture of CO₂ beyond the achievement of zero emissions. Policies pertaining to geological storage are part of this effort and are common to all CCS, no matter the origin of the CO₂ (fossil or biogenic). These are discussed in detail in the literature on fossil CCS (Bachu, 2008; Liu et al., 2016), the focus herein is on recent developments in storage-related policy or when such instruments lead to competitive dis-/advantages for BECCS vis á vis fossil CCS.

Policy Instruments and Their Evaluation

Public policy involves multiple actors and interconnected phases ranging from agenda setting, via policy formulation and decision making, to implementation and evaluation (Fischer et al., 2007). Policy instruments are defined as “the techniques or means through which states attempt to attain their goals” (Howlett, 2011: p. 22), i.e., the specific part of public policy involving the political tools to reach objectives.

Bemelmans-Vidéc et al. (2010) have developed a 3-fold typology of policy instruments, which they refer to as economic, regulatory, and informational instruments. Economic instruments involve “the handing out or the taking away of material resources while the addressees are not obligated to take the measures involved” (p. 32). Examples include affecting market processes through taxation, the provision of subsidies, and tradeable emissions permits. Regulatory instruments are measures taken to “influence people by means of formulated rules and directives which mandate receivers to act in accordance

with what is ordered in these rules and directives” (p. 31). Examples include direct controls to limit permissible levels of emissions and the specification of mandatory processes or equipment. Informational instruments are “attempts at influencing people through the transfer of knowledge, the communication of reasoned argument, and persuasion” (p. 33). Examples include public information campaigns and appeals to corporate social responsibility.

We further distinguish between the ability of different types of policy instruments to instigate change at different steps in the development and deployment of technologies. Developing technology niches often take time and are marked by multiple failures and slow learning. When niches have been established, the cost of production per unit of output (such as per unit of captured CO₂) often falls dramatically due to economies of scale and incremental learning. This technology phase is therefore typically marked by more rapid seizure of market shares until demand is fulfilled at specific costs (Lehmann and Gawel, 2013; Mercure et al., 2014; Hammond, 2018). As such, the volume of output for a technology through the phases of development, regime introduction, diffusion, and market saturation is often depicted with an S-shaped curve (Rogers, 2003), see **Figure 2**.

Since existing policies are often modeled on existing sociotechnical systems, new technologies developed in niches often find it hard to compete with established technologies in existing regimes. This factor, together with many other dynamics, such as technology and policy lock-in effects including sunk costs, contribute to technology regimes being marked by conservatism and stability (Utterback, 1994; Geels, 2002;

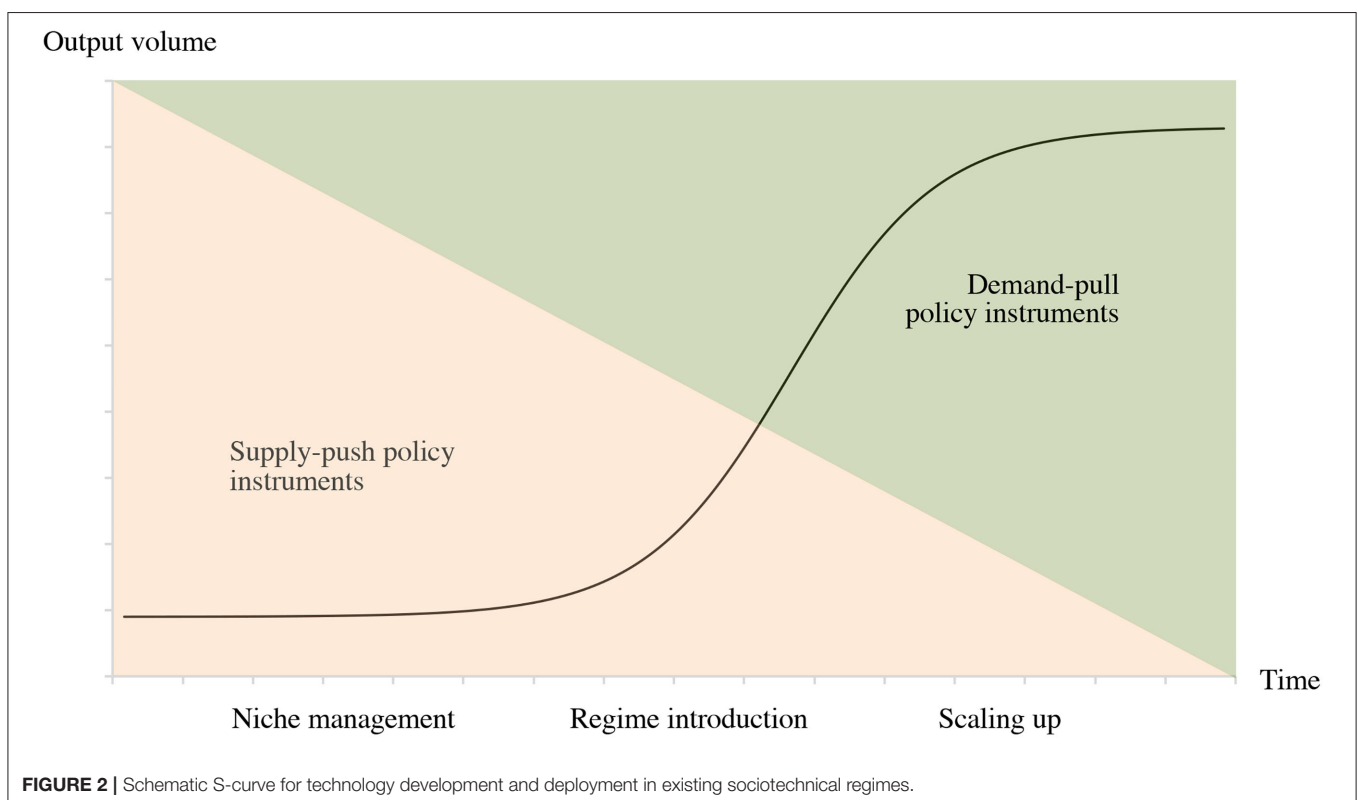


FIGURE 2 | Schematic S-curve for technology development and deployment in existing sociotechnical regimes.

Berkhout et al., 2004; Amars et al., 2017). Transitioning to a low- or net-zero emissions economy is therefore challenging. Political interventions are often required to instigate change in sociotechnical systems, such as by making new climate-friendly technical solutions competitive on existing markets. The effective and efficient use of policy to support specific technologies, such as BECCS, requires a policy mix that is capable of addressing different needs in the development, regime introduction, and diffusion phases. At low levels of technology maturity and industrial expertise, policy makers should target supply-push instruments capable of establishing niches. These may include research grants, support to knowledge centers, and subsidies for pilots and demonstration projects. Instruments capable of instigating a demand-pull are often needed when a technology matures and expertise increases (Hammond, 2018). Such instruments may include taxation or cap-and-trade systems, quota obligations, and certificate trading or systems of fees and dividends. A mix of policy instruments is often recommended to enable overcoming various types of market failures associated with blocking new technical solutions that would contribute to the fulfillment of policy objectives, such as combating climate change (Lehmann and Gawel, 2013; Gawel et al., 2017).

We used the tripartite typology of policy instruments provided by Baumol and Oates (1979) to classify different existing policy instruments at the international, supranational, and national levels. It should be noted that only *direct* incentives were evaluated; the indirect dynamic effects of other types of policy were not considered here. Regulatory instruments were assessed in terms of whether they provide favorable conditions for or raise barriers to BECCS in Sweden. Drawing on Vihma (2012), the legal arrangement was qualitatively evaluated as “soft” (amorphous, non-legally binding recommendations) or “hard” (generating precise, binding, and enforceable obligations) pertaining to BECCS in Sweden (also see e.g., Skjærseth et al., 2006; Karlsson-Vinkhuyzen and Vihma, 2009). Economic and informational instruments were assessed in terms of whether they provided weak, moderate, or strong positive incentives, did not provide incentives or disincentives, or disincentivized BECCS in Sweden. The level of incentivization was qualitatively assessed drawing on frameworks for the difficult but highly relevant *ex-ante* assessments of instrument effectiveness to initiate change at depth and at multiple levels of governance (Herrick and Sarewitz, 2000; Oikonomou et al., 2012). We did not intend to make sharp distinctions between the different levels of incentivization. Indeed, given the “uphill struggle” that faces BECCS innovators (Bellamy and Healey, 2018), it could well be argued that any lack of incentive for BECCS constitutes a disincentive. Instead, we distinguished between levels of incentives to approximate their likely influence on industrial actors or innovators that can drive the RDD&D of BECCS.

The primary scope of the instruments was also assessed, distinguishing between whether the instruments targeted: (1) research, development, demonstration, and/or deployment of BECCS technology and; (2) capture, transport, and/or storage elements of the BECCS technology chain. This allows for identifying gaps in what might represent a more coherent approach to incentivizing BECCS across instrument types and

TABLE 1 | Summary of the analytical framework to categorize and specify the relevance of economic, regulatory, and informational policy instruments for BECCS RDD&D.

Issue	Instrument type	Analytical category
Governance level	All	The following governance levels are targeted: (1) International, i.e., UN and regional multilateral; (2) Supranational, i.e., the EU, and; (3) National, i.e., Sweden
Scope	All	The instruments are evaluated in terms of their scope, i.e., carbon dioxide: (1) Capture; (2) Transport, and; (3) Storage
Primary intended effect	All	The instruments are evaluated in terms of the change they seek to instigate: (1) Supply-push (research, development, and demonstration); (2) Demand-pull (deployment and diffusion)
Direction of effect	Economic and informational instruments	The instruments are evaluated in terms of providing: (1) Incentives; (2) Neither incentives nor disincentives (lack of incentive), and; (3) Disincentives
	Regulatory instruments	The instruments are evaluated in terms of being: (1) Favorable, or; (2) A barrier
Relevance to BECCS	Economic and informational instruments	Used as a proxy for their importance to BECCS, incentives/disincentives are evaluated as: (1) Weak; (2) Moderate, or; (3) Strong
	Regulatory instruments	The regulations are evaluated as: (1) Soft (unspecific, guiding, facilitative), or; (2) Hard (precise, binding, and enforceable)

their primary scope, at multiple levels of governance. The analytical framework is summarized in **Table 1**.

After mapping the multi-level landscape for direct incentives of relevance to BECCS in the different RDD&D phases in Sweden, the paper discusses the incentives provided by the aggregate, multi-level policy mix.

