Environmental Sciences Europe

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Potential and goal conflicts in reverse auction design for bioenergy with carbon capture and storage (BECCS)

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Abstract

Bioenergy with carbon capture and storage (BECCS) is considered as a future key technology to provide baseload electricity, heat, pulp, paper, and biofuels, while also enabling atmospheric carbon dioxide removal (CDR). Sweden seeks to lead the way in bringing this technology up to scale, introducing a EUR 3.6 billion reverse auction scheme to facilitate market entry of companies producing BECCS. We explore instrument design preferences among politicians, regulators, and prospective BECCS operators to identify trade-offs and explore feasible policy design. Based on 35 interviews with experts in the latent BECCS sector in Sweden, we identify under which circumstances prospective operators would be willing to place bids and discuss how actor preferences both align with and challenge auction theory. The analysis concludes that at least four dilemmas need attention. These concerns how to: (1) balance the state's demand for BECCS to be implemented already in 2030 against the prospective BECCS operators' fear of the winner's curse, i.e., a fear of bidding for a contract that turns out to be too costly to implement; (2) allocate contracts at the margin of the auctioneer's demand for BECCS without driving up costs; (3) design compliance mechanism to achieve effectiveness without undermining efficiency, and; 4) integrate the auction with the voluntary carbon market—if at all—in a manner that safeguards the environmental integrity of the auctions.

Keywords Bioenergy with carbon capture and storage (BECCS), Incentives, Policy design, Reverse auctions

Background

Compliance with the Paris Agreement's aspirational goal to reach a global balance between greenhouse gas sources and sinks requires vast amounts of carbon dioxide (CO_2) removal (CDR). Adopting this goal has led to a surge in mid-century net-zero targets, for which CDR needs to become an essential element of climate policies considerably before the mid-century [1, 2]. Bioenergy with carbon capture and storage (BECCS) is considered to be among the most important CDR approaches in modelled emissions pathways, but its actual share in future climate politics is still uncertain [3]. Since, in the European Union (EU), physical leakage from storage sites is regulated, a liability framework that makes BECCS suitable for a decentralised, market-based development of carbon capture is already in place. However, the current EU climate policy provides no incentives for BECCS [4, 5]. While an efficient development of BECCS in the EU requires its inclusion in the EU Emissions Trading System (EU ETS)—an EU-wide cap-and-trade system for cost-efficient reduction of emissions from industry, power production, aviation, and shipping—or the development of other union-wide incentives, individual EU member

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states like Sweden could accelerate development by providing extra incentives to lower market-entry costs for BECCS operators, in particular with respect to the considerable capital cost of BECCS installations [6, 7]. Previous research has highlighted that policy incentives for BECCS are virtually nonexistent, especially those consonant with demand-pull policy [4, 8, 9]. In this context, calls for responsible incentivisation of BECCS are becoming increasingly strident [10–13].

While the research interest in BECCS demand-pull policy design is increasing, a few governments are actively exploring such options [1]. Sweden constitutes one of the few exceptions in this respect [1, 14]. With unusually good preconditions for BECCS due to a bioeconomy with associated emissions of biogenic CO_2 located in large point sources from power and heat as well as pulp and paper production, the Swedish government has commissioned the Swedish Energy Agency to develop a fully operational BECCS support scheme [15]. The Swedish Energy Agency, largely in line with earlier suggestions from a public inquiry commission, promotes reverse auctions due to their potential to reward operators close to the marginal specific costs of deployment, in an attempt to minimise overcompensation and state expenditure [16]. The Swedish government has dedicated EUR 3.6 billion for the auctions, to be allocated to BECCS operators in the period 2026–2046.

Potential efficiency gains have been a key argument in favour of reverse auctions. Policy instruments, however, also need to be effective and feasible. Fullerton [17] notes that feasibility is at the core of enabling effects of policy. Reverse auctions are no exception. Securing political support is a prerequisite for feasibility, and an effective auction scheme also requires bidders. If an auction only manages to attract scant engagement, competition is eroded, something which in its turn is likely to undermine cost-efficiency [18].

The effectiveness of reverse auctions rests largely on prospective actors accepting its premises [19]. A system design that is viewed as too complex, or as unfair (risking the generation of high unforeseen costs or unstable revenues), will lack participating actors and fail to deliver BECCS. Accommodating most potential priorities among prospective bidders may, however, also undermine the efficiency and effectiveness of the auctions. Ensuring feasibility through compromising between stakeholders' preferences is often done at the expense of efficiency [20–22].

Studies of BECCS reverse auctions are impeded by lack of empirical evidence on how such auctions would work. This article therefore utilises a unique possibility to turn to Sweden as an empirical case to explore potential goal conflicts and dilemmas that may emerge from designing reverse auctions for BECCS, in the EU or elsewhere. The aim of this paper is to explore under which circumstances prospective Swedish BECCS operators would be willing to place bids in a reverse auction, and how their auction design preferences converge. A second aim is to study how expressed operator preferences may generate dilemmas when compared to preferences among respondents that represent the auctioneer, i.e., the Swedish state. For this purpose, we conduct 35 qualitative interviews with experts at public and private companies with high technical potential for implementing BECCS, as well as regulators in the national administration and in national politics in Sweden.

Climate policy objectives in Sweden and the EU

Sweden, a member of the EU since 1995, along with the EU, has committed to legally binding targets for net-zero greenhouse gas emissions. The goal for Sweden is to reach net-zero emissions by 2045, while the EU aims to achieve this by 2050.

The Swedish target stipulates a minimum reduction of 85% in emissions by 2045, compared to the levels in 1990 excluding the net uptake in Swedish land use and forestry. The Swedish gross emissions in 1990 were 71.2 million tonnes (Mt) of CO_2 equivalents (eq), and the net uptake in land use and forestry was 51.4 $MtCO_2$. Thus, the gross emissions are to be reduced by at least 60.5 $MtCO_2eq$ by 2045. The maximum residual emissions allowed in 2045 are 10.7 $MtCO_2eq$, i.e., 15% of total gross emissions in 1990. Any remaining emissions in 2045 can be offset through BECCS, as well as additional measures in land use and forestry or verified carbon credits.

It is important to note that the existing large net sink in Swedish forestry, which corresponds to approximately 35–45 $MtCO_2$, cannot be used to offset these residual emissions. The offsetting of residual emissions by CO_2 uptake in land use and forestry is limited to measures that are additional to the existing sink and are a direct result of new policy. This design of the 2045 target, which restricts the use of sinks in land use and forestry, has sparked significant interest in BECCS within the Swedish government. It has led to efforts to incentivize BECCS and explore ways to offset anticipated residual emissions in sectors such as agriculture and waste.

CCS and BECCS policy incentives

Carbon Capture and Storage (CCS) is a technology that can be applied to any large CO_2 point sources, irrespective of the CO_2 molecule's origin. However, it is often differentiated from BECCS. CCS involves processes that combine the burning of fossil fuels or calcination of limestone with technology that captures and stores the resulting fossil CO_2. As such, CCS leads to reduced emissions, for instance, from power or cement plants.

