

Wähling, Lara-Sophie; Fridahl, Mathias; Heimann, Tobias; Merk, Christine

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Original research article

The sequence matters: Expert opinions on policy mechanisms for bioenergy with carbon capture and storage

Lara-Sophie Wähling^{a,*}, Mathias Fridahl^b, Tobias Heimann^a, Christine Merk^a^a Kiel Institute for the World Economy, Kiellinie 66, 24105 Kiel, Germany^b Department of Thematic Studies, Unit of Environmental Change, Centre for Climate Science and Policy Research, Linköping University, 581 83 Linköping, Sweden

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ABSTRACT

This paper presents the results of a globally distributed survey on policies for incentivizing bioenergy with carbon capture and storage (BECCS). The current lack of policy incentives to support the implementation of BECCS constitutes a major deployment barrier. Therefore, scientists and policymakers are now debating the optimal BECCS policy framework. Previous studies have presented theoretical analyses of policy options to spur deployment, yet despite the considerable influence of experts on policy processes, very few studies have explored expert opinions. Drawing on an online survey of experts ($N = 46$), we explore their policy preferences and whether those preferences differ or converge between experts from different working sectors. The results show that a tax and refund scheme, a flat-rate subsidy, and reverse auctioning are considered more suitable than other measures. Furthermore, most experts agree that rather than a stand-alone policy, a policy mix would be needed in order to support BECCS deployment. Several experts propose a sequence of policies, moving from publicly funded supply-push policies in the short term to budget-neutral demand-pull policies in the longer term. Regarding various subsidy schemes, respondents favor investment subsidies or results-based subsidies based on stored biogenic carbon dioxide. The relatively minor differences in the response patterns between groups of experts suggest that a consensus on a preferred BECCS policy pathway might be forming across different sectors and interest groups. Therefore, our results could inform policymakers on policy instruments for BECCS that are considered most suitable by experts and thus help to shape the policy pathway for BECCS.

1. Introduction

Deploying negative emission technologies (NETs) to remove carbon dioxide (CO₂) from the atmosphere will be crucial to achieve the targets of the Paris Agreement [1]. Bioenergy with carbon capture and storage (BECCS) has been highlighted as a key technology to deliver negative emissions and limit global warming to 1.5 °C or 2 °C [2–4]. BECCS is indispensable in the cost-optimized modelled emissions pathways compiled by the Intergovernmental Panel on Climate Change (IPCC) in its 6th Assessment Report. Emissions pathways that hold global warming at or below 1.5 °C by 2100 (>50%), with limited or no temperature overshoot compared to pre-industrial levels, rely on BECCS to deliver removals in the order of 30–780 GtCO₂ accumulated between 2020 and 2100 [3]. To illustrate the scale of BECCS deployment in these scenarios, the lower bound is about the 2021 annual global CO₂ emission from fossil fuels and industry (37 GtCO₂), while the upper bound comes close to the cumulated historical (1750–2021) CO₂ emissions from fossil fuels

and industry for the United States (USA), European Union (EU) and United Kingdom (UK) combined (793 GtCO₂) [5–7]. In the likely event that global emissions will continue to increase during the 2020s and the carbon budget for 1.5 °C is eventually overdrawn resulting in a temperature overshoot, the reliance on BECCS and other methods to remove CO₂ from the atmosphere increases even further [3,4].

BECCS can be applied in processes that combust biomass to generate electricity, heat, pulp and paper, and other goods, or those that use biomass in energy conversion plants to generate biogas or liquid biofuel [8,9]. These facilities are equipped with carbon capture technologies, so that the CO₂ released during biomass conversion is captured, compressed, transported and stored in geological formations to prevent it from entering the atmosphere [8,10,11]. One major advantage of BECCS is that it can offset residual emissions from hard-to-abate sectors (e.g., CO₂ from aviation and shipping, diffuse emissions of methane from agriculture and waste) [1,11–13]. Furthermore, the use of biomass as an energy source can substitute the use of fossil fuels [11,14]. In contrast,

* Corresponding author.