Legal Repositories

Empirically, this study focused on three data sources. First, at the international level, it focused on the most central international bodies related to BECCS, i.e., the treaties and decisions of the UN Framework Convention on Climate Change (UNFCCC), the International Maritime Organization (IMO), the Convention on Biological Diversity (CBD), the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), and the Baltic Marine Environment Protection Commission

(HELCOM), as well as the methodological guidelines on GHG inventories of the Intergovernmental Panel on Climate Change (IPCC). All documents were accessed via the UNFCCC and the IMO online repository for treaties and decisions and the IPCC document portal.

Second, at the supranational level, it focused on EU regulations (directly binding), directives (that specify goals to be implemented through domestic laws), and decisions that addressed Sweden or Swedish industry (that are binding on those they address), as well as policy evaluations commissioned by the EU Commission (*ex-post* as well as *ex-ante* evaluations). All documents were accessed via the EU online repository for laws and preparatory acts, EUR-Lex.

Third, at the national level, it focused on Swedish laws and strategies (such as guidelines, goals, and directions agreed on by Parliament) as well as government-commissioned policy evaluations (*ex-post* as well as *ex-ante* evaluations) conducted by the most central government agencies concerned with BECCS (i.e., the Swedish Energy Agency, the Swedish Environmental Protection Agency, and the Geological Survey of Sweden). All documents were accessed via the Swedish Government's online repository for laws and the Swedish Parliament's online repository for bills and other policy-related documents.

For access to all repositories, see “Data Availability Statement” below.

FINDINGS

International Level: UN and Regional Multilateral Cooperation

Sweden has ratified several international agreements of which the UNFCCC, the Kyoto Protocol, and the Paris Agreement are among the most relevant for BECCS. However, some IMO regulations also impact incentives for BECCS, as do guidelines developed by the IPCC and agreed on by the UNFCCC (Tables 2, 3).

Economic Instruments

While the UNFCCC mostly sets out policy goals and principles, the Kyoto Protocol includes a stronger regulatory component: quantified emissions limitation and reduction objectives for developed countries. It also includes three economic instruments to increase the cost effectiveness of meeting the objectives: the Clean Development Mechanism (CDM), Joint Implementation (JI), and Emissions Trading (ET) (UNFCCC, 1998: Articles 12, 6, and 17). The rules regulating the flexible mechanisms under

TABLE 2 | International (UN and regional multilateral) economic policy instruments of direct relevance to BECCS RDD&D in Sweden, in descending order of significance.

Instrument	Effect and scope	Description	Incentives provided
The Paris Agreement to the UNFCCC, Article 6, cooperative approaches (UNFCCC, 2016: 1/CP.21)	Deployment Capture Transport Storage	The 2015 Paris Agreement established a credit-based market mechanism and international trading with so-called “emission reduction outcomes.” The rules for operating the mechanism and trading are currently under negotiation. The crediting mechanism to promote mitigation and support sustainable development is likely to start operating in a fashion similar to the CDM. How this mechanism will attract finance and how liquidity is to be maintained at high carbon prices remains unresolved	N/A (rules currently under negotiation)
The Kyoto Protocol to the UNFCCC, Article 17, Emissions trading (UNFCCC, 1998: 1/CP.3)		ET allows developed country Kyoto Protocol members to sell surplus Assigned Amount Units (AAUs) to other countries	Lack of incentive: through a general oversupply of Kyoto Protocol assigned amount units, leading to low prices. However, it puts framework conditions in place for regional emissions trading systems to be used in compliance with Kyoto commitments
The Kyoto Protocol to the UNFCCC, Article 12, the Clean Development Mechanism, CDM (UNFCCC, 1998: 1/CP.3)	Deployment Capture Transport Storage	The CDM, established in 1997 with operational rules agreed on in 2001, is in part an instrument of tradeable emission rights. Developed countries can invest in mitigation activities (CDM projects) in developing countries. Proven emissions reductions, compared to a baseline, generate tradeable emission rights that can be used for developed countries' compliance with their Kyoto Protocol commitments. In 2011, the UNFCCC decided to include CCS in the CDM	Lack of incentive: targets deployment outside Sweden and through an extremely low price on CDM-certified emission reduction credits generated by BECCS, following on a market collapse
The Kyoto Protocol to the UNFCCC, Article 6, Joint Implementation, JI (UNFCCC, 1998: 1/CP.3)	Deployment Capture Transport Storage	JI is similar to CDM but only involves developed country parties. Typically, a country with a mature market economy would use JI to invest in economies in transition	Lack of incentive: through a general oversupply of JI emission reduction units, leading to low prices

TABLE 3 | International (UN and regional multilateral) regulatory and informational policy instruments of direct relevance to BECCS RDD&D in Sweden, in descending order of significance.

Instrument	Type, effect, and scope	Description	Incentives provided
The London Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter, including amendments to Annex 1 [IMO, 1996: LP.4(8); 2006: LP.1(1)]	Regulatory Deployment Transport Storage	The London Protocol, agreed in 1996, regulates sub-seabed disposal of CO ₂ (Annex 1) and transboundary movement of CO ₂ (Article 6)	Favorable (hard): adopts the 2006 amendment to dispose of CO ₂ in sub-seabed storage complexes
Amendment of Article 6 of the London Protocol [IMO, 2009: LP.3(4); 2019: LP.5(14)]	Regulatory Deployment Transport	The London Protocol was amended in 2009 to allow export of CO ₂ for disposal provided that an agreement or arrangement has been entered into by the countries concerned. A resolution agreed in 2019 allows for the provisional application of the 2009 amendment until the latter has entered into force	Favorable (hard): allows the provisional application of the 2009 amendment that circumvents the London Protocol's export prohibition. Yet it raises barriers by creating high administrative burdens pending lack of entry into force of otherwise more simplified procedures
The Convention for the Protection of the Marine Environment of the North-East Atlantic [OSPAR], including amendments to Annex 2 and 3 (OSPAR Commission, 1992)	Regulatory Deployment Storage	A regional multilateral convention for cooperation on the protection of the marine environment in the North-East Atlantic. Originally agreed on in 1972 and 1974, substantially updated in 1992, and with amendments of relevance to CCS concluded in 2007, the Convention currently has 16 contracting parties, including the EU	Favorable (hard): allows sub-seabed storage in accordance with the amendment to Annex 1 of the London Protocol (see above, same table) and the CCS-directive (see Table 5)
IPCC Guidelines for National Greenhouse Gas Inventories; Developed by the IPCC and adopted with small amendments by the UNFCCC to apply under the Paris Agreement (IPCC, 2006, 2019; UNFCCC, 2019a,b)	Informational (IPCC) Regulatory (UNFCCC) Deployment Capture Transport Storage	Accounting guidelines concluded in 2006, including how to account for emissions avoided through BECCS	Favorable (hard): allows a government to include BECCS in national greenhouse gas inventories and in accounting toward targets N.b., the UNFCCC adopted IPCC 2006 guidelines apply to greenhouse gas inventories only (18/CMA.1). The rules for accounting toward targets are more flexible, but require the application of methodologies and common metrics assessed by the IPCC and transparent reporting thereof (4/CMA.1)
The Convention on the Protection of the Marine Environment of the Baltic Sea Area (HELCOM, 1992)	Regulatory Deployment Storage	A regional multilateral convention for environmental policymaking among countries on the Baltic Sea. Agreed on in 1992, the Convention currently has 10 contracting parties, including the EU	Barrier (hard): prohibits sub-seabed storage in the Baltic Sea. As the EU is a contracting party to the Convention, the convention's prohibition takes precedence over the CCS Directive (see Table 5) that would otherwise allow such storage in the northern Baltic Sea
The Convention on Biological Diversity [CBD] (CBD, 2010: X/33)	Regulatory Deployment Capture Transport Storage	Paragraph 8(w) states that "in the absence of science-based, global, transparent and effective control and regulatory mechanisms for geo-engineering, and in accordance with the precautionary approach and Article 14 of the Convention, that no climate-related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities"	Barrier (soft): puts a moratorium on climate-related geoengineering activities that may impact biodiversity negatively. BECCS is treated ambiguously as both geoengineering and mitigation "broadly defined" so the moratorium may or may not apply, notwithstanding ongoing evolution around the terminology. Allows research and development, if easily contained to specific sites

the Kyoto Protocol will, however, lose relevance after 2020. For the period after 2020, the objectives of the UNFCCC will largely be operationalized through the Paris Agreement instead of the Kyoto Protocol. However, it is still relevant to ask if the flexible mechanism of the Kyoto Protocol has incentivized BECCS in Sweden. Experience from the Kyoto Protocol is a key in UN deliberations on how to operationalize the market mechanisms developed under the Paris Agreement.

The CDM is an instrument of tradeable emission credits generated from emissions reductions in developing countries. Such emissions reductions are compared to a baseline and generate tradeable certified emission reductions (CERs) credits. CERs can in turn be used by developed countries to comply with their Kyoto Protocol commitments. In 2011, the UNFCCC decided to include CCS in the CDM. Zakkour et al. (2014a) argue that, as CDM involves "issuances of 'credits' against a baseline

minus actual emission irrespective if these are negative” (p. 6827), opening up for CCS methodologies means that the CDM can theoretically be used to recognize negative emissions generated through BECCS. However, the focus of the mechanism on implementation in developing countries excludes direct support to BECCS in Sweden. Swedish engagement in CCS CDM projects would be limited to increasing Swedish knowledge about BECCS through engagement in deployment abroad. In addition, no Swedish actors were involved in any such projects abroad. In fact, not one single methodology for a CCS CDM project has, thus far, been approved. Approval is also unlikely to occur in the future for at least two reasons: First, the market for CERs from the CDM collapsed with the decline in interest in the Kyoto Protocol and the EU’s restriction on using such emission rights in order to comply with the EU Emissions Trading System (EU ETS, see section “Supranational level: EU policy instruments”). Zakkour et al. (2014b) note that the approval of the CCS CDM rules coincided with the downturn in interest in the CDM. Second, the requirements for the approval of CCS methodologies are unusually strict, involving host country domestic regulations on “site selection and characterization, access rights to storage sites, redress for affected entities and liability” (Dixon et al., 2013, p. 7598). While the need for strict methodologies can be motivated given that CCS technology is less mature than other mitigation technologies, the requirement has likely contributed to limiting interest in engaging in CCS CDM projects.

In addition—in line with the aforementioned EU restrictions to limit use of CERs after 2012 to credits generated from projects registered in least developed countries (LDCs)—the Swedish government has decided to focus on LDCs for its CDM engagement. The potential for BECCS is generally limited in LDCs (Hansson et al., 2019). Thus, even if the CER market would not have collapsed and the CCS methodology requirements would have been less strict, Swedish engagement in CCS CDM projects would probably have been non-existent.