The distinction between CCS and BECCS lies in the origin of the CO_2 molecule. For a process to qualify as BECCS, the captured and stored CO_2 molecule must be of unfossilised biogenic origin. The carbon in biomass comes from atmospheric CO_2 absorbed by plants through photosynthesis. This implies that biomass used in industrial processes has first sequestered CO_2 from the atmosphere, which is then re-released back into the atmosphere when the carbon is oxidised [23].

Biomass is utilised in various processes where BECCS can be applied, such as the production of ethanol, biogas, pulp, paper, heat, and electricity. In carbon accounting, both uptakes and emissions are accounted for in the land use and forestry sectors. Therefore, emissions that occur when biomass is used in a facility should be reported as carbon neutral to avoid double counting, i.e., at both biomass harvest and use. Consequently, while CCS reduces emissions from the industrial use of fossil carbon, BECCS generates negative emissions from the industrial use of biomass [8].

This implies that while CCS is incentivised by putting a price on CO_2 emissions, BECCS is not. A facility owner that emits fossil CO_2 can avoid paying a carbon tax or surrendering allowances in a cap-and-trade system by implementing CCS. However, this is not the case for BECCS, as a price on CO_2 emissions does not apply to carbon-neutral activities [4, 14].

Designing conducive policy environments for BECCS is key to its deployment [12]. Mindful of the virtually complete lack of BECCS demand-pull policies in the late 2010s, some researchers have turned their attention to how such instruments could hypothetically be designed. Rickels et al. [24] and [5] explore various ways in which BECCS could be incentivised by inclusion into emissions trading systems, while Parson and Buck [25], assessing different policy options, argue that inclusion within public procurement is most advisable in view of the need to maintain a high degree of state control over volumes of CDR. Further, Pour et al. [26] take up the possibility of using quota obligations and certificate trade or a fee and dividend system. Jenkins et al. [27] also propose to use quota obligations put on fossil fuel extractors. Other have explored design options at the UN governance level, governance principles, and the potential to cooperate in climate clubs [8, 9, 14, 28].

Very few studies focus on actor preferences for BECCS. Studies that do have such a focus tend to explore views of global potentials and investment preferences [29], domestic policy barriers and preferred policy scenarios [11, 30], or trade-offs in and opportunity costs of BECCS investments [31]. Up until today, researchers have seldom, if at all, focused on how actors prioritise among detailed policy design options, a process which is in focus for this paper.

Reverse auctions

Reverse auctions are effectively creating a temporary marketplace with one buyer (auctioneer) and many potential sellers (bidders). The use of reverse auctions dates back at least to the nineteenth-century pauper auctions offering compensation for organisations caring for people in need [32, 33]. It was not until the late twentieth century that reverse auctions became popular in environmental governance. From 1990 onwards, the British government organised a series of reverse auctions to increase the supply of fossil-free electricity. The auctions reduced marginal costs for renewable electricity in the UK, and have often been evaluated as being relatively cost-efficient [34–36]. Just over a decade later, Brazil followed the British example and replaced feed-in tariffs with reverse auctions to spur renewable power generation, which contributed to making solar and wind energy competitive in Brazil [37, 38].

After the UK and Brazil broke this new ground, many more countries followed suit in the early 2010s. The number of countries that conducted at least one reverse auction for renewable electricity increased from seven in the period before 2005 [39] to at least 106 in 2018 [40]. Experiences from the UK, Brazil, and many other countries confirm that reverse auctions can be effective and efficient in spurring installed capacity and reducing production costs. There is, however, also ample evidence of less effective reverse auctions—undermined by breaches of contracts and the winner's curse, i.e., when the winning bids are too low to finance the cost of compliance [36, 41–43]. Ideally, however, auctions stimulate installations close to the marginal cost of production. This is a particularly attractive feature of auctions in situations where authorities lack detailed knowledge of production costs and have difficulty determining an appropriate premium. This is a central trait of BECCS. Due to the lack of experience with demonstration of full technology chains for BECCS, regulators struggle to accurately assess the level of support required for BECCS. Under such circumstances, auctions can prove to be very valuable in revealing costs and mitigating information asymmetries between businesses and regulators [19, 44].

Reverse auctions, predominantly used in environmental governance to support renewable energy, have unique implications when applied to BECCS. Unlike renewable electricity, BECCS does not yield a product that can be traded on an existing, mature market. This distinction makes it challenging to support BECCS through reverse auctions, which typically cover the difference between the market price for electricity and the auction strike price. Given the immaturity of carbon removal markets and the resulting unstable investment horizons, investors are unlikely to back the substantial investments required to develop and operate a BECCS facility in sectors like pulp and paper or power and heat production without guarantees for long-term and predictable revenues.

Moreover, BECCS differs from renewable energy in that its operating costs are significant, whereas renewable energy is dominated by investment costs. This combination of a lack of a marketable product and significant operating costs necessitates continuous support for BECCS to maintain operations. From this perspective, BECCS aligns more closely with payments for ecosystem services than with renewable electricity. Reverse auctions have been applied also to allocate payments for ecosystem services [45]. While negative emissions resulting from BECCS, like many ecosystem services, contribute to a public good, BECCS does not generate local co-benefits that could help drive investments into the technology, a common feature of ecosystem services. Furthermore, procurement of ecosystem services typically involves relatively small individual investments from a large pool of potential suppliers [46, 47], whereas BECCS is almost invariably large scale and involves high capital and operating costs from a relatively small pool of potential suppliers. These factors make it challenging to directly apply auction designs adapted for renewable electricity or ecosystem services to BECCS.

However, several positive international experiences with reverse auctions are highly relevant to BECCS. Reverse auctions can address problems with asymmetric information. Given the lack of experience with BECCS, it is difficult for authorities to accurately assess the support level required to realize a project. For instance, feed-in tariffs set without accurate cost knowledge can be too low to achieve the desired effect, as was the case with the Greek feed-in tariffs for renewable electricity. Conversely, they can be set too high, leading to overcompensation and high inefficiency, with risks of investment bubbles and unnecessarily high consumer prices, as seen with feed-in tariffs for solar energy in Spain [36]. For BECCS, the problem of asymmetric information is likely substantial, as a lack of experience places authorities at an informational disadvantage relative to potential BECCS suppliers.

The specific costs of integrating CCS into bioenergy facilities are very diverse, impacted by factors such as the level of concentration of CO_2 in flue gases [48, 49], the availability of excess heat [7, 50], and the distance to storage sites and transport infrastructure [51, 52]. The heterogeneity of costs improves the likelihood of achieving cost-efficiency with an instrument that acts on the marginal cost curve for BECCS, such as well-designed auctions—at least compared to instruments based on flat-rate reimbursements [19]. However, auctions could also easily falter if they do not strike a balance between design features so as to sufficiently encourage prospective BECCS operators to place bids while including sufficiently stringent design elements to assure effectiveness and efficiency. If such a balance cannot be struck, a reverse auction would be unfeasible or, at minimum, a less attractive option for incentivising BECCS.