E-mail address: lara-sophie.waehling@ifw-kiel.de (L.-S. Wähling).

relying on biomass as an input for deploying BECCS can result in trade-offs with land and water, and thus become a threat for achieving the sustainable development goals (SDGs) [15–17]. A common argument is that bioenergy production requires large amounts of woody and crop-based biomass, which means upscaling it could create new competition with land used for food production, leading to higher food prices and affecting food security [10,16,18]. In contrast, other studies argue that depending on specific criteria the growing of perennials for biomass production in agricultural landscapes can be beneficial for biodiversity and ecosystem services [19–21]. Further, to meet the increasing bioenergy demand and to limit the trade-offs with land, there is an ongoing research that residues from forestry and agriculture can be additionally used for bioenergy supply in the future [9,16,22]. Additionally, deploying BECCS might exacerbate water scarcity, because the irrigation of bioenergy plantations leads to water withdrawals putting additional pressure on freshwater systems [16,23–25]. Also, CCS is water intensive and especially the capture process relies on large water consumption [26,27].

So far, BECCS is still for the most part pre-commercial. While a few pilot projects exist, e.g., in North America and Northern Europe, a struggle to identify viable business models for BECCS has limited deployment to a few facilities, often publicly supported [9,28]. Hitherto there has been little progress towards implementation on a large scale. The IPCC projects that pathways limiting global warming to 1.5 °C will have to rely on NETs, and thus national policy agendas have begun to recognize the importance of NETs for climate mitigation pathways [2,4]. However, many states do not provide precise information on which NETs they intend to implement or how high their removal potential should be, nor a political roadmap to support them [4]. Therefore, one major barrier to the successful deployment of BECCS is the current lack of policy incentives [29,30]. Incentivizing BECCS would require substantial policy reforms, either by redesigning existing climate policy or defining new policy instruments [31]. Possible policy designs have been discussed in the literature, e.g., various subsidies [32] of which several such policies are already in force, including the US federal government's tax credits for geologically stored CO₂ and the EU's Innovation Fund, extension of the EU emissions trading system (EU ETS) to account for negative emissions [33], a carbon tax with a refund scheme for negative emissions [34,35], quota obligations [36,37] while the Swedish government plans to implement a reverse auctioning system [31,36–38]. Considering suitable policy instruments for BECCS, a distinction may also need to be drawn between net-zero and net-negative emissions. The fact that the Paris Agreement's aspiration to limit global warming to 1.5 °C cannot viably be achieved unless the world achieves net-zero CO₂ emissions by the middle of this century, followed by net-negative CO₂ emissions to accommodate for residual methane and nitrous oxide emissions from sources that are hard to abate, has potential implications for BECCS policy [39]. Net-negative CO₂ emissions, on the one hand, require a higher reliance on NETs, and on the other, put a heavy mitigation burden on future generations. From a global effort-sharing perspective, it is also quite likely that emissions in developing countries will peak later and that headroom for their emissions will have to be created by achieving net-zero and net-negative greenhouse gas emissions targets in developed countries [40]. Bednar et al. [41] claim that more stringent policies are necessary when considering intertemporal financial transfer to avoid intergenerational inequity.

There has been much discussion among researchers about appropriate policy instruments for incentivizing BECCS, but so far experts directly involved in BECCS policy processes and implementation have rarely been asked about their own views on these instruments. This paper addresses this gap in the literature by asking experts from research, business and industry, and policymaking to assess the policy options discussed in the literature. Therefore, we conducted an online expert survey exploring which policy instruments experts would prefer in general, which ones they would consider suitable in their country of residence, and which ones they feel are most likely to be implemented

by policymakers in the future. The survey also included questions on whether the respondents' policy preferences would be the same if the objective were to achieve net-zero emissions compared to net-negative emissions. The experts' extensive know-how of BECCS deployment and the substantial influence of expertise on climate policy processes warrant a closer examination of their policy preferences. Gauging their expertise can be useful both in order to explore appropriate policy incentives for BECCS and to project the direction in which policy might develop. In particular, experts from business and industry, who deal with the implementation of BECCS in practice, will be directly affected by proposed policy instruments, and therefore it would be informative to explore their instrument preferences. In line with this, it is of interest to analyze whether the policy preferences of experts from research, business and industry, and policymaking are similar or diverge. A survey looking at the spread of opinions regarding policy incentives for BECCS is yet lacking.

The paper is structured as follows: Section 2 provides an overview of studies that include surveys on BECCS and NETs in general. Section 3 describes the survey presented in this paper, while Section 4 shares the results, with a special focus on differences in the assessments between respondents from research, business and industry, and policymaking. In Section 6, which includes a discussion, we draw conclusions about the level of agreement among experts from different sectors regarding suitable policies for BECCS and explore the implications for the governance of BECCS.