While JI is very similar to the CDM and is unlikely to spur BECCS deployment in Sweden for much the same reasons (Kosoy et al., 2015), ET is a different story. ET is an economic instrument that allows developed country Kyoto Protocol members to sell surplus Assigned Amount Units (AAUs) to other developed countries, for compliance. In theory, ET could incentivize countries to support domestic BECCS deployment if such deployment is understood as a measure to generate surplus AAUs that can be sold and generate income. However, the aggregate surplus was large in the Kyoto Protocol’s first commitment period. A large surplus of AAUs was generated from the collapse of the former Soviet Union’s industry rather than as an effect of the climate policy itself. This surplus was subsequently labeled “hot air” and could be traded cheaply. Some assessments even suggest that countries pursued strategies of complying through buying cheap hot air mainly from Poland, Romania, and the Czech Republic rather than conducting more expensive domestic mitigation actions (Shishlov et al., 2016; Martínez de Alegría et al., 2017). Under such circumstances, the economic incentive provided by ET for investments in relatively expensive BECCS—to comply with

commitments or to generate a tradable AAUs surplus—was very low.

More recently, the Paris Agreement has detailed the objective of the UNFCCC by providing, among other things, a temperature goal: “Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels” (UNFCCC, 2016: Article 2.1.a). The objective is further detailed in Article 4.1: “Parties aim to reach global peaking of greenhouse gas emissions as soon as possible [...] so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century” (UNFCCC, 2016). This is clearly relevant for BECCS. However, the rules operationalizing the Paris Agreement are currently under negotiation. The Agreement established a mechanism to promote mitigation and support sustainable development (Article 6.4) that is likely to start operating in a fashion similar to that of the CDM. Whether this mechanism, which is sometimes referred to as the Sustainable Development Mechanism (SDM), will attract funding and how liquidity is to be maintained at high carbon prices—sufficient to drive investments in BECCS—are currently unresolved questions. It is, however, still too early to evaluate how the international carbon market will develop under the Paris Agreement (Honegger and Reiner, 2018).

The Paris Agreement also allows the trading of so-called Internationally Transferred Mitigation Outcomes (ITMOs, Article 6.2), which are similar to ET under the Kyoto Protocol. While ITMOs and the SDM are intrinsically linked, the market for ITMOs involves a broader opportunity for countries to sell surplus emissions reductions that are not credited toward their mitigation pledges under the Paris Agreement. ITMOs opens up a door for countries to sell surplus mitigation outcomes to raise international finance for domestic BECCS expenditure. While there is a cap on the amount of Swedish supplementary measures that can be credited toward target fulfillment (maximum 10.7 MtCO_{2eq}, see “Introduction”), there is no cap on the amount of supplementary measures that can be reported or that can be sold as ITMOs.

The international economic climate policy instruments are summarized in **Table 2**.

A key problem pertaining to both ET and ITMOs is how these instruments relate to supranational climate policy. Negative emissions generated by BECCS can currently be seen as falling between the cracks of the main EU climate policy instruments (see section “Supranational level: EU policy instruments”). As such, negative emissions from BECCS cannot be used to comply with EU targets, which makes it infeasible for Sweden (or any other EU Member State) to trade in surplus emissions reductions generated by BECCS.

Regulatory and Informational Instruments

In addition to the economic instruments defined at the UN level, the Paris Agreement is based on a collective, global goal to which Member States voluntarily contribute through so-called Nationally Determined Contributions (NDCs) that are regularly updated. To date, no NDC refers to BECCS. Moreover, Sweden

has no NDC of its own. Instead, it adheres to a collective NDC submitted by the EU based on the EU's climate policy goals. Therefore, EU policy on fulfilling EU goals, including Sweden's contribution to this task, is more relevant for understanding Swedish BECCS deployment than what is stipulated in the joint EU NDC (see section "Supranational level: EU policy instruments"). This includes the opportunity for Sweden to sell surplus supplementary measures on an ITMO market since any such surplus would have to first be deducted from other EU Member States' potential underachievement. While the EU can sell surplus ITMOs, it is debatable how this opportunity pertains to Sweden.

Two regional multilateral conventions provide a more relevant regulatory frame for BECCS in Sweden. The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) is aligned with the 2006 amendment to the London Protocol, i.e., allowing for sub-seabed CO₂ storage. The Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention), on the other hand, prohibits sub-seabed CO₂ storage in the Baltic Sea. This—along with legal barriers for sub-seabed CO₂ storage in the southern Baltic Sea introduced by the EU CCS Directive (see **Table 3**)—has led the Swedish committee of inquiry on negative emissions to conclude that CO₂ captured in Sweden will most likely have to be exported, for example to Norway, for sub-seabed storage (GoS, 2020c).

The 2006 amendment of the 1996 London Protocol (to the 1972 IMO Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter) is a more relevant UN regulation. It permitted the previously forbidden sub-seabed disposal of CO₂ within a country's territory (IMO, 1996, 2006). However, Article 6 of the London Protocol prohibits transboundary movement of CO₂ if the intended final use is sub-seabed disposal (IMO, 1996). The Protocol was amended in 2009 to allow the export of CO₂ for disposal "provided that an agreement or arrangement has been entered into by the countries concerned" (IMO, 2009). The rules for operationalizing the amendment by specifying what an "agreement or arrangement" means were adopted in 2013 (IMO, 2013). For permits to be granted, export agreements shall include, for example, a clear distribution of responsibilities, risk and environmental impact assessments, and monitoring schemes. By the end of 2020, however, the amendment had not been ratified by the number of Parties required for it to enter into force. This means that the London Protocol still prohibits export of CO₂ among contracting parties (see e.g., Dixon et al., 2014). Since 2019, however, Parties to the London Protocol can apply the amendment provisionally, providing an opening for CO₂ export (IMO, 2019). Pending entry into force of the amendment to the London Protocol, such export would require a bilateral agreement between the importing country (such as Norway) and the exporter (Sweden) for the amendment to provisionally be applied.

There is also the question as to whether or not BECCS would be affected by decision X/33 of the tenth meeting of the Conference of the Parties to the Convention on Biological Diversity (CBD), in which parties agreed that, "in accordance with the precautionary approach and Article 14 of the

Convention, no climate-related geo-engineering activities that may affect biodiversity take place," without adequate scientific understanding and consideration of risks and social impacts. In the CBD's technical report on the matter, BECCS was labeled as both geoengineering and mitigation "broadly defined" (CBD, 2016). Despite this ambiguity, since the decision was made geoengineering terminology has evolved to mainly refer to solar radiation management techniques, while carbon removal methods have formed their own, separate category. At any rate, the moratorium set out by the CBD is in reality an imprecise, non-binding, and non-enforceable, soft regulation which is unlikely to affect BECCS going forward.

The international community also designs accounting guidelines in addition to regulated prohibitions, emission reduction targets, and various economic implementation instruments. These can be understood as regulatory instruments that can have effects on BECCS; if the rules do not allow accounting for negative emissions, they raise barriers for BECCS. All project-based instruments of tradeable emission rights—the CDM, JI, and the Paris Agreement's mechanism—in principle allow¹ accounting for negative emissions to generate credits (Zakkour et al., 2014a). This is because credits are generated from the extent to which emissions reductions deviate from a baseline that would, hypothetically, have been the case without a project intervention. Accounting for negative emissions is principally not prohibited, as long as it is proven that they are additional to any emission reductions that would have occurred in the absence of the project (Zakkour et al., 2014a; Torvanger, 2019).

Both the Kyoto Protocol (Article 5) and the Paris Agreement (Article 13) link national accounting to IPCC methodologies. The 2006 IPCC accounting guidelines state that emissions "of CO₂ from biomass fuels are estimated and reported in the AFOLU [Agriculture, Forestry and Other Land Use] sector," and that "emissions from combustion of biofuels are reported as information items but not included in the sectoral or national totals to avoid double counting" (IPCC, 2006: volume 2, chapter 2, p. 33). However, if a combustion plant is supplied with biofuels, "the subtraction of the amount of gas transferred to long-term storage may give negative emissions. This is correct since if the biomass carbon is permanently stored, it is being removed from the atmosphere" (volume 2, chapter 2, p. 37). The possibility to capture CO₂ from industrial processes has also been acknowledged (volume 3, chapter 1.2.2). The 2019 refinement of the 2006 guidelines further clarify that BECCS should be treated consistently with fossil fuel CCS, and that net emissions, including negative emissions generated by BECCS, should be reported in the energy and/or the industrial processes and product use sectors (IPCC, 2019: volume 1, chapter 8, p. 5).

Under the Paris Agreement, national greenhouse gas inventories are to be based on the 2006 IPCC guidelines

¹The accounting rules of Article 6 of the Paris Agreement have not yet been agreed on. However, it is likely that the rules will apply a "deviation from baseline" approach allowing the generation of credits from negative emissions. Weather emission removals or sinks shall be explicitly prohibited or not is still, however, under negotiation.

(UNFCCC, 2019b). As a consequence of the different scope that NDCs can have, accounting rules for the fulfillment of NDCs are less rigid and more flexible than under the Kyoto Protocol. Parties to the Paris Agreement are encouraged to use methodologies and common metrics assessed by the IPCC, such as accounting guidelines, and to describe how they have done so. If a NDC takes on a form that makes it hard to use IPCC guidelines, the NDC must contain information on the alternative methodology used (UNFCCC, 2019a).

Thus, accounting rules under the UNFCCC provide favorable regulatory conditions for governments to pursue carbon dioxide removals such as through BECCS. However, this does not translate into incentives to subnational entities or businesses. The international accounting rules establish a foundation for accounting for stored biogenic CO₂ as negative emissions in the event the Swedish government wishes to develop policy incentives for domestic actors to engage with BECCS. Torvanger (2019) has, however, shown that BECCS would benefit from a more standardized accounting and rewarding framework that resolves outstanding issues, especially issues related to sustainability safeguards and carbon cycle dynamics. Although these issues fall outside the scope of this article, it is worth noting that developing effective and at the same time broadly acceptable criteria for sustainable biomass production—a vital component to guarantee negative emissions from BECCS—is challenging for the international community.

Supranational Level: EU Policy Instruments

Sweden joined the EU in 1995. The EU shares competence on the environment with Member States (EU, 2012a). As such, sovereign rights are partly transferred from Sweden to the EU, which makes the EU a supranational union (Wettestad et al., 2012).

