Discover Energy

Discover

Perspective

The missing piece in policy for carbon dioxide removal: reverse auctions as an interim solution

Liv Lundberg[1] · **Mathias Fridahl**[2]

Received: 19 January 2022 / Accepted: 6 April 2022
Published online: 20 April 2022

Abstract
The expectation that carbon dioxide removal (CDR) will play a crucial role in the climate transition is starting to gain traction in policy. An increasing number of countries are expanding their CDR policies, from specification of objectives (via elimination of regulatory obstacles) to market development. Among the many CDR options, sustainably sourced bioenergy with carbon capture and storage (BECCS) is often cited as having the greatest theoretical potential. Unlocking this potential will necessitate new and robust economic incentives. However, at present, there is a serious gap between actual policy and the required incentive structures, and developing these policies in a responsible way will likely take many years. To get BECCS started sooner than it otherwise might, we argue that an interim policy for allowing BECCS to mature would help identify potential trade-offs or pitfalls, and would help test how firms react to incentives for CDR before rolling our large scale international incentive structures. In this Perspectives article, we provide an insight into the current status of BECCS and CDR policy based on interviews with key policy makers and experts. We also provide a special insight into Sweden's development of interim policy that takes the form of a reverse auction.

1 1. Introduction

Recent multilateral diplomacy has put the spotlight on the role of carbon dioxide removal (CDR) in the climate transition [1]. The Paris Agreement's temperature objective, the insufficient mitigation ambition in countries nationally determined contributions to the Agreement, and Article 4.1's provision to balance sources and sinks all point to the need for CDR. Increased attention has been paid to CDR in the wake of the Intergovernmental Panel on Climate Change's (IPCC) 2018 special report on 1.5 °C warming. This report shows that limiting heating to + 1.5 °C is effectively impracticable without CDR [2]. Since the adoption of the IPCC special report, the IPCC has updated its accounting guidelines on CDR [3], the International Maritime Organization has lowered the regulatory barrier for export of carbon dioxide (CO_2) intended for sub-seabed storage [4], the Glasgow UN climate conference has agreed to rules for international trade in carbon credits [5], and the European Commission has launched a process to develop a CDR certification scheme [6].

The contribution of Working Group I to the 6th Assessment Report of the IPCC confirms the picture. Out of five emission scenarios, two are likely to keep global heating below + 2 °C. The best estimates of heating in these scenarios result in + 1.4 °C (1.0–1.8) and + 1.8 °C (1.3–2.4) [7]. Both 2 °C-compatable scenarios assume that the world will have net-negative CO_2 emissions after 2050. Achieving global net-negative emissions obviously requires large volumes of CDR. Regional estimates of how to achieve net zero targets show similarities in CDR demand, such as those named in a communication

✉ Mathias Fridahl, mathias.fridahl@liu.se | [1]Research Institute of Sweden (RISE), Box 857, 501 15 Borås, Sweden. [2]Unit of Environmental Change, Department of Thematic Studies, Centre for Climate Science and Policy Research, Linköping University, 581 83 Linköping, Sweden.

from the European Commission anticipating that the EU can only reach net zero emissions by 2050 in scenarios that include sizable volumes of CDR [8].

There are several methods for CDR, including afforestation, carbon sequestration in soils, direct air carbon capture and storage (DACCS), and bioenergy with carbon capture and storage (BECCS). CDR policies are developing quickly on some fronts but not others. A shortcoming in emerging CDR policies is that the existing policy leverage is incapable of generating the revenues needed to motivate investments in technological CDR at scale [9]. BECCS is a case in point. Facilities that use sustainably sourced biomass to produce heat, electricity, paper or biofuels could install BECCS to assure that the CO_2 absorbed from the atmosphere during plant growth is captured and stored geologically instead of being re-releasing into the atmosphere. The theoretical potential for BECCS is very high, as approximated in Paris Agreement-compatible emissions pathways derived by integrated assessment models, in which BECCS features heavily. The latest IPCC assessment of scenarios to limit heating to 1.5 °C with no or limited overshoot project accumulated BECCS deployment of 364–662 $GtCO_2$, a modeled estimate based on the middle 50% of the assessed scenarios (the interquartile range) [2].