2. Literature review

Several survey- and interview-based studies with experts have been conducted in recent years, often with a focus on uncertainties related to modeling BECCS and the feasibility of deploying BECCS on the scale suggested in the technology-cost-optimized scenarios produced by integrated assessment models (IAMs). Rickels et al. [42] conducted an online expert survey with Earth system and integrated assessment modelers to evaluate the importance of NETs in future climate policies, as well as the socio-political, techno-economic and biophysical constraints on NET deployment. They found that, of the NETs assessed, BECCS faced the most constraints, but that nevertheless most experts would include BECCS in a NET portfolio.

The need to explore the feasible scale of NET deployment was highlighted by Grant et al. [43], who conducted an online expert survey on the potential of BECCS to remove CO₂ from the atmosphere in the period 2020–2100. The authors conclude that the experts' disparate estimates of BECCS's CO₂ removal potential indicate considerable uncertainty about the future role of BECCS in achieving climate policy objectives. Due to this uncertainty, they conclude that policymakers urgently need to offer additional incentives to reduce emissions and minimize dependency on a future deployment of NETs at scale.

Haikola et al. [44] arrive at a similar conclusion. Like Rickels et al., they conducted interviews with Earth system and integrated assessment modelers, but also compared the interview data with survey data from delegates participating in UN climate change conferences. Haikola et al. identify a major discrepancy between expectations about the removal potential of BECCS among the UN delegates and the role of BECCS in the IAM pathways, arguing that the detachment of IAMs from real-world developments in BECCS undermines the models' policy relevance. Additionally, Vaughan and Gough [45] carried out an expert elicitation focusing on assumptions made in IAMs to strengthen the feasibility of BECCS for reaching the 2 °C target, with the result that only technical assumptions concerning CCS are deemed to be realistic, while assumptions about bioenergy production, social acceptability and policy framework are considered to be unrealistic. Thus, they conclude, that the representation of BECCS in IAMs needs improvement but also the framework conditions to achieve the targets needs to be clarified in order to avoid an overestimation of BECCS' potential. Based on interviews with integrated assessment modelers as well as critics of IAMs

from different disciplines, Low and Schäfer [46] determined that the respondents had different interpretations regarding the feasibility of BECCS within modeling, which in turn led to different suggestions on how to reform IAMs. They suggest that future modeling exercises should engage experts from a wider range of disciplines, so as to resolve discrepancies and avoid misunderstandings.

Forster et al. [47] held an expert workshop discussing feasibility criteria for BECCS and afforestation, resulting in proposed approaches to account for social and political dimensions in IAMs. Based on this research and additional expert elaborations, Clery et al. [48] gathered a wide range of technical and socio-political criteria for the feasibility of BECCS supply chains that need to be considered in future integrated assessments and by policymakers.

In brief, previous studies have mainly focused on the feasibility of implementing BECCS at the scale assumed in the mitigation pathways derived from IAMs. In this regard, previous research emphasizes that the lack of appropriate policy instruments constitutes a major obstacle to BECCS deployment. Political inaction has often been discussed in the literature, but to the best of our knowledge, experts in the field of BECCS have never been asked what policy instruments they feel are desirable and politically feasible. This paper addresses this gap by focusing exclusively on policies for incentivizing BECCS, which are already being discussed in political circles and the scientific community, and by asking experts specifically about their views on these instruments.

3. Method

3.1. Survey design and data collection

The data analyzed in this paper was collected through a survey of experts from policymaking, research, and business and industry who were involved in BECCS and/or CCS. The survey was distributed in two versions among two partially overlapping sets of respondents. The first questionnaire included a core set of questions about BECCS policies coupled with an extensive set of questions on expected technical developments and costs. The invitation and two reminders were sent by email in December 2021 and were distributed to 145 international experts, with a response rate of 16 % ($N = 25$). Since the survey consisted of a technical and a more policy-focused part, we invited experts who had mainly technical and/or political expertise regarding the value chain of CCS, BECCS and bioenergy production. In order to find qualified experts in this field, we screened suitable scientific papers and their authors, and searched for contacts on a global level from universities, scientific institutions, consultancies, NGOs, as well as practitioners at CCS and BECCS plants, and power and heat providers dealing with bioenergy. It was considerably easier to find contact data for experts from research than from business and industry, or from policymaking. Therefore, we invited more researchers ($N = 92$) than experts from business and industry ($N = 48$) or policymaking ($N = 5$). As it was not always easy to identify respondents' working sector, we added a question about this to the survey.