The EU has ratified the Paris Agreement and deposited its first NDC with the goal to reduce emissions by at least 40% by 2030 compared to 1990 levels (EU, 2016), within the EU 2030 climate and energy framework. The goal is to be achieved mainly with three instruments: the EU Emissions Trading System (EU ETS) to reduce emissions by 43% compared to 2005 levels, domestic actions in non-EU ETS sectors to reduce emissions by 30% compared to 2005 levels, and no-debit emissions from land use, land use change, or forestry (LULUCF). Thus, the EU's flagship climate policy instrument is the EU ETS, complemented with regulating mandatory emission reduction commitments in the non-ETS and no-debit emissions in the LULUCF sectors through the Effort Sharing Regulation (ESR) and the LULUCF Regulation (EU, 2018c,h,i). The ESR requires Sweden to reduce emissions by 40% in 2030 compared to 2005 levels. A number of related economic policy instruments, mostly designed to subsidize investments, are also notable. These have been established through the EU ETS Directive as well as through other decisions, directives, and regulations. These instruments are all of relevance to BECCS RDD&D in Sweden and will be discussed in more detail below. In 2019, the European Council agreed that the goal shall be revised during 2020, to increase ambition. If the ambition increases, consequential amendments

of the EU ETS, ESR, and LULUCF Regulation will have to be adopted.

Economic Instruments

The EU ETS is an instrument of tradeable emission rights called EU Allowance Units (EUAs). The Kyoto Protocol's ET rules formed the basis for the EU ETS, developed to achieve cost-effective compliance with the EU Kyoto commitments (EU, 2003, 2009c, 2018c).

The system is based on allowances rather than credits and would require substantial amendments to allow the generation of new allowances based on negative emissions. Such procedures would also increase the amount of EUAs and create perverse outcomes unless negative emissions do not lead to a stricter cap or a corresponding cancellation of EUAs, e.g., in future auctions. Neither does the EU ETS cover emissions from LULUCF. The political appetite for incorporating LULUCF into the EU ETS has been very low (Ellison et al., 2014). The fact that the EU ETS is an allowance-based system and that attempts to include LULUCF emissions has been considered a dead end politically, which gives a gloomy outlook on agreeing on rules to generate EUAs from BECCS. However, the permanency and certainty of geologically stored CO₂ is much greater than LULUCF sinks, which opens a door for the possibility to integrate BECCS into the EU ETS. The fact that the EU ETS already covers fossil CCS further opens a door for integrating BECCS, as regulation to deal with possible leakage from geological storage has already been adopted (Rickels et al., 2020).

Any emissions from LULUCF activities are reported in the LULUCF sector under the LULUCF Regulation (EU, 2018h). This rationality applies even if the harvested biomass is transported to centralized entities, and emissions are released at point sources in operations where fossil emissions are often covered by the EU ETS, such as cement production. It should be noted, however, that the EU ETS does in fact cover large point sources of biogenic CO₂ if they are mixed with fossil CO₂, such as from pulp and paper production or heat and power production. Installations that exclusively use biomass fuels in their operations are, however, excluded from the EU ETS. Even if a facility using biomass is covered by the EU ETS, emissions from biomass arising at the facility should always be rated as zero. For biofuels and bioliquids, the zero-emissions assumption is only valid if the fuel fulfills the sustainability criteria of the Renewable Energy Directive (EU, 2018e). Black liquor from the pulp and paper industry, however, is treated as a solid biomass instead of a liquid biofuel. Thus, facilities with great potential to deploy BECCS are often already covered by the EU ETS (unless they exclusively use biomass fuels) and account for their biogenic emissions as zero emissions. Sweden has also implemented the so-called opt-in article of the EU ETS Directive (Article 24). The article allows a unilateral opt-in of additional emissions that are not covered by the EU ETS. Sweden has done this for emissions from small installations in the district heating sector. The opt-in provision further improves the scope for incentivizing BECCS through the EU ETS, yet achieving this would require substantial amendments to the existing EU law (Rickels et al., 2020).

Several researchers have, however, noted the failure of the EU ETS to drive innovation, for example of fossil CCS (e.g., Åhman et al., 2018). The most cited reason is the low price for EUAs (Koch et al., 2014). Other reasons include the free allocation of EUAs to installations classified as energy-intensive trade-exposed (EITE) industries at risk of carbon leakage (Nicolai and Zamorano, 2018). Both steel and cement are EITE industries that are suitable for CCS technology. Combined with an increase in the use of bioenergy in these industries, part of any CO₂ captured at such installations could theoretically be accounted for as negative, i.e., as BECCS. EITE industries are entitled to freely allocated emission permits instead of having to buy them at auction.

The fact that the low and unstable EUA price is currently not strong enough to drive investments in CCS, and that the carbon leakage provides perverse incentives for EITE industries to argue for the unavailability of technical solutions to lower emissions, add to the lack of incentives provided by the EU ETS for developing BECCS. The innovation deficit has also been acknowledged by the EU, which has designed a number of R&D subsidies to complement the EU ETS. The idea behind combining R&D funding schemes with the EU ETS is straightforward: use supply-push R&D instruments to de-risk investments, put new technologies on the shelf, and make them more competitive, and to use demand-pull instruments, such as the EU ETS, to spur the diffusion of these technologies. Some of these R&D subsidies are funded from selling emission permits while others are funded from the core budget (Table 4).

In addition, many of the R&D funding sources target a CCS supply-push yet they limit funding to CO₂ of fossil origin. This provides no direct incentives for BECCS although this may indirectly incentivize BECCS through technical overlaps with fossil fuel CCS. Some of the funding sources are open to financing BECCS, such as Horizon 2020 and its successor Horizon Europe, the Connecting Europe Facility (CO₂ transport), and the Innovation Fund, although the eligibility criteria for the latter are still under consideration.

Some funding sources for BECCS R&D and demonstration are available, of which Horizon 2020 (2014–2020) and Horizon Europe (2021–2027) are the most notable for providing large R&D grants to legal entities, such as businesses and universities. Funding is provided in isolation from a supportive policy mix for commercial deployment. This allows BECCS operators to raise revenues to cover operational expenditure and, in that manner, create market pull incentives. Åhman et al. (2018) commenting on the failure of The New Entrants Reserve (NER300) to finance CCS despite targeting such projects, concluded that the low carbon price of the EU ETS failed to create a market pull for fossil CCS. This lack of a market “made investments in CCS unprofitable and highly risky” (Åhman et al., 2018: p. 104) due to high operational expenditure, despite large public co-funding of capital expenditure (see also Gough et al., 2018). In their evaluation of NER300 and the Regulation on European Energy Programme for Recovery (EEPR), the European Court of Auditors (ECA) concurred with the conclusions made by Åhman et al. (2018): “A key factor in the failure of CCS deployment has been the low carbon market price after 2011” (EU ECA, 2018:

p. 9). The ECA found that the CCS project applicants assumed that the price for EUAs would be high and rising, thus creating a demand-pull for CCS. This situation for BECCS is even worse given the fact that the weak market pull provided by the EU ETS for fossil CCS is nonexistent for BECCS.

The ECA (2018) also underscored that the failure of EEPR and NER300 to deploy CCS in the EU was, in part, due to complex and inflexible application procedures and, in part, because of a lack of coordination.

The new framework program Horizon Europe is promising in this regard. It is “mission oriented,” meaning that it will be oriented around concrete goals to address societal problems, including climate change. Among other things, this is likely to improve links between EU climate goals and research that focuses on the crucial role of demand-pull policy for BECCS. This approach to organizing R&D funding is well-aligned with the recent developments in innovation policy studies. These policy studies underscore the extremely dire need to deliberately steer innovation in directions that harmonize with political goals for societal challenges (Hekkert et al., 2020). The Innovation Fund is also promising in this regard, established in 2018 as the successor to NER300. Based on lessons learned from the failure of NER300, the Innovation Fund will use simpler and more flexible application procedures, will be able to provide more up-front rather than results-based funding, and will be able to cover a larger share of operational expenditure (60% instead of the 50% available under NER300). In preparation for the fourth trading period (2021–2030), the EU ETS has also been reformed to reduce the EUA surplus to strengthen the system’s price signal. This provides a better context for capitalizing on the Innovation Fund, from auctioning 450 million EUAs during the trading period, and the Innovation Fund is also mandated to spend unused NER300 funding (EU, 2019a).

Developing infrastructure for BECCS is equally as important as developing a demand-pull policy. One of the challenges with BECCS is to get the whole technology chain in place in parallel. BECCS technology systems are marked by a chicken-and-egg problem. It is meaningless to capture CO₂ for storage if a company has no access to storage sites. Vice versa, developing storage capacity without some type of financial derivatives that obligates actors to future delivery of CO₂ at specific prices is financially extremely risky (Fridahl, 2019). In 2020, the EU acknowledged this problem and awarded the Northern Lights Project the status of a European Project of Common Interest (PCI). A PCI focuses on cross-border infrastructure projects that link European energy systems, in this case, the transport and carbon storage infrastructure in northern Europe, and grants infrastructure developers access to apply for funding from the Connecting Europe Facility (EU, 2019a). Accepting the Northern Lights Project as a PCI creates potential to significantly lower the financial risks of investments for private actors and nation states.

In practice, EU funding sources have not been directed at CCS projects in Sweden, regardless if it is fossil energy, bioenergy, or both. However, the Swedish utility company Vattenfall was granted EEPR funding for a fossil CCS project in Janschwalde, Germany, which had to be canceled due to public resistance and a legal impasse created through the German government’s

TABLE 4 | Supranational (EU) economic policy instruments of direct relevance to BECCS R&D in Sweden, in descending order of significance.