However, while the technical potential for BECCS is high, the market potential is virtually nonexistent [9, 10]. Markets for goods that deliver CDR as a co-benefit exist, such as for long-lived harvested wood products and biochar. There are also both public and private initiatives for market development, such as trading allowed under the Australian Emissions Reduction Fund, the European Commission's Carbon Farming initiative, and the marketplace developed by the Finnish-based company Puro Earth. Markets for carbon removal are, however, still immature. BECCS requires large upfront investments and have long depreciation periods. The existing CDR markets do therefore not guarantee sufficient returns on BECCS investments [11].

2 Status of carbon dioxide removals policy in the EU, its Member States, the UK, and the US

The policy landscape for BECCS and CDR is evolving quickly. This section provides a brief overview of the current policy development in Europe and the US. The overview is based on a summary of policy documents, academic literature, and interviews. The interviews were conducted with representatives from the governments in Finland (Ministry of Economic Affairs and the Finnish Energy Authority), Germany (Ministry for Economic Affairs and Climate Action), the Netherlands (Ministry of Economic Affairs and Climate Policy and the Netherlands Enterprise Agency), Sweden (Swedish Energy Agency) and the EU (European Commission), as well as with representatives from academia and NGOs with a focus on CDR-policy in the UK and the US. In total 13 interviews were conducted in September to December 2021. The interviewed experts were chosen from central organizations and agencies in countries that are currently pioneering CDR policy and that have experience of reverse auctions in environmental governance. The interviews lasted for approximately one hour and were semi-structured, spanning batteries of questions on climate policy objectives and existing CDR policy, via taking stock of ongoing CDR policy processes including those intended to create incentives for BECCS, to detailed questions about technical potentials for BECCS. The interviews ended with a set of questions about experiences with reverse auctions.

All interview respondents reported that they see an increasing interest in CDR, including BECCS, both politically and from interest groups. This includes countries like Germany where there previously has been a strong opposition towards fossil fuels with carbon capture and storage, which has had repercussions for the public opinion on BECCS. A reason for the increased interest in CDR, which was mentioned by almost all respondents, is that many countries, and the EU as a whole, now have net zero goals and view CDR as being necessary for reaching that target.

Interviewees from the US raised that in November 2021, the US Secretary of Energy announced the "Carbon Negative Shot" labeled as "the U.S. government's first major effort in CDR" [12]. The initiative recognizes CDR as a key factor for the US net-zero emission 2050 goal, which will necessitate deployment of CDR on a scale of gigatons. The aim of the initiative is to stimulate innovation and to reduce the cost of CDR to less than 100$/$tCO_2e$. In 2020 and 2021 the US government allocated significant budget posts for research and development of carbon capture, utilization, and storage (CCUS) and DACCS [13]. The interviewees also referred to regional initiatives, such as the "Carbon Dioxide Removal Leadership Act" which was put forward in the state of New York in January 2022. If adopted, the bill would commit the state of New York to hold reverse auctions to procure CDR on a yearly basis. The state-financed auction would be open to all types of CDR that fulfill sustainability standards [14].

In Europe, the EU Climate Law (with its consequential amendments to the EU climate legislation) translates the 2050 net zero target into obligations for the member states. The Land-Use, Land Use Change and Forestry (LULUCF) Regulation

already requires the EU member states to maintain their existing LULUCF sinks (this is called the 'no-debit rule'), and the European Commission is proposing to further increase the volume of aggregated, obligatory removals by 2030, to extend the current requirement and to also include agriculture under the no-debit rule [15]. In parallel the European Commission is developing rules for the certification of carbon removal (CRC) [6]. The lack of a clear and internationally recognized certification of negative emissions was mentioned by several European interviewees as a key barrier to developing national CDR policies, one that the European Commission is seeking to address through the initiative. The CRC scheme will tentatively be proposed in the last quarter of 2022, and will constitute a key building block of the circular economy action plan [6, 16].