Methods

This article utilises the possibility to turn to Sweden as an empirical case, so as to explore potential goal conflicts and dilemmas that may emerge from designing reverse auction for BECCS. The study accounts for preferences both on the supply side (bidders) and on the demand side (the auctioneer) by interviewing 35 BECCS practitioners in Sweden (see Table 1). Interviewees were identified based on explicit interests in deploying BECCS and

Table 1 List of interviewees by type and sector

Employer (with the no. of interviewees from the same organisation listed in parenthesis)	Actor type (with the associated sector listed in parenthesis)
Borås energi och miljö (2); E.ON (1); Kraftringen (1); Lantmännen Agroetanol (1); Mälarenergi (1); Renova (1); Stockholm Exergi (1); Sysav (2); Söderenergi (1); Tekniska verken (1); Vattenfall (2); Växjö energi (2); Öresundskraft (1)	Company (energy)
Avfall Sverige (1); Energiföretagen (1)	Trade association (energy)
Holmen (2); SCA (2); Stora Enso (1); Södra Cell (1)	Company (pulp and paper)
Skogsindustrierna (1)	Trade association (pulp and paper)
Centre Party (1); Christian Democrats (1); Green Party (1); Social Democratic Party (1)	Politics
Swedish Energy Agency (1); Swedish Environmental Protection Agency (2); Swedish Agency for Growth Policy Analysis (1); Public inquiry commission (1)	National administration

their key roles in designing policy incentives. Additional interviewees were contacted until empirical saturation was achieved, i.e., "when no additional issues or insights" [53] (p. 592) emerged from the data.

Four actor types of key significance to reverse auctions for BECCS were interviewed for this study: climate and energy spokespersons for political parties in the Swedish national parliament, civil servants with key responsibilities in the national administration of CCS—including BECCS—in Sweden, staff responsible for planning for and developing BECCS at companies with high BECCS potential in Sweden, and BECCS-experts at Swedish trade associations whose member companies consist of a large share of prospective BECCS operators.

The interviews were held in Swedish and were semi-structured around open-ended questions regarding the suitability of using reverse auctions to incentivise BECCS. The guide covered issues such as views on technical potential and accuracy of cost estimates, policy instrument choice to incentivise BECCS, necessary framework conditions for BECCS support, ownership over negative emissions resulting from BECCS, legal deployment barriers, compliance mechanisms, and bid procedures for auction systems. The surveys were conducted online in the first quarter of 2021, lasted for about 60 min each, and were ultimately transcribed and inductively coded into themes [54]. An English translation of the interview guide for business representatives is presented in supplementary materials. The interview guide was tailored to the specific capacities and roles of the four different actor categories; each guide covered the same overarching themes.

It is important to note that the study has several limitations. First, the interviews were held in an early phase of planning for BECCS reverse auctions in Sweden. The results of this study should therefore be viewed in light of a continually evolving capacity of the interviewed actors to understand the BECCS technology chain and the reverse auctions instrument. Second, although plans for reverse BECCS auctions are far advanced in Sweden which has triggered an interest in auction design among owners of facilities with technical potential for BECCS as well as in the national administration and politics, the data collected are limited to Sweden. Interviews of similar nature could be held with similar actors in other countries, providing a richer data set. Finally, at the time of writing the article, no BECCS auction had been carried out anywhere in the world, limiting the possibility of relating to practical experience of conducting such auctions. Although the novelty of reverse auctions for BECCs in Sweden is one of the primary arguments for studying its emergence, it clearly also limits the possibility of relating to previous research. Due to the lack of experience from reverse BECCS auctions, literature on analogous reverse auctions for renewable energy and ecosystem services have been used to inform the interview guide and discuss the data. This literature suggests several key aspects to consider when designing effective and efficient reverse auctions, including numerous potential trade-offs and dilemmas. Understanding actor preferences regarding those aspects are key to understanding the prospects for using reverse auctions to effectuate BECCS efficiently; however, it should be noted that practical experience of using reverse auctions to incentivise BECCS is lacking and that parallels to analogous reverse auctions should be made with care due to the differing characteristics of BECCS and renewable electricity as well as ecosystem services, as discussed in the subsection "Reverse auctions" in the Background section.

Results and discussion: actor preferences for BECCS reverse auctions

Three broad themes emerged from the interviews, which resonate with key discussions in the auction literature: (1) entry criteria and scope of auctions; (2) bidding procedures and winning criteria; and (3) risk sharing. The interviews reveal differing expectations regarding these themes, with choices between different auction design options that involve trade-offs with a need to balance various concerns. The results and discussion are presented below, with key findings summarized in Tables 2, 3, 4 and 5 at the end of each subsection. The tables summarize key findings regarding circumstances under which prospective BECCS operators would be more likely to place bids in a reverse auction and how these expressed operator preferences may generate dilemmas when compared to preferences among respondents that represent the auctioneer, i.e., civil servants in the national administration and politicians.

Entry criteria and scope

The first theme concerns entry criteria and scope. In context of reverse auctions for renewable energy, Matthäus [55] recommends to adopt rather strict entry criteria to attract "boost realization rates" and encourage "more serious bids" (p. 2). Strict entry criteria should ideally keep fraudulent or unserious actors out and let serious bidders in, yet Marambio and Rudnick [56] caution against too high entry barriers that reduce participation and undermine efficiency. The interviewees generally agree that entry criteria should be tweaked to reduce collusion and unserious bids, but voice two significant qualifications. First, the technical potential for BECCS is mainly concentrated to large point sources of biogenic CO_2 which involve relatively

Table 2 Summary of key findings pertaining to entry criteria and scope

Perspectives of key actors	Dilemma	Policy recommendations
Bidders: Stringent prequalification criteria may deter the limited number of potential operators from placing bids. This effect is compounded by uncertainties and the potential benefits of a wait-and-see approach Auctioneer: Lax prequalification criteria may invite non-serious participants, thereby lowering the realisation rate	Striking a balance between relaxed prequalification standards for maximum participation and efficiency, and stringent criteria to ensure maximum effectiveness	Integrate reverse auctions with substantial feasibility study subsidies to mitigate uncertainties and lower entry barriers; disseminate as many feasibility study results as possible to amplify learning through spillover benefits