Instrument	Effect and scope	Description	Incentives provided
Directive on a scheme for greenhouse gas emission allowance trading [EU ETS] (EU, 2003, 2018c)	Deployment Capture Transport Storage	Established in 2003 and operational in 2005, the EU ETS was designed to enhance the cost effectiveness of meeting the EU commitment under the Kyoto Protocol. The fourth trading period commences in 2021, through amendments for the period 2021–2030 (EU, 2018a). Other amendments have been implemented too, and the EU ETS also includes rules for monitoring emissions (EU, 2007, 2018a)	Lack of incentive: lacks a price on CO ₂ of biogenic origin and not allowing the offset of CO ₂ of fossil origin through BECCS
Regulation on Horizon 2020 (EU, 2013a) and Regulation on Horizon Europe (EU, 2018f)	Research Development Demonstration Capture Transport Storage	Established in 2013, Horizon 2020 is the 8th so-called Framework Programme for Research and Innovation, which is designed to deliver an innovation-friendly environment in Europe. Horizon 2020 provides R&D grants and is open to legal entities, primarily from within the EU. Its successor, Horizon Europe (the 9th Framework Programme), has been provisionally agreed on and will finance R&D and demonstration including BECCS Administered by the European Commission with multiple partners; Timespan: 2014–2020 (Horizon 2020) and 2021–2027 (Horizon Europe)	Incentive (moderate): provides grants to R&D (including BECCS)
Regulation on the Connecting Europe Facility [CEF] (EU, 2013b) and Commission delegated regulation on Project of Common Interest [PCI] (EU, 2019b)	Deployment Transport	Established in 2013, the CEF provides financing for cross-border CO ₂ transport infrastructure with a view to the deployment of CCS. Such funding could be used to build transport networks between Swedish biogenic point sources and established offshore storage sites in Norway The 2020 award of the Northern Lights Project, a commercial CO ₂ cross border transport connection project in northern Europe, status of a PCI substantially improves the possibility of accessing CEF funding Administered by: The Innovation and Networks Executive Agency; Timespan: 2014–2020	Incentive (moderate): opens for funding for cross-border CO ₂ transport networks with a view to the deployment of CCS (including BECCS)
Amendment to Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments [incl. the Innovation Fund] (EU, 2018c, 2019a)	Demonstration Deployment Capture Transport Storage	Established in 2018, the Innovation Fund is designed to support low-carbon transformation as a complement to the market pull provided by the price on CO ₂ established through the EU ETS Administrative entity to be determined by the European Commission; Timespan: 2021–2030	N/A. CCS is to be eligible for funding, yet even though the fund has established the framework rules (including eligibility criteria for various types of CCS), detailed specification has not yet been agreed on. By learning from the failure of NER300, the Innovation Fund is likely to become more effective and has the potential to provide a strong incentive for BECCS
Decision on financing of commercial demonstration projects of environmentally safe CO ₂ capture and geological storage as well as projects of innovative renewable energy under the EU ETS [NER300] (EU, 2010b)	Demonstration Deployment Capture Transport Storage	Established in 2010, the NER300 was capitalized by 300 million EUAs, monetized to about €2.1bn. NER300 funding can be combined with other EU funding yet requires substantial co-funding. €0.3bn has been dispatched to a CCS project (the White Rose project, a coal-fired power plant adjacent to the Drax power station in North Yorkshire, UK), a project that was abandoned in 2015 after the UK government withdrew its co-funding Administered by the European Investment Bank; Timespan: 2011–2020	Lack of incentive: primarily targets fossil and not biogenic CO ₂ , and the low price on EUAs in the EU ETS have led to a failure to finance NER300 at economic scales sufficient to provide large CCS co-funding. However, unused NER300 funding will be transferred to the Innovation Fund, which can be used to finance BECCS
Regulation on European Energy Programme for Recovery [EEPR] (EU, 2009e)	Demonstration Capture Transport Storage	Established in 2008 as part of the European Economic Recovery Plan, the EEPR was designed to boost the economy through low-carbon development while increasing energy security. In 2010, the EEPR granted €1.0bn to six CCS demonstration projects (Don Valley Hatfield, UK; ROAD Rotterdam, Netherlands; Belchatow, Poland; Compostilla, Spain; Porto Tolle, Italy; and Jämschwalde, Germany). Only one project has been completed thus far (Compostilla). Four projects were terminated. In 2016, €0.4bn of the €1.0bn had been dispatched Administered by the European Commission; Timespan: 2010–TBD	Lack of incentive: limits co-funding for CCS to coal-fired CHP plants and for transporting CO ₂ captured at a steel plant (i.e., excluding BECCS)

(Continued)

TABLE 4 | Continued

Instrument	Effect and scope	Description	Incentives provided
InnovFin Energy Demonstration Projects facility [EDP], European Investment Bank and European Investment Fund in cooperation with the Commission, mandated by Regulation on the financial rules applicable to the general Union budget (EU, 2012b, repealed by: EU, 2018g)	Demonstration Deployment Capture Transport Storage	Established in 2014, the InnovFin EDP was designed to carry risks associated with moving technology, including BECCS, from the pilot phase to demonstration of commerciality. The fund is organized as a loan scheme under Horizon 2020, allowing a higher risk profile than otherwise possible and designed to facilitate the delivery of the EU Strategic Energy Technology Plan. The fund receives unspent NER300 funding as of the end of 2017 and onwards Administered by the European Investment Bank; Timespan: 2014–2020	Lack of incentive: only provides loans or guarantees to bankable projects, i.e., projects that can guarantee sufficient revenues, which, under the current lack of a price on biogenic CO ₂ and an inability to sell credits, cannot be guaranteed by BECCS project developers in Sweden

adoption of their own CCS law (Kapetaki et al., 2017). This example shows that regulatory certainty also influences the willingness to invest in technology such as BECCS, and are a complement to R&D funding and policy instruments that create market pull. Nevertheless, the funding likely contributed indirectly to the Swedish capacity for BECCS.

Regulatory and Informational Instruments

While the supranational economic instruments largely do not provide incentives for BECCS, several regulatory instruments do create favorable conditions for deployment. The most notable is the CCS Directive (EU, 2009d). As noted by Duscha and del Río (2017), it “enables CCS within the European Union in general and sets the rules for the geological storage of CO₂” (p. 16). As such, it settles important issues related to, for example, responsibility sharing for storage. The CCS Directive is important because it provides partial clarity on the playing field and thus grants security to investment planners. However, economic incentives are instead supposed to be provided by other instruments. As noted in the above section, the existing economic instruments are not particularly well-designed to incentivize major opportunities for BECCS in Sweden. It should also be noted that the CCS Directive requires any physical leakage of CO₂ from storage to be compensated for by surrendering EU ETS allowances. This is regardless of whether the CO₂ can be considered to be of biogenic or fossil origin.

As also noted in the section “International level: UN and regional multilateral cooperation,” biogenic emissions (whether a source or a sink) are reported in the LULUCF sector. Like the CCS Directive, the LULUCF Regulation provides a positive context for BECCS through enhanced regulatory clarity, yet the regulation does not provide any direct economic incentives for deployment.

The above, and other, regulatory instruments originating from the EU are summarized in Table 5.

At least three informational instruments also have a bearing on BECCS RDD&D in Sweden: First, the European Commission has also set the goal to make the EU climate-neutral by 2050 (EU, 2018b), with the goal endorsed both by the Parliament and the Council. Through the European Green Deal, the Commission has also proposed to put the climate-neutrality target into law. Although the European Climate Law is still being negotiated (EU, 2020b), the vision and the proposal to manifest the target in law provides a positive framework for BECCS in Sweden. Although there are risks associated with not specifying the

climate-neutrality target in a clearly defined emission reduction target and a separate target for negative emissions (McLaren et al., 2019), the Commission has communicated its intention to keep such targets separate and with no backsliding from the previous emission reduction target for 2050 (i.e., at least –80% compared to 1990 levels). However, in the Commission’s proposal for a European Climate Law (EU, 2020b), the 2050 target remains unspecified as a net-zero GHG emissions target. While the Commission highlights that “greenhouse gas emissions should be avoided at source as a priority” (EU, 2020b: p. 7), McLaren et al. (2019) argue that distinct targets for emissions reductions and negative emissions are beneficial both in terms of avoiding mitigation deterrence and making more explicit the scale and pace of the investments required to deliver negative emissions. Although the Green Deal and the proposed European Climate Law provide a positive framework for BECCS in Sweden, the latter would benefit greatly from further specification of the 2050 EU target into separate and well-defined emissions reductions and negative emissions targets.

Second, policy objectives defined through the European Commission’s Strategic Energy Technology (SET) Plan; an informational instrument providing a strategic vision and rationale for the various EU funds targeting CCS for investments. In 2016, a set of goals were adopted for the period 2020–2030 with a subsequent Implementation Plan for CCS R&D and demonstration activities agreed on in 2017. The goals of the SET Plan are aligned with the Commission’s vision for building an Energy Union and its current regulation (EU, 2015a,c, 2017, 2018j). The Energy Union regulation requires Member States to develop a 10 year integrated national energy and climate plan (NECP) and national long-term strategies with a perspective of at least 30 years. The plans and strategies increase transparency and improve the coherence between mid- and long-term planning, on the one hand, and the goals and the actions taken to achieve those goals, on the other hand. Even if this could be viewed as soft regulation or even as an informational policy instrument, it does provide a context for countries to start thinking about negative emissions. The Commission also envisages NECPs that play a more active role under the European Climate Law (EU, 2020b). The law in its current proposal form says that the Commission is to use the information in NECPs to evaluate if the measures taken by Member States are inconsistent with the Union’s trajectory for achieving climate neutrality. The Commission

TABLE 5 | Supranational (EU) regulatory and informational policy instruments of direct relevance to BECCS RDD&D in Sweden, in descending order of significance.

Instrument	Type, effect, and scope	Description	Incentives provided
Directive on the geological storage of carbon dioxide (EU, 2009d), with links to the Waste Directive (EU, 2018d) and the Regulation on shipments of waste (EU, 2006)	Regulatory Deployment Storage	Agreed on in 2009, the CCS Directive clarifies rules for the disposal of CO ₂ . It was implemented in Sweden with the option to prohibit storage under land (due to considerably more complicated procedures). The directive exempts CO ₂ that is stored within the EU from being considered as waste. The Waste Directive stipulates that the regulation on shipments of waste applies to CO ₂ that is exported for storage outside the EU	Largely favorable (hard): establishes a scheme for sharing responsibility for long-term storage with the state. Barrier: no distinction between fossil and biogenic CO ₂ ; all leakage into water or the atmosphere is to be compensated for by surrendering EU ETS allowance units Some barriers relevant to specific applications also apply: Barrier to developing domestic sub-seabed storage in Sweden (southern Baltic Sea) due to likely leakage into EU-external (Russian) territory, which is prohibited. Barrier by prohibiting export outside EU territory unless the importing country is a member to the European Free Trade Association <i>and</i> party to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal
Guidelines on State aid for environmental protection and energy (EU, 2014) mandated by Treaty 2012/C 326/01 on the European Union and the Treaty on the Functioning of the European Union. The expiration date of the guidelines has been prolonged by one year (until 2021) in the wake of the Covid-19 crisis (EU, 2020a)	Regulatory Research Development Demonstration Capture Transport Storage	Establishes a list of exemptions from the general principle of prohibition of state aid for 2014–2021. For CCS, “both operating and investment aid is permitted” (§163). Eligible funding is defined as the gap between cost savings from implementing CCS (e.g., reduced need for EUAs) and additional costs incurred by CCS	Favorable (soft): allows state aid to finance all incremental costs associated with BECCS, i.e., removes a barrier raised by the general rule prohibiting state aid. Barrier: provides no certainty for the period beyond 2021
Decision on the effort of Member States to reduce their greenhouse gas emissions [ESD] (EU, 2009a), and regulation on binding annual emission reductions [ESR] (EU, 2018i)	Regulatory Deployment Capture Transport Storage	Establishes effort sharing for the reduction of emissions not covered by the EU ETS, to meet the EU 2020 and 2030 climate targets	Barrier (hard): does not allow for accounting for negative emissions from BECCS at the national level to comply with the national commitment specified in the ESD for 2020 and the ESR for 2030. However, the domestic Swedish emission reduction target for 2030 (–63% compared to 1990 levels) is substantially more ambitious than what is required of Sweden to comply with its ESR target for 2030 (–46% compared to 1990 levels). Thus, even with full use of supplementary measures to meet its domestic target, Sweden will be able to comply with its EU target without accounting for negative emissions. The barrier raised by the ESD/ESR will thus be less relevant in Sweden. If biogenic CO ₂ emissions were included in the EU ETS and BECCS were allowed to generate emissions credits linked to the EUA market (Rickels et al., 2020), the relevance of not allowing negative emissions from BECCS to be accounted for under the ESD/ESR would become irrelevant. If a common accounting system for BECCS was adopted, the ESR Article 5.7 would allow Sweden to sell any surplus or project-based BECCS units to other Member States
Communications on a European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy (EU, 2018b) and the Commission’s proposal for a European Climate Law (EU, 2020b)	Informational RDD&D Capture Transport Storage	Outlines the Commission’s vision of a revised long-term (2050) climate goal	Incentive (weak): provides a strategic long-term goal for a climate-neutral Europe, including scenarios that use BECCS to reach this goal. If the proposed European Climate Law was adopted, the vision would be anchored in law with the requisite subsequent amendments of the main EU climate policy instruments. This would substantially increase the significance of the long-term goal