In December 2021 the European Commission published a communication on sustainable carbon cycles that clarifies what is to be expected in terms of CDR policy developments the coming years [17]. From that communication it is clear that the European Commission is working hard on complementing the CRC scheme with an economic policy instrument to incentivize carbon removals at the land manager level in agriculture and other land-use, referred to as the Carbon Farming initiative. Capturing and storing biogenic CO_2 from industrial processes is also anticipated to be key to achieving the net zero target, but no policy incentives like the carbon farming initiative for agriculture has been drafted for BECCS [17].

From the interviews with government representatives in EU member states, it became clear that several member states have been waiting for CDR and BECCS policy to emerge at the EU level. A reason for this, given by the respondents, is the significant costs of BECCS. The estimated cost of BECCS starts at around USD 15/tCO_2, for ideal-type applications in bioethanol production, up to around USD 400/tCO_2 for application in power and heat in scenarios when competition for land and demand for biomass is very high [18]. Several respondents from national governments suggested that industrial CDR should be financed by including negative emissions into the EU emissions trading system (ETS), which would imply granting removals credits that could be traded on the ETS allowance market [19]. However, the current price on allowances, while on the rise, is still too low for technologies such as BECCS or DACCS to be profitable and it would also require amending the existing EU ETS directive.

The European Commission is yet to announce any concrete plans for including negative emissions into the EU ETS. At present, it is not clear whether CDR will be included into EU ETS or if it will be located in one of the other pillars of EU climate action, i.e. the LULUCF Regulation or the Effort Sharing Regulation. However, the European Commission [17] has recently signaled that BECCS "with a clear and verifiable climate benefit could potentially benefit from recognition" (p. 16) in the EU ETS. Including CDR in the EU ETS will most likely not happen soon because of the long processes involved in making changes to the EU ETS [19].

While many EU member states are awaiting EU policy initiative, some have begun to move ahead with national legislation [1]. Interviewees mentioned that a support scheme for CDR based on tariffs is being considered in Luxembourg and that another support scheme based on an auction is under development in Ireland. The Luxembourg scheme is supposed to be introduced in the national parliament in 2022 through a bill referred to as the "Luxembourg Negative Emissions Tariff". If the bill is adopted, the government would grant a premium per ton of removed carbon assured through five-year contracts. In Ireland, the current proposal is focused on a public-private partnership for supporting CDR through procurement auctions [20]. While the development of national policies is still in an early stage in other countries, Sweden is developing a BECCS support scheme that has already passed the legislators, warranting a closer look.

3 Reverse auctions for BECCS in Sweden

Sweden has decided to move ahead with designing national policies to support BECCS. The main reason for this decision is the national net zero target for 2045, in which it is specified that domestic emissions must decrease by at least 85% compared to 1990 levels, while the residual maximum 15% can be offset through supplementary measures. The allowed percentage of supplementary measures corresponds to approximately 11 MtCO_2e by 2045 through BECCS, interventions in forestry and land-use (in addition to the existing net sink), and international offsets. A public inquiry (SOU2020:4) identified BECCS as the supplementary measure with the largest potential (30 MtCO_2 per year, mainly from the pulp and paper industry and from electricity production and district heating). The inquiry proposed targets for BECCS of 1.8 MtCO_2 by 2030 and 3–10 MtCO_2 by 2045, and consequently the Swedish government commissioned the Swedish Energy Agency to develop a proposal for supporting BECCS in Sweden in late 2020.

The Swedish Energy Agency published its proposal in November 2021, which, in line with the public inquiry, suggested the use of reverse auctions, financed from the state budget, to support BECCS. In reverse auctions, actors submit

bids for selling their services to a buyer and the actors with the lowest bids win. Unlike many other countries, Sweden has not previously used reverse auctions in environmental governance. In addition, reverse auctions have not yet been used to incentivize BECCS on a national scale anywhere else in the world, so the policy is truly unique in both Sweden and worldwide.