Table 3 Summary of key findings pertaining to bid procedure and winning criteria

Perspectives of key actors	Dilemma	Policy recommendations
Bidders: Opinions on bid procedures are varied and uncertain; concerns are raised about identifying the final winning bid in auctions with a fixed volume cap Auctioneer: While recognizing the theoretical advantages of uniform auctions, they generally favour discriminatory auctions; they are unsure about handling a final bid that exceeds the demand set by the auction cap	If the auction's goal is to procure BECCS at the minimum cost, a discriminatory auction could be beneficial. However, regardless if the auction adopts a uniform or discriminatory design, efficiency might be compromised if it is governed by a fixed volume cap (Fig. 1)	Instead of having a set volume target for specific auctions, the auctions could be governed by a flexible mandate departing from a budget rather than volume cap. This would allow the auctioneer to solicit bids in an unspecified number of sequential auctions, continuing until the budget cap is reached and selecting winners based on the shape of the marginal cost curve

Table 4 Summary of key findings pertaining to risk sharing

Perspectives of key actors	Dilemma	Policy recommendations
Bidders: Converge around a 15-year contract term to ensure investment security while hedging against uncertainty of market development in an even longer contract term; they favour lenient sanctions and high flexibility in fulfilling obligations Auctioneer: Prefers a similar term (15 years) to guarantee a return on investment in form of negative emissions over a relatively extended period, without creating look-in in the longer term; accepts a degree of flexibility, albeit less than what the bidders request, and supports penalties	Rigorous sanctions aimed at enhancing efficacy and limited flexibility designed to assure the state of the BECCS delivery must be counterbalanced with the necessity to draw sufficient bidders to the auction to cater for competition, which is needed for efficiency reasons. Thus, inherent trade-offs between efficacy, predictability, and efficiency seem inevitable	Given that the full BECCS chain is largely unproven and therefore associated with substantial uncertainties and risk, the likelihood of failing to attract sufficient bidders to the auctions is high. It is therefore sensible to view the auctions as a vehicle for organising public–private partnerships with high flexibility and focus on a facilitative rather than enforcing compliance mechanism

Table 5 Summary of key findings pertaining to business models and credit ownership

Perspectives of key actors	Dilemma	Policy recommendations
Bidders: Agree that the auction's mitigation outcome should be registered in the Swedish greenhouse gas inventory; many (but not all) also argue that the same mitigation outcome could be traded as credits on voluntary carbon markets for offsetting purposes Auctioneer: Mostly agree that the sale of credits should be limited to contribution claims, i.e., that the credit buyer contributes to the achievement of climate targets in the host country and that the credit cannot be used for offsetting claims	Catalytic co-financing could increase the share of the BECCS potential that is realised, using public funding to leverage private funding. However, if private financing is conditioned on the ability of making offset claims, as suggested by numerous potential bidders, then the climate benefit of private financing can be questioned. Such credits may not lead to delivery of overall mitigation in global emissions, i.e., beyond existing national mitigation targets, and risks obscuring transparency in reporting intended to avoid double counting	Environmental integrity can be safeguarded either by limiting the use of credits to claims that the buyer has contributed to achieving the auctioneer's climate targets (i.e., non-offsetting claims), or by enabling the sale of credits with corresponding adjustments in national greenhouse gas inventories, which would allow for the use of attribution principles to allocate the mitigation outcomes from BECCS between government support and entities that purchase carbon credits in carbon markets

few locations. Several respondents point out that the economic potential is further constrained by factors such as access to excess energy to power CO_2 capture and compression, transport infrastructure, space to integrate BECCS equipment, and environmental permitting. These constraints mean that it might become hard to attract actors with technical potential for BECCS to also place bids in auctions. The economic constraints on technical potential may limit the already relatively few actors that may place bids in BECCS reverse auctions, which may undermine competition and lead to efficiency losses. As such, they largely agree with Marambio and Rudnick [56] that excessively strict entry criteria entail the risk putting further restraints on prospective bidders. On the other hand, entry criteria which are too permissive can encourage participation of unqualified bidders that could lead to non-performance [55–57], a risk raised by interviewees representing the auctioneer. Thus, the risk of generating efficiency losses must be balanced against possible losses in effectiveness [58].

Second, while most respondents deem the technology readiness level of individual components of BECCS to be high, getting the whole technology chain operational is considered challenging. The lack of demonstrated technology chains raises the investment risks, potentially lowering the appetite to engage in early auctions. Many interviewees raise question marks regarding the possibility to gain access to storage sites and to subcontract CO_2 transport capacity. Business respondents generally anticipate that the learning curve will initially be quite steep, which would be a typical set-up for latecomers to benefit from high knowledge spillovers associated with "learning by doing" by the early BECCS adopters. This may further limit the willingness of businesses to place bids in the first auction round.

The responses also reveal that businesses with more mature BECCS plans tend to ask for more rigid entry criteria, while businesses with less mature plans tend to want to wait with bidding until uncertainties have been reduced. The latter is a particularly strong tendency among businesses with the largest point source emissions, for which even small uncertainties can have relatively large effects on bidding readiness in absolute terms. Smaller businesses seem to be more willing to engage in early auctions, yet also typically have less mature BECCS plans or less capacity to conduct feasibility studies. If the entry barrier is placed relatively high, and large emitters do indeed wait for knowledge spillovers before they act, the number of bidders in a first auction may turn out to be too few to harvest efficiency gains. On the other hand, if the entry barriers are low, bidders with less-developed plans may win contracts that turn out to be hard to deliver on, which would reduce the auction's effectiveness.

An implication of this finding for designing BECCS reverse auctions is that an auction ought to go hand in hand with capacity-building support to businesses so as to reduce uncertainties—for example, grants to conduct advanced feasibility studies. The lack of historical experience of BECCS motivates public investments in capacity-building to reduce uncertainties for businesses. The results of feasibility studies can also be fed back to public administrators and, as such, reduce information asymmetries between the state (i.e., the auctioneer), with constrained knowledge about technical potentials and costs, and businesses (i.e., prospective bidders), with detailed knowledge about their production facilities. Feasibility studies are most likely beneficial for raising confidence for businesses to place bids, but public administrators can also use the results regarding businesses' cost estimates and technical potentials to design efficient and effective auctions.

Bid procedure and winning criteria

The second theme that emerges from the interviews pertains to tender procedure and winning criteria. While there are many theoretical models for how to organise bid procedures and design pricing rules, auctioneers almost always settle for discriminatory auctions, i.e., pay-as-bid auctions [see for example 59]. Regarding bid procedure, pricing rules, and allocation of contracts, the views of the respondents are very diverse, with preferences ranging from sealed-bid discriminatory auctions to dynamic multi-round and open-bid uniform auctions. The preferences are almost as diverse as the number of interviewees, with a slight tendency to favour discriminatory auctions. One explanation for this may lie in a lack of clear guidance on the objective of the reverse auctions at the time of the interviews. Many respondents report on what they perceive as an almost frustrating lack of clarity, particularly on whether they are intended to demonstrate BECCS technology or to realise Swedish BECCS potential at the lowest possible cost to the state. While the interviewed politicians mostly voice an interest in using reverse auctions for cost-efficiency reasons, many actors across the board express that they would prefer clearer guidance form the government. Given this lack of clarity, business respondents argue for what they believe is the objective for the auction system, and for what they view as the most appropriate bid procedures for delivering on these objectives.