(Continued)

TABLE 5 | Continued

Instrument	Type, effect, and scope	Description	Incentives provided
Decision on monitoring and reporting guidelines for greenhouse gas emissions from CCS (EU, 2010a) and Implementing Regulation on the monitoring and reporting of greenhouse gas emissions pursuant to the EU ETS (EU, 2018a)	Regulatory Deployment Capture Transport Storage	Amends the guidelines for monitoring and reporting emissions covered by the EU ETS with guidelines for how to monitor and report avoided emissions from CCS	Barrier (hard): unclear if it is permitted to deduce biogenic CO ₂ from calculated levels of emissions from an installation. Further barrier: requires conservative methodologies to avoid attributing CO ₂ of biogenic origin to fossil sources
Communications on the Energy Union (EU, 2015a,b), and The Strategic Energy Technology Plan (EU, 2015c)	Informational Research Development Demonstration Capture Transport Storage	Outlines the Commission's vision of a secure and low-carbon Energy Union, aligned with its SET plan identifying key areas for the R&D of CCS. The SET plan for CCS aligns with the objectives of the EU CCS funding sources (see Table 4)	Incentive (weak): provides a strategic, informative umbrella for EU funding directed toward CCS. This would include funding for which BECCS is eligible through CEF and Horizon 2020
Regulation on the governance of the Energy Union and climate action (EU, 2018j)	Regulatory RDD&D Capture Transport Storage	Requires EU Member States to submit national energy and climate plans (NECPs) covering the period 2020–30, biannual reports on progress toward the plans, and national long-term strategies with a perspective of at least 30 years	Favorable (soft): the EU Member States are to provide plans for how they intend to implement the agreed EU energy and climate targets. The Commission reviews the plans and provides recommendations for changes. The Member States are to then take due account of the recommendations or publicly explain why they do not. The first Swedish NECP (GoS, 2020b) affirms that BECCS is part of the long-term strategy for reaching net-zero emissions by 2045
Directive on the promotion of the use of energy from renewable sources (EU, 2009b, 2018e)	Regulatory Deployment Pre-capture (bioenergy)	Establishes targets for the share of renewable energy in each Member State by 2020, including energy from biomass. Revised in 2018 to establish an aggregate 2030 EU target	Favorable (hard): promotes the bioenergy component of BECCS systems with potential effects on the production of bioethanol, electricity, and heat
Communication on supporting early demonstration of sustainable power generation from fossil fuels (EU, 2008)	Informational RDD&D Capture Transport Storage	Establishes a European CCS Demonstration Project Network. Facilitates coordination among first movers, information exchange, increased visibility, and access to financial support	Lack of incentive caused by the focus on fossil CCS

is mandated to issue recommendations for Member States to get into compliance if it identifies inconsistencies. Member States must report how they take due account of these recommendations. The significance of NECPs will be upgraded if this procedure is eventually adopted as part of the European Climate Law.

Sweden, in its first long-term strategy, also restates its intention to potentially develop climate action that is supplementary to emission reductions. The framework allows for using supplementary measures to offset up to 10.7 MtCO_{2e} residual hard-to-mitigate emissions by 2045, such as emissions from the agriculture and waste sectors, and includes the option to use BECCS (GoS, 2019).

Third is the European CCS Demonstration Project Network (EU, 2008). This network, facilitated by the EU, gathers actors involved in CCS demonstration projects to share information and learning, partly, for policy development purposes. However, the network targets fossil CCS and is therefore less likely to acknowledge the specificities of policy for BECCS.

National Level: Swedish Policy Instruments

The Swedish climate law (GoS, 2017d) requires each successive Swedish government to propose a climate policy implementation plan, including policy instruments, and to relate how the instruments contribute to achieving the goal of net-zero emissions by 2045 and negative emissions thereafter. Thus, Sweden has a nationally regulated target, and it is the responsibility of each successive national government (in the period 2020–2045) to design instruments to meet this target.

Economic Instruments

Two of the oldest climate policy instruments in Sweden have been discussed by Börjesson et al. (2017): “[t]he carbon dioxide (CO₂) tax on fossil fuels introduced in 1991 and renewable electricity certificates of 2003 represent two important political incentives behind the significant increase in bioenergy” (p. 18). Both are economic instruments.

The carbon tax is an instrument of tax on households and firms. Established in 1991 at SEK 250 (€26) per MtCO₂ in general and SEK 63 (€7) per MtCO₂ for industry (nominal

values, October 2017 exchange rates), it increased to SEK 1120 (€116) per MtCO₂ in 2016. In 2016, industry was still entitled to some tax reductions, but these had almost completely expired in 2018. The tax is adjusted annually along with the Consumer Price Index. In addition, an annual increase of 2% is added to the tax level to account for GDP developments (GoS, 2016; Börjesson et al., 2017).

At these levels, the tax could be expected to incentivize substantial amounts of BECCS in Sweden. However, the tax includes several exemptions, including taxation on biogenic CO₂ emissions. Even if the tax provided incentives to avoid biogenic CO₂, it would only incentivize reductions toward zero emissions; negative emissions are not rewarded through taxation. Brännlund et al. (2014) have also shown that before the introduction of the EU ETS, the ability of the carbon tax to decarbonize the pulp and paper industry was unusually low; pulp and paper was the only industry in Sweden in 1991–2004 that did not achieve an absolute decoupling of economic growth and emissions.

The tax, however, has in part incentivized the development of the Swedish bioeconomy in terms of increasing the share of bioenergy in the production of electricity and heat and in shifting from fossil fuels to biofuels for transportation (Börjesson et al., 2017). To some extent, a reduced tax for non-road mobile machinery used in the agriculture and forestry sectors has also likely contributed to the development of the bioeconomy. This tax reduction is one of few that remained in force after 2018 on the rationale that these sectors face unusually strong international competition (GoS, 2016).

It should also be noted that since 2011, industries covered by the EU ETS do not pay any carbon tax in Sweden. Given that the carbon price in the EU ETS is substantially lower than the tax, the incentive for these installations to shift from fossil fuels to bioenergy is lower than for entities outside the EU ETS.

The Swedish Renewable Energy Certificates system is a special form of instrument for tradeable emission rights. Each MWh of produced renewable energy generates a certificate that can be sold on a common Norwegian and Swedish market. The buyers are usually electricity producers and other actors (e.g., heavy industry) with a liability to own certificates in a given proportion to their electricity production or consumption. The system is designed to support investments in renewable electricity production but is not directly proportional to emission reductions, thus the certificates cannot be linked to other emissions trading schemes in which one unit usually corresponds to one tCO₂. The price for a certificate in Sweden averaged €3.1 MWh⁻¹ in 2016 (SEA NWRED, 2017).

Some electricity installations fueled with bioenergy receive certificates. In 2016, certificates were granted for 1,967 GWh from biofuel and peat. This is not insignificant; it amounts to 16.8% of the total certificates generated in 2016. Yet the allocation is not based on emission levels but on a predefined list of eligible electricity production types and their production volume. Therefore, the system rewards the expansion of biofuel for electricity, thus increasing the potential for BECCS. Nevertheless, it does not reward negative emissions as such in its current form.

Two recent instruments, the Climate Leap Program (*Klimatklivet*) and the Industrial Leap scheme (*Industriklivet*) subsidize investments. The Climate Leap Program, established in 2015, allows municipalities, organizations, and businesses to apply for funding for immediate and direct local climate benefits (GoS, 2015b). In other words, this program prioritizes direct emission reductions over R&D and actions resulting in indirect climate benefits. R&D with high investment risks and high potential for emission reductions, is not supported.

The Industrial Leap scheme, established in 2017, is a pledge to provide 300 m SEK (€31 m) annually from 2018 to 2040 to mitigate process-related industrial emissions. The fund subsidizes much needed R&D and demonstration. It acknowledges that Swedish process-related emissions remain high and stable and that reducing them requires technological leaps that are both expensive and risky. Biorefineries, a sector with potential for BECCS, are eligible for funding.

The pulp and paper industry, however, was originally not eligible for funding from the Industrial Leap. This raised concerns that partly led to adjustments in 2019. Parallel to reinforcing the Industrial Leap to a total of 600 mSEK (€52 m) annually in 2020–2022 and thereafter 400 mSEK (€41 m) annually until 2027, the directive was amended with an appropriation for negative emissions through BECCS or direct air CO₂ capture and storage (GoS, 2017c). The appropriation is limited to 100 mSEK (€10 m) in 2019–2022 and 50 mSEK (€5 m) in 2023–2027 but the appropriation opens the Industrial Leap for applications from the pulp and paper industry.

The Industrial Leap is thus, in part, promising for incentivizing R&D and demonstration of BECCS and could potentially be used to raise required co-funding for companies seeking EU funding from the Innovation Fund (see “Supranational level: EU policy instruments”). However, the fund is imperfect in that long-term funding is not secured upfront. By mid-2020, 1.8 bnSEK (€0.19 bn) of the total 6.9 bnSEK (€0.72 bn) pledged for 2018–2040 had been secured. The promise of future funding cannot be guaranteed unless the current government capitalizes the fund upfront and designs a mechanism to protect the funding from future government interventions.