The Energy Agency proposes that the first reverse auction should be held at the end of 2022, with a volume of 0.6 $MtCO_2$, followed by two consecutive reverse auctions before 2030 capped at 0.6 and 1.0 $MtCO_2$, respectively. The Energy Agency proposes to use sealed bids for the price per ton of captured and stored biogenic CO_2 that will be delivered. The actors submitting bids will be companies that capture biogenic CO_2, and they will be responsible for overseeing both transport and storage, either by themselves or by subcontractors. Since Sweden does not operate any large CO_2 storage facilities, storage will most likely be contracted abroad, such as by the Norwegian Northern Lights facility. The actors that win the reverse auctions will be awarded contracts for 15 years and will be paid-as-bid. The reverse auction system was approved in early 2022 but many details remain to be decided, such as the number and frequency of auctions, and the exact appropriations for each consecutive auction.

There is a strong interest in BECCS among companies in Sweden's heat-and-power sector. Several companies have expressed an interest in taking part of a reverse auction and the most ambitious actors, such as Stockholm Exergi (which was awarded funding through the EU Innovation Fund), claim that they could start operations in 2025 or 2026 if they secure sufficient funding.

4 The need for interim policies for BECCS

Even though individual countries are starting to develop CDR policy, a long-time solution for CDR-policy may need to be on a larger, multinational scale. Removing carbon from the atmosphere brings global benefits but the potential for CDR is not evenly distributed globally [18, 21] and it is not realistic to assume that the countries with high technical potentials single handily should pay for realizing that potential [22, 23]. Hence, it is likely that international diplomacy is needed to distribute the costs of implementation, as well as to ensure that global emissions eventually become net-negative [24, 25]. Multilaterally agreed incentive structures, such as to develop markets within the EU [19] or cooperate globally via Article 6 of the Paris Agreement [22], can provide sufficient scale to improve cost efficiency.

CDR is however not uncontroversial, which is especially true for BECCS. There are arguments that BECCS may impede on the possibility to achieve sustainable development goals such as zero hunger, through competition for recourses, and life on land, through possible biodiversity losses [26, 27]. Several additional potential challenges to BECCS deployment has also been raised in the literature, e.g. social acceptance [28, 29], political prioritization [30], path dependencies [11], and trade-offs in competition for resources [18]. To reduce the risks of negative side effects and to ensure political and public acceptance, it is imperative that any large scale BECCS incentivization is done in a responsible manner [29, 31]. To paraphrase Bellamy [31], the key to responsible incentivization lies with including citizens with diverse interests in deliberating principles and choosing technologies and instruments. At least two arguments underpin calls for responsible incentivization. First, involving key stakeholders in participatory policy design processes is key for assuring more robust and more ethical outcomes. Second, failing to incentivize BECCS responsibly may well prove counterproductive because of the risk of undermining the feasibility of policy implementation. Hasty policy designs that trigger unwanted outcomes may even compromise future market potential by triggering social protests and reducing acceptability.

Several promising candidates for policy instruments to incentivize BECCS at scale have been discussed in the literature, e.g. cap and trade [19, 32], and fees and dividends, tax credits or quota obligations [29, 33] of which the latter is sometimes also referred to as "carbon takeback obligations" [10]. To develop large scale, international incentives for BECCS in a responsible manner will however take time, and a common EU scheme to support large scale technological CDR may for example not be in place before 2030. Therefore, there are good arguments for speedier yet also more limited interim BECCS policy. CDR is urgently needed to reduce the peak of global emissions, to limit the risks of temperature overshoot triggering irreversible climate impacts, and to build capacity for future negative emissions that are capable of offsetting both failures in historical emissions reductions and any future residual emissions associated with hard-to-abate sectors. There is also an urgency to demonstrate and test how firms react to incentives for removals, which arguably is best done with interim policy that includes backstop safeguards. Testing BECCS policy in a manner limited in time and scope could also provide valuable lessons for any future policy processes that aim to deliver BECCS at scale. Here, reverse auctions, such as the one being developed in Sweden, and the ones suggested for New York state and Ireland, could play an important role.

5 Reverse auctions as a potential interim BECCS policy

Reverse auctions are an attractive option for interim BECCS policy because they incentivize cost efficiency and price discovery through competitive bidding, which is an advantage at this early stage when the actual costs of BECCS are probably best known by the companies developing the technologies. Meanwhile, long-term contracts with a fixed price per ton of captured and stored biogenic CO_2 provide auction winners with a stable investment horizon. Reverse auctions intrinsically allow the government to cap either the budget or the requested volume. Subsequent auctions can be redesigned or even cancelled if circumstances call for it.