A public actor that plans to hold auctions should start by deciding on the main objectives, not only because this parameter is fundamental for how to design the auction

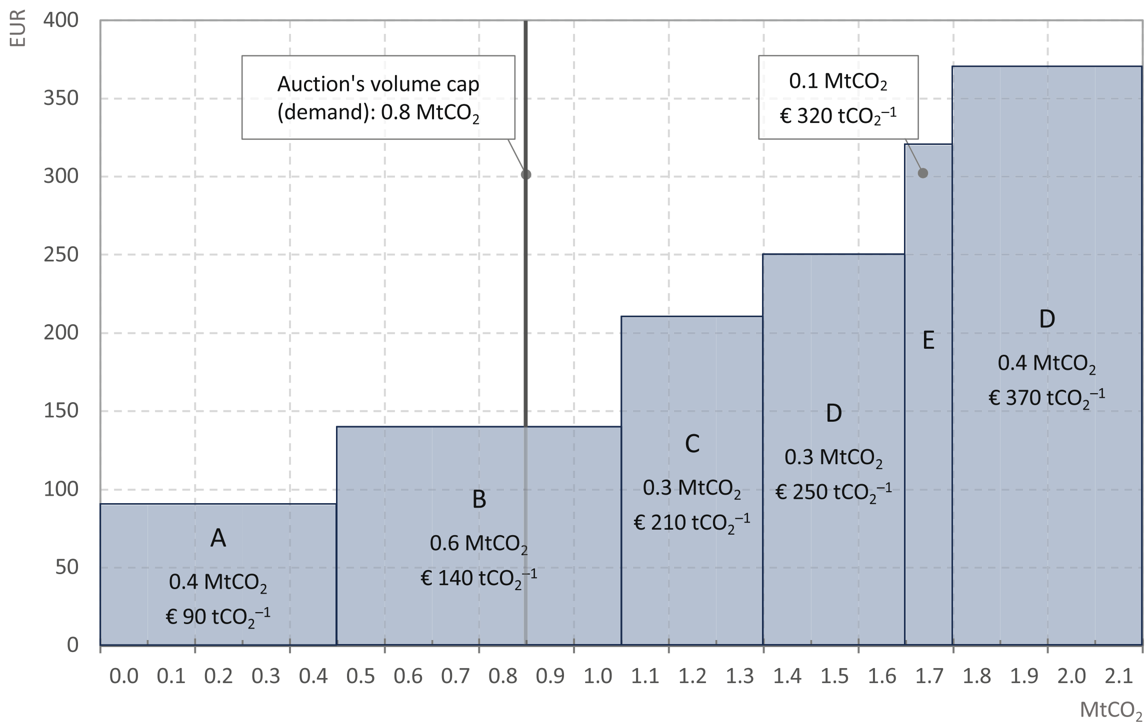

Fig. 1 Discriminate reverse BECCS auction—for illustrative purposes—with six bidders **A–F** representing annual BECCS supply and a strict auction volume cap fixed at 0.8 $MtCO_2$, representing inflexible annual demand. Due to benefits of scale, bids cannot be scaled down linearly, i.e., bidder **B** cannot accept a contract limited to supply 0.4 $MtCO_2$ annually at a price of EUR 140 per tonne CO_2. To satisfy the demand, the auctioneer would have to accept bids by bidder **A**, **C** and **E**, which sum to a supply of 0.8 $MtCO_2$ annually at an average cost of EUR 131, while accepting bids **A** and **B** would instead supply 1.0 $MtCO_2$ annually at an average cost of EUR 120

but also because it directs the focus of prospective bidders to building the necessary capacity to place bids. This may appear as common sense regarding auctions, but the Swedish example shows that common sense is not always perceived or acted on. At the time of the interviews, lack of clarity caused a lot of unnecessary uncertainty among prospective bidders. Energy was channelled towards sorting out the consequences of possible objectives rather than towards more active preparation of capacity to place bids.

In theory, uniform auctions are often preferred over discriminatory auctions if the auctioneer seeks to reveal costs rather than maximise efficiency. Since bidders tend to know more about true costs than auctioneers, discriminatory auctions could lead to strategic bidding in which bidders take financial advantage of information asymmetries. In contrast, uniform auctions reward winning bidders equally, often the last winning or first losing bid—as in, e.g., the 2016 Spanish reverse auction for biomass electricity, held in part to reveal the cost of biomass power so as to inform future investment support [39]. According to Khezr and Cumpston [60], uniform auctions are generally considered to be better at revealing true costs, because they reduce the incentives to bid strategically, which makes uniform auctions preferable if price discovery is a prioritised goal. At the same time, Cason and Gangadharan [61] have shown that uniform auctions for ecosystem services normally also lead to overcompensation, i.e., potential losses of efficiency, due to the fact that the bidders are normally paid at higher rates than what they bid for. If cost-efficient technology dissemination is the primary objective, then auction designers might instead want to consider arranging discriminatory auctions.

A combination of objectives could also be achieved. Auctions sometimes have multiple objectives associated with multiple winner criteria that consider costs in tandem with various co-benefits, conglomeration bonuses, demonstration of different approaches, commissioning time, and more [57]. Some respondents are asking for a multi-criteria assessment of bids, including what they refer to as “cluster bonuses”, a form of conglomeration bonus based on being able to cooperate locally to increase benefits of scale, or bonuses for facilities that are integrated with fossil CCS. Experiences from auctions with multiple objectives differ. Chilean auctions with allocation rules that combine demand coverage and price show that these have been less efficient than auctions centred on price, such as the Brazilian equivalents [57]. Moreno et al. [57] argue that multi-objective award rules "may increase the bidder's uncertainty, which in turn increases the likelihood of cost-effective contract award".

The interviews indicate that not knowing the objective of the auctions leads many actors to spend substantial resources on lobbying for one or the other perspective. Others adopt wait-and-see strategies rather than starting more active preparations for bids. Some actors also voice regret that lack of clarity leads them to become more cautious regarding knowledge-sharing and cooperation, fearing that generous knowledge-sharing might lead to competitive disadvantage in future auctions. A clearly stated conglomeration bonus or other types of incentives to share knowledge could have mitigated the tendency to conceal knowledge.

Another concern voiced by many respondents relates to how to deal with bids on the margin between winners and losers. Problems can occur when determining the last winning bid in auctions with a set cap—a volume of units auctioned or a budget cap—if the last competitive bid results in supply that is substantially higher than the demand determined by the auction cap. International experience with reverse auctions for renewable electricity generation indicates that the marginal cost curve at the cap of auctions is relatively flat, so that the choice between bids on the margin has low effect on the cost-efficiency of the auction. Experience from auctions of ecosystem services, similarly, rarely has problems with matching the volumes offered by bidders with the demand set by the cap, since the bids often involve relatively small volumes—something which simplifies finding an acceptable fit with an auction cap.