Finally, several funds are available to support R&D of relevance to BECCS. These funds are complementary to EU funding, such as Horizon 2020 and Horizon Europe, and are governed through the decrees on which instructions to governmental line agencies rest (GoS, 2008, 2015a, 2017b). The most notable decrees relate to public R&D support within the field of energy (to a large part administered by the Swedish Energy Agency) and within the fields of environment, agricultural sciences, and spatial planning (to a large extent administered by the Swedish Research Council, Formas). These funding sources support not only technical development but also policy development, capacity building, and the exploration of social preconditions for deployment. As such, they build the general capacity to understand preconditions for BECCS in Sweden and the capacity to develop hardware. The Swedish economic climate policy

TABLE 6 | National (Swedish) economic policy instruments of direct relevance to BECCS RDD&D, in descending order of significance.

Instrument	Effect and scope	Description	Incentives provided
Decree on support to actions for decreasing the industry's process-related emissions, and negative emissions [The Industrial Leap] (GoS, 2017c)	RDD&D Capture Transport Storage	Aims to reduce process-related emissions from Swedish industry	Incentive (moderate): partly provides funding for BECCS. Most of the annually dedicated funding, however, targets process-related fossil emissions
Decrees on public support to R&D (GoS, 2008, 2015b, 2017b)	Research Development Demonstration Capture Transport Storage	Regulates public support targeted for R&D and demonstration activities, generally within the fields of energy, the environment, and planning	Incentive (weak): provides grants to R&D and demonstration and to building capacity not only to develop technology but also to understand the preconditions for deployment
Decree on support to local climate investments [The Climate Leap] (GoS, 2015c)	Deployment Capture Transport Storage	Aims to reduce emissions locally, open to all legal entities, prioritizes projects with the highest potential for emission reduction per invested Swedish krona	Lack of incentive: provides small-scale grants focused on direct emission reductions
The electricity certificates law (GoS, 2011)	Deployment Capture Transport Storage	Aims to incentivize renewables by regulating the issuance and use of certificates generated from renewable electricity production. The tradeable certificates are used by power producers to fulfill quota obligations proportional to a share of their electricity production and use	Lack of incentive: focuses on rewarding renewable electricity production with no reward for capturing biogenic CO ₂ . However, the system does provide incentives for the expansion of biomass-based electricity production
The energy tax law (including the carbon tax) (GoS, 1994)	Deployment Capture Transport Storage	Regulates tax on electricity and fuel (including a tax on carbon in specific fuels). It specifies, e.g., tax levels, the carbon content of different fuels, and tax exemptions	Lack of incentive: does not cover biogenic CO ₂ (and, if it was covered in the future, no incentives are provided for emission reductions beyond zero)

instruments of relevance to BECCS are summarized in **Table 6**.

Other economic climate policy instruments exist too, such as subsidies for solar cells and RDD&D investments in fossil-free transports, as well as a bonus-malus system to penalize high-emitting and reward low-emitting vehicles. However, these are unlikely to have any substantial, direct impact on BECCS in Sweden.

Regulatory and Informational Instruments

The long-term (2045) goal is complemented by mid-term goals for emission reductions in the non-ETS sectors. Emissions in the non-ETS sectors are to be reduced by at least 63% in 2030 and by at least 75% in 2040, compared to 1990 levels. LULUCF is explicitly not included nor is international transportation (bunker fuels). Thus, even though LULUCF is covered by the new EU regulation and can be used in accounting to meet the Swedish 2030 EU target, it is already decided that it will not be used to meet the domestic target (GoS, 2017a,d).

The Swedish climate policy framework also specifies that the intermediary targets for 2030 and 2040 can be met by using a maximum of 8 and 2% of so-called supplementary measures, respectively. Such actions include BECCS, international offsetting, and net LULUCF uptake (even though LULUCF is not covered as a whole, an aggregate increase in net uptake can be accounted for as a supplementary measure). The framework also specifies that the 1990 non-ETS emissions were 46.7 MtCO_{2eq}, meaning that if no other supplementary measures are used to meet the goal, BECCS will be limited to 3.7 MtCO₂ in 2030 and to 0.9 MtCO₂ in 2040. Any additional BECCS will not be allowed to be applied toward meeting intermediary goals. This regulation

makes sense from a precautionary perspective; the targets should be based on known mitigation potentials and should be independent of loopholes or unproven technologies, yet the regulation also caps the amount of BECCS that Sweden can use to meet its target. In this manner, the regulation can influence future discussions on the level of state spending on BECCS RDD&D. The regulation may act as a barrier to BECCS, not only because it limits the share of allowed BECCS but also because this share declines in the mid-term (i.e., from 2030 to 2040) before it increases again by 2045. The uncertainty of the Swedish climate policy framework would be repealed if the proposal by the Swedish committee of inquiry on negative emission is adopted and specifies BECCS targets for 2030 and 2045, respectively, and assumes roughly linear upscaling (GoS, 2020c).

The climate policy framework also specifies that the share of allowed supplementary measures, including the option to use BECCS, will likely have to increase in the long term, beyond 2045, to achieve net-negative emissions. Although the climate policy framework also fails to quantify goals for net-negative emissions after 2045, setting quantified goals for long-term net-negative emissions would provide greater certainty for near-term expenditure on BECCS or other negative emission technologies, it sets out a clear long-term direction for greater significance for BECCS beyond 2045. In view of the clarity of the long-term trajectory, the disincentive provided by a mid-term decline in how much BECCS will be allowed to contribute to Swedish climate policy objectives is relatively weak.

The favorable regulatory environment is more positive in terms of the Swedish policy mix that targets the deployment of storage infrastructure. The Swedish potential for geological storage is primarily found offshore, in the Baltic Sea. As such,

instruments targeting offshore storage are the most relevant. The existing policy mix consists primarily of three instruments: The Directive on Geological Storage of CO₂ (GoS, 2014), the Continental Shelf Law (GoS, 1966), and the Environmental Code (GoS, 1998). The Environmental Code also provides clarity on requirements for building and operating a piped transport network, complemented by the Law on Certain Pipelines (GoS, 1978).

Although clarity is provided, which provides a positive context as it increases the predictability of the market conditions for BECCS (Jänicke, 2017), this positive context is undermined, albeit for good reasons, by the administrative burden bestowed on actors wanting to open new storage facilities. The Continental Shelf Act demands authorization, which for storage of more than 0.1 MtCO₂ within the Swedish economic zone must be tested and, if accepted, granted by the Land and Environment Court. The EU Commission must be notified of draft applications and has the opportunity to submit comments. As a final step, the Government of Sweden is to approve or decline applications. Authorization is required both to examine potential storage and for actual storage. Simplified procedures apply to sites intended for storage of <0.1 MtCO₂ for research purposes. The juridical interpretation of the law has proven more ambiguous than the law itself, creating uncertainties around expected outcomes even if the legal requirements appear to have been fulfilled at the time of application for authorization (Stigson et al., 2016).

The Swedish regulatory and informational climate policy instruments of direct relevance to BECCS are summarized in **Table 7**.

CONCLUDING DISCUSSION

Even though BECCS is considered a key mitigation technology in almost all 1.5°C and most 2°C compatible climate change mitigation scenarios (Fuss et al., 2014; IPCC, 2018), there is a significant gap between BECCS deployment and the capacity of this technology to deliver on those scenarios. This implementation gap has been described as the result of an incentive gap between the tentative targets for BECCS deployment and existing policy enablers. To characterize this incentive gap, this paper mapped incentives provided by existing climate policy instruments for BECCS research, development, demonstration, and deployment (RDD&D) in Sweden. Sweden was chosen as a case study country because of its particularly high theoretical potential for BECCS.

The overall trends in the composition of policy instruments across different levels of governance are summarized as follows: A number of patterns were observed with respect to the prevalence of different types of policy instruments and their effects at different levels of governance using the tripartite typology of policy instruments, and an understanding of the relevance of

TABLE 7 | National (Swedish) regulatory and informational policy instruments of direct relevance to BECCS RDD&D, in descending order of significance.

Instrument	Type, effect, and scope	Description	Incentives provided
The climate policy framework, including the climate law (GoS, 2017a,d)	Regulatory RDD&D Capture Transport Storage	The Climate Act links the Government's climate policy to the long-term climate goal defined by Parliament (2045 and beyond), demands continuous implementation plans, and mandates an independent council to review the implementation plans in light of the long-term policy objective	Favorable (soft): allows for BECCS to contribute to fulfilling Swedish climate policy objectives. The positive framing is weakened by a cap on the amount of BECCS allowed to comply with the 2045 target and by establishing an intermediate decline in the allowed use of BECCS
Decree on geological storage of CO ₂ (GoS, 2014)	Regulatory Deployment Storage	Regulates storage above a total of 0.1 MtCO ₂ , including provisions on, e.g., ex-ante modeling of geological properties, the purity and pressure of the CO ₂ injected, monitoring, and responsibility sharing	Favorable (hard): allows for and provides clarity on rules for prospecting for geological storage of CO ₂ . Barrier: cumbersome application processes
The environment code (GoS, 1998)	Regulatory Deployment Transport Storage	Aims to support sustainable development in Sweden and regulates, e.g., permit approval and reporting requirements for storage sites above a total of 0.1 MtCO ₂ ; requires environmental considerations in building infrastructure; mandates national administration to issue fees for costs incurred; and mandates the government to issue decrees related to the storage of CO ₂	Favorable (hard): provides clarity on rules for dumping CO ₂ in geological formations in Sweden and environmental considerations for the construction of pipelines
The continental shelf law (GoS, 1966)	Regulatory Deployment Storage	Regulates the exploration and utilization of the seabed and the sub-seabed within the Swedish economic zone, including the issuance of permits for exploring the sub-seabed as a CO ₂ storage site	Favorable (hard): allows for and provides clarity on rules for the geological storage of CO ₂ on the Swedish continental shelf. Barrier: cumbersome authorization
The certain pipelines law (GoS, 1978)	Regulatory Deployment Transport	Regulates the issuance of concessions required for the pipe-bound transportation of liquid or gaseous fuels longer than 20 km, including CO ₂ intended for storage	Favorable (hard): allows for and provides clarity on rules for pipe-bound transport of CO ₂

TABLE 8 | Incentives/disincentives for BECCS RDD&D across different levels of governance.