However, even though reverse auctions have been shown to be appropriate for renewable energy support-schemes [34–36], BECCS is different on several key points. Unlike electricity from renewable energy sources, CDR from BECCS have no monetary value of their own. BECCS is also generally limited to existing large-scale industrial point sources of biogenic CO_2 emissions, meaning that there might be a very limited number of actors who could enter a national auction for BECCS. These factors, along with the fact that BECCS as a technology system is still immature, were concerns raised by several interviewees when asked about risks of using reverse auctions to incentivize BECCS.

Because BECCS differs from renewable energy in several ways, we may need to look to other technologies and policy schemes for relevant lessons. One such option is Carbon Capture and Storage (CCS) where carbon from fossil origins is captured and stored. Since 2021, CCS has been included in the Dutch tender called Stimulation of Sustainable Energy Production and Climate Transition (SDE++), which supports emission reduction technologies and renewable energy. One challenge of both CCS and BECCS that was mentioned by representatives from the Netherlands in the interviews, is the role of infrastructure and spatial dependencies.

The infrastructure systems for BECCS (as well as DACCS and CCS) are in general characterized by a division of responsibilities and liability, as there are usually several actors involved in the process. In most cases, one company owns the plant where the capturing takes place, but that company is then reliant on other actors for transport and storage. Since the captured carbon dioxide needs to be transported to storage sites, there are potential benefits in coordinating the transport (pipelines could be a viable solution in some cases). When contracts for CCS are given based on a reverse auction like in the Netherlands, there is a risk that spatial coordination is lost, which can increase the cost for transporting the emissions to storage sites. The UK is looking to solve this problem by providing support to specific clusters of CCS and BECCS facilities. The goal is to capture and store in total 20–30 $MtCO_2$ per year, from at least four different clusters, by 2030.[1] In 2021, two clusters (which are due to start operating in the mid-2020s) were chosen for funding, one including the Drax power station that aims to be converted into a BECCS facility.

While the UK government is open to fund clusters of both CCS and BECCS, the Swedish reverse auctions will only provide support to BECCS. The Dutch auction system instead focuses on supporting fossil fuels with CCS. For facilities that emit a mixture of fossil and biogenic carbon dioxide, such as waste incinerators, the Swedish and Dutch systems are challenging. The most cost-efficient solution is often to capture and store a large share of a facility's emissions. With mixed emissions sources, the owner only becomes eligible for support for a share of the emissions.

The question of which types of CDR that should be incentivized is not limited BECCS. In the New York state, Ireland, and Luxemburg, the proposed systems are open for different types of durable CDR. In Luxemburg and New York, the plan is also to allow projects in other parts of the world to compete for funding. A challenge with these more technology neutral support systems is to make CDR with vastly different characteristics comparable, e.g., in regards to permanence and technology maturity. The advantages with focusing on a specific CDR technology, such as BECCS in the case of the Swedish reverse auctions, is that the bidders will be more homogenous, making it easier to compare them and to design the system to fit their needs. The downside is that one type of CDR is promoted over others, and that other new and promising solutions may be overlooked. The optimal approach is likely to vary between countries. How to weight and balance support to different types of CDR is a question where experimentation within interim policies, such as the proposed auctions in Sweden, New York, and Ireland, could provide important knowledge that can be used in the design of more large-scale incentive structures.

[1] https://www.rigzone.com/news/uk_picks_two_ccs_projects_for_government_funding-20-oct-2021-166769-article/.

6 Conclusions and policy recommendations

By taking stock of existing policy and current policy processes, supported by interviews with key actors in several jurisdictions that pioneer CDR policy development, we hope to have demonstrated that carbon dioxide removals (CDR) policy is currently progressing rapidly. CDR policy is maturing at multiple levels of governance: both research and demonstration funding are on the rise, regulatory barriers are reduced or abolished, accounting guidelines and certification schemes are agreed upon, and forms for international collaboration are emerging. We even see emerging CDR markets being developed through both private and public initiatives.