However, the interview responses indicate that BECCS poses new challenges for reverse auctions. The interviewees report significant benefits of scale involved in BECCS, which means that downward adjustment of the operating volume at a BECCS facility normally leads to increased cost per unit of CO_2 captured. This means that bids based on a specific operating volume cannot easily be scaled down linearly. It also means that the benefits of scale will generally make it economically unviable to compete with bids to capture CO_2 at smaller point sources. As a result, it is likely that the auctioneer needs to deal with trade-offs in selecting bids on the margin of a fixed auction cap (see Fig. 1).

At the time of the interviews, the respondents foresaw a static volume cap, which could cause the type of efficiency losses illustrated in Fig. 1. A potential solution to this problem could be derived from the Australian Carbon Credit Units Scheme. The auctioneer of this scheme is granted the flexibility to select winners based on the shape of the marginal abatement cost curve. Rather than a static demand expressed in CO_2 for a specific auction, the auctioneer is granted an overall budget allocated to an auction programme that includes an undefined number of consecutive auctions aiming to maximise the effect of the budget appropriation.

A BECCS auctioneer would benefit from a similar mandate to allocate contracts relatively freely to winners, potentially over several consecutive auctions. Rather than clearly communicating a target volume for specific auctions, the state could announce a large and long-term budgetary framework for the auction scheme, and could also announce that auctions will be arranged until the budget is depleted. By refraining from specifying the number and frequency of auctions as well as the volume or budget cap of each auction round, the public administrators can increase their degree of freedom to select winning bids according to their competitiveness, rather than on the basis of satisfying predefined demand by filling up a set volume quota, such as accepting bids by bidders A and B in Fig. 1.

Risk sharing

The third prominent theme in our responses concerns risk sharing. According to Engel [19], this theme involves issues such as the length of contracts and design of compliance mechanisms. Short-term contracts involving technologies with high capital costs result in short depreciation periods and therefore higher contracted costs per unit of delivered goods. Longer contracts can, however, increase uncertainties, for example regarding price development for input goods. Longer contracts therefore require larger safety margins for bidders. A bid for a BECCS contract could realistically be based on a district heating or combined heat and power facility sourcing externally, or using internally produced electricity at an expected price, to operate a hot potassium carbonate capture unit from which heat is recovered and sold via the district heating networks, a BECCS facility-type depicted by Levihn et al. [7]. If the cost of electricity is higher and the revenue from the heat market is lower than expected, this kind of bid may become unprofitable. Almost all respondents note that uncertainty increases with the length of the time horizon—longer contract terms require higher safety margins and thus would also result in higher costs per unit of stored CO_2. Some respondents also note that if a combined heat and power plant sources electricity from its own production, the calculation involves an opportunity cost in terms of a lost opportunity to sell electricity.

To deal with such eventualities, the auctioneer could allow bids to be based on a system in which the level of compensation fluctuates with the price of important inputs for carbon capture and compression. Almost all respondents, however, see such a system as unnecessary. The risks, they argue, can be managed through granting flexibility in delivery, for example regarding the annual delivery of stored CO_2, while maintaining a fixed subsidy per unit of stored biogenic CO_2. Flexibility also allows for operating BECCS facilities for maximum utility and economic efficiency. This would allow operators of biomass-based facilities to turn the CCS component on and off depending on market signals, e.g. the price of fuels, electricity or heat, and public needs. Public needs could be electricity supply at peak loads, contributions to grid stability or satisfying CDR demand [62]. As a compromise, the responses converge around a contract length of about 15 years to balance various aspects of uncertainty, technical lifetime, and depreciation periods.

There are multiple forms of possible flexibilities that can alleviate the risk of unexpected price developments [63]—for example, allowing temporary deficits to be offset by banked surpluses. Another example of flexibility-based approaches is constituted by Australia's CDR auctions, in which the contracting parties are rewarded for flexibility through trade in certified carbon credits, allowing them to compensate for inability to deliver on contractual obligations by buying surplus from other contractors [64, 65]. Further examples of similar flexibility are Chile's renewable energy auctions, in which contractors can use the electricity market for compliance [56], as well as the UK's renewable electricity auctions that allow installed capacity to deviate from contracted capacity [66]. A specific issue that here emerges as potentially problematic for BECCS auctions is to match delivery of CDR to specific target years. If a BECCS auction is designed as an instrument to deliver removal units to achieve a climate policy objective by a given target year, then flexibility may compromise the possibility of the auction to achieve this objective. Again, whether this constitutes a problem or not depends on how the objective(s) of BECCS auctions are defined. If, for example, the objective is to demonstrate technology, flexibility may help rather than impede achieving this objective.

In addition, experience from payments for ecosystem services shows that weak sanctions undermine compliance [67], and experience from renewable energy auctions shows that high penalties increase compliance [55]. However, although compliance rules can determine how effective an auction is once contracts have been awarded, penalties which are perceived as too demanding may also limit participation in the auction. Most respondents from business are in favour of quite high flexibility and low penalties, arguing that BECCS is a new technology system that involves many steps in a complex technology chain, introducing great uncertainties and thus increasing investment risks. Respondents in the national administration echo this conclusion, arguing that the state needs to be mindful of the challenges that businesses face in these auctions, and that it ultimately needs to be proved that BECCS can be delivered.

Penalties have been treated differently in different auctions. In Polish wind power auctions, for example, a fairly large deviation from defined project delivery is allowed, combined with high monetary penalties [68]. In the Netherlands, penalties have instead been imposed in the form of exclusion from future auctions [69]. In French solar power auctions, penalties have been handed out in the form of reduced contract periods [70], and in Danish wind power auctions as a percentage reduction of the compensation [71].

For BECCS reverse auctions, however, the respondents note that high penalties may even result in higher costs for the auctioneer. Since a penalty involves a risk for the bidder, this would normally lead to a bid with a higher safety margin. All of the above indicates that sanctions intended to maximise the effect of an auction need to be carefully balanced against the aim to maximise the number of participants and keep the total cost down. Trade-offs between effects and cost-efficiency appear to be immanent—if one objective gains the upper hand, this may in the worst case lead to an unfeasible auction design.

Business models and credit ownership

In addition to the three themes that resonate with the scientific literature on reverse auctions, close to all respondents addressed a fourth theme specific to BECCS reverse auctions: concerns over the relationship between state-financed auctions and emerging voluntary markets for carbon removal credits (CRCs). Transaction volumes on voluntary carbon markets (VCM) have reached record levels in 2021 and 2022—followed by a steep downturn (accompanied by an average price increase) in 2023, largely driven by a demand for carbon credits from non-state actors increasingly formulating their climate goals in terms of carbon neutrality and net-zero emissions [72]. Demand for credits is predicted to continue growing [73, 74]. The concepts of carbon neutrality and net-zero are still evolving, and the related goals and achievements remain heterogeneous [75]. Many climate targets explicitly refer to offsetting, i.e., the use of carbon credits emanating from mitigation outcomes (emission reductions or CDR) achieved outside of an actor's value chain or relevant system boundaries to counterbalance the climate impact of specific emissions.