	Economic			Regulatory		Informational		
	Incentive	Neither incentive nor disincentive	Dis-incentive	Favorable	Barrier	Incentive	Neither incentive nor disincentive	Dis-incentive
International	0	4	0	4	2	1	0	0
Supranational	2	5	0	4	2	2	1	0
National	2	3	0	5	0	0	0	0
Total, all levels	4	12	0	13	4	3	1	0

The category "Neither incentive nor disincentive" also includes the few instruments whose effects on BECCS are yet to be assessed pending ongoing policy processes. For instruments that have both incentivizing and disincentivizing effects, the overriding effect is counted and reported in the table.

policy instruments for generating a supply-push or demand-pull across the RDD&D phases of BECCS (see **Table 8**).

It is clear from the analysis that a large number of regulatory instruments actively govern BECCS RDD&D in Sweden. The majority of these instruments are so-called "hard," i.e., precise, binding, and enforceable instruments that provide a mostly favorable regulatory environment. Some exceptions to this rule exist and have notable international and supranational legal barriers and unclarity. Overall, however, the multi-level regulatory regime would allow for RDD&D of the full BECCS technology chain; the existing regulatory barriers are unlikely to substantially impede BECCS RDD&D. Although the regulatory instruments rarely explicitly inhibit BECCS RDD&D, they do not provide the incentives necessary for widespread deployment, nor do they coerce action. Instead, the EU and Swedish regulatory instruments generate high transaction costs, e.g., transaction costs related to permit application to explore and operate CO₂ storage sites and transaction costs related to trade export agreements. This increases the urgency for economic incentives to cover costs, not only the costs of technology investments and operation but also the transaction costs associated with regulatory compliance.

The analysis also identified an almost equal number of economic instruments of relevance to BECCS. The pattern was less positive than the regulatory regime. Most economic instruments of potential relevance to BECCS, at all levels of governance, were found to neither provide incentives nor disincentives for BECCS. All of the economic instruments that do provide incentives target research, development, and demonstration. As such, they cover at least a substantial part of the supply-push needs. However, there is a complete lack of demand-pull instruments for BECCS deployment.

This may appear to make perfect sense; the maturity of the full BECCS technology chain has thus far not been demonstrated. It would therefore seem logical to focus economic policy efforts on technology development and demonstration. The problem for BECCS is that individual components of the technology chain are already relatively well-developed. Additional supply-push instruments that do not initiate any demand-pull are therefore likely to lead to well-developed components of the technology chain. In some cases, the available funding may even serve to

demonstrate the full chain yet fail to spur more widespread deployment. As pointed out by de Coninck et al. (2010), even fossil fuel CCS is prone to end up in the technology "valley of death" between the public funding of R&D and more widespread private funding of deployment on established markets. Fossil CCS faces this risk despite existing economic instruments that provide incentives for reducing the emissions of fossil-based CO₂. This study confirms the concern raised in previous research (Fridahl, 2017; Torvanger, 2019): demand-pull instruments for capturing and storing CO₂ of biogenic origin are completely lacking, at least in the EU and in Sweden.

Only a few relevant informational instruments could be identified, all of which are inter- or supranational and almost all target action by governments. These informational instruments are mostly supportive, e.g., by allowing to the countries to account for negative emissions in compliance with commitments. As yet, however, relevant informational instruments do little to provide deployment incentives for industrial actors. Given that BECCS provide no added private value to consumers, and hence are unlikely to seem attractive for commercial companies, the gap between prospective policy objectives and their delivery requires substantial incentives to be bridged.

In its current form, therefore, there is no question that the policy mix will fail to incentivize more widespread BECCS deployment. The present study found a number of key implications for policymaking in this area if BECCS RDD&D is to be successfully incentivized.

First, there is a need to introduce new economic instruments that can incentivize BECCS at all levels of governance, either through reforming existing instruments, such as the EU ETS, or by designing new instruments, such as the proposed Swedish reversed auctions dedicated to BECCS. Other policy alternatives include certificates or negative emission refund schemes (Pour et al., 2018). Such demand-pull instruments would complement existing supply-push instruments as well as complement calls for new RDD&D funding streams that target either specific aspects of BECCS, such as new bio-feedstocks, or negative emissions technologies in general (Lomax et al., 2015; Burns and Nicholson, 2017; Cox and Edwards, 2019). The potential for capturing biogenic CO₂ in Sweden and the Swedish proximity to Norwegian storage sites (Kjärstad et al., 2016),

combined with the long storage permanence associated with the geological storage of CO₂ compared to many other forms of negative emissions (Fridahl et al., 2020), improves the likelihood that economic instruments that target BECCS will result in tangible and substantial contributions to addressing climate change. Among the several options available for the design of economic instruments, Parson and Buck (2020) argue that public procurement is the most appropriate form of instrument to incentivize negative emissions. According to Parson and Buck (2020), procurement allows for better control of the volume of CO₂ removed from the atmosphere in the event that global warming is eventually limited and carbon dioxide removals, if unmitigated, cause problematic global cooling. Based on this argument, however, other instruments, e.g., quota obligations and certificate trade or cap-and-trade systems, could provide the state with a similar control, as the level of quota obligations, or the cap, can be adjusted. Even subsidy schemes or fees and dividends can be designed to retain control over the volumes of BECCS that the instruments seek to effectuate (Fridahl, 2019). In any case, public procurement options ought to allow enough security for investments and ought to incentivize BECCS relatively expeditiously. This is also an option that would interfere relatively little with the existing climate policy mix designed to incentivize emission reductions rather than removals.

Second, there is a need to amend regulatory instruments that raise deployment barriers at international and supranational levels, i.e., to remove regulatory barriers. Regulatory harmonization across levels of governance, a process that has clearly already been started by reforming UN and other multilateral regulation to harmonize with EU regulation, must continue. There is also scope to continue lowering the supranational regulatory barriers, e.g., to sort out unclarity regarding the leakage of biogenic CO₂ from geological storage sites under the CCS Directive. These would complement calls for clearer frameworks for licensing sub-soil access for CO₂ storage (Cox and Edwards, 2019).

Third, there is scope to introduce informational instruments at all levels. In pursuit of supporting BECCS, it may be particularly useful to initiate networks intended for sharing experience and fostering mutual learning (Fridahl and Johansson, 2017) and to organize lobby power to balance the power of conservative policy networks in incumbent sociotechnical regimes (Normann, 2017).

Fourth, given that incentives are lacking on international and supranational levels, and that actions on these levels are beyond the direct control of national governments, countries that are serious about assigning a limited role to BECCS within their mitigation portfolio should act proactively and independently to pursue RDD&D activities. Waiting for an international carbon price to reach levels sufficient to incentivize BECCS is certainly the wrong approach. The technology may turn out to be a technological dead-end for reasons difficult to foresee from the present vantage point. As Mazzucato (2018) argues, in the pursuit of clean-tech innovations, national governments must look beyond the “market-fixing” approach of previous decades and dare instead to pursue “market shaping” and “market cocreating.” The Swedish government has a better opportunity

than most to play an active role in supporting the domestic RDD&D of BECCS, bearing the risk for the companies willing to be involved, and thus contributing valuable lessons about the global potential for negative emissions.

There is another key factor that depends on the incentivization of BECCS, however. The incentivization of BECCS must be done responsibly to determine whether and to what extent BECCS diffusion is feasible and desirable, socially speaking (Bellamy, 2018). After all, BECCS, like any other technology, is not simply a technical artifact but one that is dependent on—and inseparable from the social contexts in which it would reside. In the United Kingdom, for example, research has shown significant public opposition to the technology if BECCS was incentivized with guaranteed price premiums. The public was opposed to using a system in which companies using biomass boilers to produce electricity and heat would be guaranteed a price premium if they ran their installations with BECCS (Bellamy et al., 2019). Understanding the industrial actors’ perspectives, or BECCS acceptance, is also an important social context. Investigations of the large-scale emitters of biogenic CO₂ in Finland and Sweden have, in addition to the policy aspects raised in this paper, revealed challenges to, e.g., process integration, trade-offs between various firm-specific sustainability goals, willingness to become a first mover, and beliefs in the responsibility to mitigate climate change. The results indicate that these firms often seem unwilling to decrease biogenic CO₂ emissions if such investments crowd out investments intended to fulfill other sustainability targets (Rodriguez et al., 2020). This means that broad societal participation is necessary in the evaluation of which negative emission technologies might be used, the selection of policy instruments for bringing these technologies to development, and the design of governance principles that reflect the diverse values and interests of key actors in society.

In conclusion, at the dawn of the 2020s, the existing climate policy mix is unfit for the purpose of incentivizing BECCS deployment. If unreformed, the existing policy mix will most likely lead to substantial public expenditure on BECCS research, development, and demonstration without leading to any substantial deployment and diffusion. Even if there is scope to reform existing regulatory instruments and to initiate new informational instruments, the incentive gap between the tentative targets for BECCS and existing policy enablers is largely characterized by a complete lack of economic demand-pull instruments. There is therefore an urgent need for future research to characterize alternative demand-pull policy instrument pathways, and to formally evaluate these pathways in terms of their potential to deliver net-negative emissions through a variety of means in technically effective and socially responsible ways.

If supported by the Swedish government and adopted by Parliament, the proposed Swedish negative emission strategy (GoS, 2020c) would shift the Swedish policy mix in the direction suggested herein. Mid-term reversed auctions would then be used to instigate a limited but long-term state-led demand for BECCS by 2030. This would allow for testing both the willingness of the industry to deliver BECCS and the societal

response to such delivery. In line with socially robust policy development, the design of an instrument to generate demand in the longer and grander 2045 perspective would require both actor-specific feedback and policy development in the EU and internationally. In addition, the proposed strategy would task the Swedish Energy Agency with leading a much-needed knowledge and policy network on CCS including BECCS. If combined with new demand-pull policy instruments developed in the EU, this proposal would go a long way toward closing the incentive gap for BECCS deployment in Sweden.

Although this article has focused on Sweden, the findings are relevant for all EU Member States that are interested in using BECCS for target fulfillment, yet that have not developed a strong demand-pull for BECCS as part of their national climate policy mix. While several EU Member States have shown an interest in BECCS, to the best of our knowledge, no EU Member State has as yet adopted such a policy. If this holds true, the findings of this article can be used as a departure point for policy making in interested EU Member States and supranationally in the Union itself.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: The datasets analyzed for this study can be found in the online document

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AUTHOR CONTRIBUTIONS

MF designed the research and collected the data. MF and RB conducted the analysis and wrote the majority of the article. AH and SH contributed as critical reviewers, discussants, and as authors of specific sections of the paper. All authors contributed to the article and approved the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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