However, a persistent gap remains in the rapidly developing mixture of policies aimed at CDR, which is the lack of incentives for investing in and operating large-scale technological CDR. Bioenergy with carbon capture and storage (BECCS) is the most obvious case in point. BECCS requires large up-front investments which, we dare say, are far from incentivized through existing markets or with current policy in any part of the world.

We believe that BECCS has a role to play in the climate transition, but we also understand that there is cause for concern related to issues such as biodiversity, food security and competition for land, water and nutrients, the optimal use of biomass in the climate transition, and safe and robust carbon storage. Therefore we firmly believe that any BECCS incentive scheme needs to be developed responsibly, even though doing so will take time. For that reason, we are also of the opinion that developing BECCS incentives responsibly would benefit from establishing interim BECCS policy to demonstrate a limited set of full scale BECCS deployment. A robust interim BECCS policy can (among other things) facilitate identification of and help mitigate negative consequences, understand how businesses and investors react to incentives, discover as well as reduce costs, and increase the capacity to act in the event that we eventually use incentive schemes to diffuse BECCS more widely.

We suggest that reverse auctions can be a suitable instrument for closing the gap between the current lack of incentives and future responsible incentivization of BECCS. Reverse auctions provide long-term economic stability for early adopters that will push the technical frontier while at the same time providing natural budget or volume caps that will enable governments to control development by speeding up or slowing down these processes as deemed necessary.

Acknowledgements This work was supported by the Swedish Energy Agency Energimyndigheten (Grant Number 51569-1) and the Swedish research council Formas (Grant Numbers 2019-01973 and 2019- 01993).

Authors contributions LL and MF contributed equally to the data collection, analysis, and authoring of the paper. Both the authors read and approved the final manuscript.

Funding Open access funding provided by Linköping University. This work was supported by Energimyndigheten (the Swedish Energy Agency, Grant Number 51569-1), and the Swedish Research Council Formas (Grant Numbers 2019-01973 and 2019-01993).

Data availability Not applicable.

Code availability Not applicable.

Declarations

Competing interests The authors have no relevant financial or non-financial interests to disclose.

References

1. Schenuit F et al. Carbon dioxide removal policy in the making: assessing developments in 9 OECD Cases. Front Clim. 2021; 3(7).
2. IPCC. Global Warming of 1.5 °C: an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. 2018, Intergovernmental Panel on Climate Change: Cambridge.