Markets for carbon credits, created through baseline and credit mechanisms, emerged during the initial years after the adoption of the Kyoto Protocol. The Kyoto Protocol introduced two project-based mechanisms that enabled the international transfer of mitigation outcomes to promote flexibility and cost-efficiency of compliance [76]. The Kyoto Protocol included provisions for maintaining environmental integrity of international transfers on compliance markets, i.e., provisions that a decision to meet part of a commitment through international transfer should not lead to a global increase of emissions [77]. Environmental integrity provisions included the demonstration of additionality, i.e., that the mitigation outcome to be credited under a project-based mechanism would not occur without project registration, and that any international transfers of credits between two countries with emission caps under the Kyoto Protocol was based on issuing credits by converting assigned amount units, thereby avoiding double counting of the same mitigation outcomes towards both the host and buyer country's Kyoto targets [76].

In parallel with the compliance market under the Kyoto Protocol, the voluntary use of carbon credits developed on the basis of Kyoto credits and private carbon crediting programmes. The voluntary use of carbon credits lacked international oversight, but the principles of additionality and prevention of double counting that applied to compliance markets were largely adopted also on the VCMs [78]. The practice that developed for what makes a legitimate offsetting claim on the compliance market meant that if a company opted to use carbon credits to offset their emissions in a country that had a Kyoto target, this should lead to an increased global mitigation ambition. This is clear if we consider that (i) the mitigation outcome would not be counted towards the mitigation commitment of a country and (ii) the mitigation outcome underlying the carbon credits was additional and, when emanating from projects in countries with Kyoto commitments, associated with the surrender of assigned amount units for carbon credits. In other words, the country in which a company used credits to offset emissions would not have to do less to comply with its Kyoto commitment and, at the same time, mitigation outcomes beyond business-as-usual or any existing national mitigation commitments would be achieved elsewhere.

The practice for voluntary use of carbon credits for offsetting is relevant for the concerns expressed by respondents in this study regarding the relationship between state-financed auctions and emerging VCMs for CRCs. Those concerns have to do with the right to claim the underlying mitigation outcome and perceptions concerning double counting, and are part of a wider ongoing international debate about the role of VCM within the architecture of the Paris Agreement. Kreibich and Hermwille [78] have analysed the debate and identified a number of different approaches for dealing with the issue of double claiming of the mitigation outcome underlying carbon credits between project host country national mitigation targets and a purchasing entity's use of an outcome towards achieving mitigation targets (e.g., carbon neutrality or net-zero target). Three of the identified approaches are relevant for Swedish BECCS auctions where the mitigation outcome falls within the scope of the national greenhouse gas inventory and potentially contributes to achieving Sweden's share of the EU's nationally determined contribution (NDC), provided that BECCS will be integrated into EU climate policy [4]:

1. NDC support units are defined as projects that contribute to the achievement of a host country's NDC but cannot be used for offsetting purposes. The scope of support units could be extended to the achievement of national targets beyond an NDC.
2. Non-compliance credits are units that can be used for offsetting claims (e.g., to support neutrality claims) and are at the same time counted towards the host country mitigation target. Kreibich and Hermwille [78] argue that such credits face serious legitimacy concerns and lead to double claiming, entailing reputational risks of companies buying those credits, and distort perceptions of global collective action.
3. NDC crediting takes place with corresponding adjustments, which Kreibich and Hermwille [78] regard as the only solution that safeguards environmental integrity, as well as strengthening and protecting the legitimacy of using carbon credits for offsetting. A corresponding adjustment means that the host country does not count credit-related mitigation outcomes towards its NDC or national mitigation target beyond the NDC target.

The analysis by Kreibich and Hermwille [78] is useful as a conceptual background for the views of the respondents in this study and the current Swedish debate concerning the relationship between state-financed auctions and emerging VCMs for CRCs, where the main point of contention is whether and why double claiming should be avoided when carbon credits are used as the basis for companies' offsetting claims.

Several business respondents interviewed in this study argue that BECCS mitigation outcomes could be awarded results-based payments from the Swedish state, and could be counted towards the Swedish national mitigation target. At the same time, these same mitigation outcomes would make the basis for issuance of carbon credits that could be sold on the VCM to be used by purchasing entities towards offsetting claims (i.e., approach two above). This view has also been reported in the literature [79] and is repeated in official company positions, e.g., by Stockholm Exergi [80], and through the business association Swedenergy [81]. It is clear that this approach would mean a departure from the widely adopted practice on VCM, namely that credible voluntary offsetting claims should be based on carbon credits that represent mitigation that goes beyond existing national mitigation targets—i.e., mitigation action that is additional, incentivised by the opportunity to sell carbon credits. Such an alternative approach could therefore be considered to lower the bar with regard to what a carbon credit should represent to be eligible for making offsetting claims.

For the case of Swedish BECCS, making corresponding adjustments could in theory enable the issuance of carbon credits under Article 6 of the Paris Agreement that would represent mitigation beyond national mitigation targets (i.e., approach three above). Such carbon credits would then be aligned with requirements for using carbon credits towards credible offsetting claims as proposed by, e.g., the Greenhouse Gas Protocol [82] and others [83–85]. However, the current EU legislation does not enable member states to make corresponding adjustments in their greenhouse gas accounting [86]. The Swedish Energy Agency, as appointed auctioneer, has issued a memorandum stipulating that projects receiving support from auctions also can issue carbon credits to be sold on VCMs, but expresses two caveats: (1) the Agency clarifies that the NDC support unit approach should be applied (i.e., approach one above), which means that users of the carbon credits should not make offsetting claims, and (2) revenues from credit sales will be deducted from government support.

The Swedish Energy Agency's suggested that revenue deduction is in line with how reverse auctions are often applied, which is to procure commodities for which primary markets already exists, e.g., electricity. Such auctions typically award contracts for differences between market prices and agreed auction prices [66]. According to the respondents in this study, the most obvious potential revenue stream for BECCS involves selling CRCs. However, the incentive for businesses to sell CRCs on carbon markets under a contract for difference schemes is weak. There is therefore a high likelihood that the approach suggested by the Swedish Energy Agency will fail to generate income from VCMs, a likelihood that increases further with the limitations put on offsetting claims. An approach with contracts for difference could, in theory, save the Swedish state expenses for CDR that could be used to procure more BECCS or other actions towards achieving the Swedish national mitigation target. However, some respondents claim, as is also argued by Kreibich and Hermwille [78], that the demand for units which cannot be used for offsetting claims is uncertain.