3. IPCC. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Volume 1, General Guidance and Reporting. In: Calvo Buendia E et al., editors. The Institute for Global Environmental Strategies (IGES): Hayama, Kanagawa; 2019.
4. IMO. Resolution LP.5(14) on the provisional application of the 2009 amendment to article 6 of the London Protocol. London: International Maritime Organization; 2019.
5. UNFCCC. Advance unedited version: Decision-/CMA.3, Rules, modalities and procedures for the mechanism established by Article 6, paragraph 4, of the Paris Agreement. United Nations Framework Convention on Climate Change: Bonn, Germany; 2021.
6. EUCOM. Communication: commission work programme 2022—Making Europe stronger together. COM(2021)645. Brussels: The European Commission; 2021.
7. IPCC. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press; 2021.
8. EUCOM. Communication: A Clean Planet for all—a European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. COM(2018) 773. Brussels: The European Commission; 2018.
9. Fridahl M et al. Mapping multi-level policy incentives for bioenergy with carbon capture and storage in Sweden. Front Clim. 2020;2(25).
10. Jenkins S, et al. Upstream decarbonization through a carbon takeback obligation: an affordable backstop climate policy. Joule. 2021;5(11):2777–96.
11. Rodriguez E, et al. Tensions in the energy transition: Swedish and Finnish company perspectives on bioenergy with carbon capture and storage. J Clean Prod. 2020;280:124527.
12. DOE. Secretary Granholm Launches Carbon Negative Earthshots to Remove Gigatons of Carbon Pollution from the Air by 2050. 2021 [cited 2022 12 January]; Available from: https://www.energy.gov/articles/secretary-granholm-launches-carbon-negative-earthshots-remove-gigatons-carbon-pollution.
13. Global CCS, Institute. The Global Status of CCS: 2021. Melbourne: Global Institute; 2021.
14. Burdick S et al. The Carbon Dioxide Removal Leadership Act. New York Assembly Bill 8597. New York: The New York State Assembly; 2021.
15. EUCOM. Proposal for a regulation amending Regulations (EU) 2018/841 as regards the scope, simplifying the compliance rules, setting out the targets of the Member States for 2030 and committing to the collective achievement of climate neutrality by 2035 in the land use, forestry and agriculture sector, and (EU) 2018/1999 as regards improvement in monitoring, reporting, tracking of progress and review. COM(2021) 554. Brussels: The European Commission; 2021.
16. EUCOM. Communication: A new circular economy action plan for a cleaner and more competitive Europe. COM(2020) 98. Brussels: The European Commission; 2020.
17. EUCOM. Communication: sustainable carbon cycles. COM(2021) 800. Brussels: The European Commission; 2021.
18. Fuss S, et al. Negative emissions—part 2: costs, potentials and side effects. Environ Res Lett. 2018;13(6):063002.
19. Rickels W, et al. Integrating carbon dioxide removal into European emissions trading. Front Clim. 2021;3:690023.
20. Beckett J et al. Draft policy proposal: catalysing carbon dioxide removal sector development. In: Ireland through a Public–Private Procurement Partnership. Carbon Gap: Los Altos: OpenAir Collective; 2022.
21. Fridahl M. Socio-political prioritization of bioenergy with carbon capture and storage. Energy Policy. 2017;104:89–99.
22. Honegger M et al. Who is paying for carbon dioxide removal? Designing policy instruments for mobilizing negative emissions technologies. Front Clim. 2021. 3(672996).
23. Hansson A, et al. Preconditions for bioenergy with carbon capture and storage (BECCS) in sub-Saharan Africa: the case of Tanzania. Environ Dev Sustain. 2020;22:6851–75.
24. Mohan A, et al. UNFCCC must confront the political economy of net-negative emissions. One Earth. 2021;4(10):1348–51.
25. Lee K, Fyson C, Schleussner C-F. Fair distributions of carbon dioxide removal obligations and implications for effective national net-zero targets. Environ Res Lett. 2021;16(9):094001.
26. Gough C, et al. Challenges to the use of BECCS as a keystone technology in pursuit of 1.5 °C. Global Sustain. 2018;1:e5.
27. IPCC. Climate Change and Land: An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Intergovernmental Panel on Climate Change: Cambridge; 2019.
28. Dütschke E, et al. Differences in the public perception of CCS in Germany depending on CO_2 source, transport option and storage location. Int J Greenhouse Gas Control. 2016;53:149–59.
29. Bellamy R, et al. Incentivising bioenergy with carbon capture and storage (BECCS) responsibly: comparing stakeholder policy preferences in the United Kingdom and Sweden. Environ Sci Policy. 2021;116:47–55.
30. Fridahl M, Lehtveer M. Bioenergy with carbon capture and storage (BECCS): global potential, investment preferences, and deployment barriers. Energy Res Social Sci. 2018;42:155–65.
31. Bellamy R. Incentivize negative emissions responsibly. Nat Energy, 2018.
32. Zetterberg L, Johnsson F, Möllersten K. Incentivizing BECCS—a Swedish Case Study. Front Clim. 2021;3.
33. Fridahl M. Incitamentsstrukturer för bioenergi med koldioxidavskiljning och-lagring i Sverige och Europeiska unionen: Underlagsrapport till Klimatpolitiska vägvalsutredningen (M 2018:07). Linköping univeristy and Stockholm Environment Institute: Linköping; 2019.
34. Buckman G, Sibley J, Ward M. The large-scale feed-in tariff reverse auction scheme in the Australian Capital Territory 2012 to 2016. Renew Energy. 2019;132:176–85.
35. Moreno R, et al. Auction approaches of long-term contracts to ensure generation investment in electricity markets: lessons from the Brazilian and Chilean experiences. Energy Policy. 2010;38(10):5758–69.
36. Welisch M, Poudineh R. Auctions for allocation of offshore wind contracts for difference in the UK. Renew Energy. 2020;147:1266–74.