If it were possible for EU member states to make corresponding adjustments, attribution principles [87] could be applied to allocate the mitigation outcomes from BECCS between government support and revenues from selling carbon credits. Only the portion of mitigation outcomes allocated to government support would be accounted towards the Swedish national target. With an attribution approach, carbon finance could contribute to mitigation beyond the Swedish national target and thus also towards the realisation of more of the Swedish BECCS potential sooner. This leads us to conclude that exploring changes and updates to legislation on the national level in Sweden, and more generally on the EU level, should be prioritised both in the short and long term to enable corresponding adjustments.

Conclusions

This article has explored potential goal conflicts and dilemmas that may emerge from designing reverse auction for BECCS. We have gauged under which circumstances prospective BECCS operators would be willing to place auction bids, and how these circumstances compare with preferences among actors that represent the auctioneer. The analysis concludes that policymakers need to consider at least four dilemmas that are pronounced when designing reverse auctions for BECCS, compared to reverse auctions for renewable electricity or ecosystem services.

First, attracting enough bidders to reverse auctions so as to cater to a competitive bid procedure is crucial for achieving cost-efficiency in the allocation of auction contracts. However, our interview data indicate an immanent risk that competition is undermined by factors that restrain actors from placing bids in auctions. The pool of potential bidders is restrained by the relatively few facilities with technical potential for BECCS. Moreover, fear of the winner's curse, i.e., of placing a bid that is too low and does not finance the cost of compliance, leads many of the prospective BECCS operators to adhere to a wait-and-see strategy with opportunities to gain from knowledge spillovers by learning from first movers. A wait-and-see strategy seems sensible from many bidders' perspective, given the high political risks and technological uncertainties, but from the perspective of the state, it is also likely to undermine the cost-efficiency of auctions. The interviews indicate that public subsidies for conducting feasibility studies may increase confidence among prospective BECCS operators to place bids in auctions by creating greater certainty around technical potential and costs. We therefore recommend policymakers to combine announcements of future BECCS reverse auctions with generous public subsidies for feasibility studies, which may prove to be effective in attracting a higher number of bidders to the auction, which in turn may pay off by improving the cost-efficiency of the auction.

Second, our analysis further indicates that allocating contracts in reverse BECCS auctions may be more challenging than in more common reverse auctions, e.g., for renewable energy or ecosystem services. Given the significant benefits of scale involved in BECCS, governing auctions under a strict volume cap likely leads to efficiency losses. If, for example, the auctioneer demands 1 million tonnes annually around a specific target year, bidders with larger facilities would need to bid below their technical capacity, which would increase the cost per unit of captured CO_2. Benefits of scale also means that bids that exceeds the demand cannot easily be scaled down linearly without increasing the cost per unit of captured CO_2. While our interviews indicate an interest among representatives of the auctioneer—the Swedish state—to govern the auction cap based on a predefined demand for negative emissions resulting from the national climate target structure, efficiency is most likely improved if the administer of the auction is mandated to award contracts flexibly, based on the marginal cost curve profile rather than a predefined strict volume cap.

Third, the auctioneer is faced with a dilemma regarding the design of compliance mechanisms. Soft compliance rules have been shown to undermine the effect of reverse auctions for renewable energy. On the other hand, a rigid enforcement branch of the instrument's compliance mechanism may further impede prospective BECCS operators from placing bids, i.e., aggravate problems associated with attracting enough bidders to reverse auctions so as to cater to a competitive bid procedure. Considering the untested nature of the complete BECCS chain, it carries significant risks and uncertainties, further increasing the risk of insufficient auction participation. Thus, we believe that it is prudent to see these auctions as a means to foster flexible public–private partnerships, and recommend policymakers to emphasizing facilitation over enforcement when designing the compliance mechanism.

Fourth, finally, the interviews indicate a clear interest among many prospective BECCS operators in translating negative emissions into financial assets. Many business representatives foresee revenue streams from selling certified carbon dioxide removal credits on international voluntary carbon markets. While it may be tempting, from the auctioneer's perspective, to allow co-finance from market revenues, it comes with risks of undermining the climate benefit of the auctions. If the auctioneer intends to use the auction to procure negative emissions to be accounted towards a specific climate target, we highly recommend that carbon credits, if issued, should only be authorized for making claims that the buyer has contributed to achieving the auctioneer's climate targets, and thus not underpin credit buyer's offset claims. This policy recommendation is aligned with research on good governance of carbon removal credit trading.

The analysis points towards several trade-offs that are hard to resolve and require attention form policymakers, implying that they need to be balanced rather than overcome when designing the auction. Future research on solutions to dilemmas arising from designing reverse BECCS auction may explore issues such as the use of supplementary or overlapping policy to improve auctions, including grant schemes to feasibility studies and research facilities in industry.

As this study is limited by lack of practical experience from reverse auctions for BECCS, future research could also evaluate the efficacy of the upcoming Swedish BECCS auctions, and compare it to alternative support instruments for BECCS, if and when experience from such incentives is available for evaluation.

Abbreviations

BECCS	Bioenergy with carbon capture and storage
CCS	Carbon capture and storage
CDR	Carbon dioxide removal
CO_2	Carbon dioxide
CRC	Carbon removal credits
EU	The European Union
EU ETS	The European Union Emissions Trading System
EUR	Euro
Eq	Equivalents
Mt	Megatonne
NDC	Nationally determined contribution
UK	The United Kingdom of Great Britain and Northern Ireland
VCM	Voluntary carbon markets

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12302-024-00971-0.

Additional file 1.

Acknowledgements

This research was funded by Energimyndigheten (the Swedish Energy Agency), under Grant Nos. P2022-00172 and P2022-01125, the Volkswagen AG as part of an endowed professorship via the Stifterverband, and the EU Horizon Europe programme under Grant Agreement No. 101081521.

Author contributions

MF: conceptualization, methodology development, data collection and curation, analysis, writing (original draft, review and editing), project administration, and funding acquisition; KM writing (original draft, review and editing); LL: methodology development and writing (review and editing); WR: writing (review and editing).

Funding
Open access funding provided by Linköping University. This research was funded by Energimyndigheten (the Swedish Energy Agency), under Grant Nos. P2022-00172 and P2022-01125.

Availability of data and materials
The dataset generated and analysed during the current study is not publicly available. The respondents in this study have been anonymized to protect their personal integrity. The anonymization would be compromised if the dataset was published publicly.

Declarations

Ethics approval and consent to participate
Ethics approval is not applicable; all personal data have been rendered anonymous and is therefore no longer to be considered personal data. However, informed consent to participate in the study has been recorded for all respondents, to safeguard compliance with the European Union's General Data Protection Regulation for the short period of time required to fully anonymize the collected data.

Consent for publication
Not applicable; all personal data have been rendered anonymous and are therefore no longer to be considered personal data.

Competing interests
The authors declare that they have no competing interests.

Received: 19 April 2024 Accepted: 30 July 2024
Published online: 16 August 2024

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