To increase the number of responses on the policy-related questions, and to further refine the data on policy expectations, a second questionnaire with additional policy-related questions was developed. The second questionnaire and two reminders were sent to 125 experts (including the 25 respondents that answered the first questionnaire) in February and March 2022. Overall, this survey reached a response rate of 25 % ($N = 30$, of which nine also responded to the first survey). The second survey targeted only those experts with a more policy-focused expertise on the value chain of CCS, BECCS and bioenergy production. Here, more experts from business and industry ($N = 67$) were contacted compared to those from research ($N = 18$) or policymaking ($N = 15$). Table 1 shows that in total 46 respondents answered the core set of policy questions, while 30 respondents replied to the expanded set of policy questions.

All experts were asked background questions about their occupation,

Table 1

Overview of survey topics and their distribution to the expert groups.

Topic	Group A	Group B	N
Perceptions of BECCS	●	✓	30
Suitability of policy instruments	✓	✓	46
Necessity of a policy mix	✓	✓	46
Suitability of policy instruments in own country of residence	●	✓	30
Suitability of policy instruments in the context of achieving net-zero/net-negative emissions	●	✓	30
Suitability of different subsidies	✓	✓	43
Likelihood of implementation for different subsidies	✓	✓	43
Appropriateness of reverse auctioning	✓	✓	43

Note: Group A includes experts who responded only to the core set of policy-related questions (16 experts), while group B include experts who responded to the core and expanded policy-related questions alike (30 experts). The number of respondents, N, could be less than A plus B, as not all respondents answered all questions.

e.g., the sector they primarily worked in, their professional background, and the country of their primary employment. As reported in Table 2, a large share of the respondents was based in Europe, followed by North America. Most of the experts worked in research, followed by business and industry, and policymaking (one expert indicated that none of the sectors applied). Further, multiple responses were possible, so that four experts claimed to work in research and policymaking, while three listed research, and business and industry as their working sectors. In the survey, participants were asked to categorize their expertise, so most participants claimed to have profound knowledge on policy instruments for supporting BECCS ($N = 21$), CO₂ capture ($N = 21$), CO₂ storage ($N = 20$), costs of CCS ($N = 16$) and technical integration of BECCS ($N = 16$). It can be deduced that most of our respondents were knowledgeable concerning CCS in general and BECCS in particular, and further that a significant share of them were familiar with policy instruments to support BECCS, which is a good basis for evaluating the suitability of policy instruments. Furthermore, half of the participants worked in their expert field for >10 years ($N = 23$) (<2 years: $N = 3$, 2–5 years: $N = 14$, 6–10 years: $N = 6$).

3.2. Questionnaire design

Besides questions on the respondents' backgrounds, we asked about the general suitability of various policy instruments to support the deployment of BECCS. The core set of policy-related survey items in the first and second questionnaire were based on the scientific literature on BECCS policy. Experts were asked to assess the suitability of the most frequently discussed policy instruments, including: a general subsidy [32], the integration of BECCS in cap-and-trade systems [33], a carbon tax with a refund scheme [34,35], a quota obligation [36,37], and

Table 2

Respondents ($N = 46$) divided by primary sector of work and region.

	Research	Business and industry	Policy	Multiple responses	Not stated
North America	3	3	●	2	●
Europe	13	8	4	3	1
Rest of the world	1	●	●	1	●
Not stated	5	●	1	1	●
N	22	11	5	7	1

Note: North America includes Canada and the USA; Europe includes Austria, Belgium, Denmark, Germany, Italy, the Netherlands, Norway, Sweden and the UK; Rest of the world includes Brazil and South Korea.

Table 3
Overview of policy instruments addressed in the survey, which were also available to the experts.

Policy instrument	Explanation
Subsidy	BECCS operators receive a financial benefit from the government to support the deployment phase. A distinction is made between different forms of subsidies: subsidizing investment, bioenergy production, biomass usage, or with focus on emission reductions, i.e., a subsidy on emissions stored with BECCS and a subsidy on emissions stored with CCS with no distinction between fossil and biomass sources [32,49].
Integration in a cap-and-trade system	A cap on CO ₂ emissions forces emitters to surrender emission allowances in accordance to their amount of emissions. Those allowances would reenter the trading pool when CO ₂ is removed from the atmosphere [33].
Carbon tax combined with a refund scheme	A carbon tax would set a price on fossil and biogenic carbon. But a standalone carbon tax would not incentivise emission reductions beyond zero. A possible solution might be a linking of a tax with a refund scheme, where a BECCS plant would receive a refund for each ton of CO ₂ removed from the atmosphere [34,35].
Quota obligation	Emitters of specific sectors are obliged to purchase BECCS units in proportion to their emission release or directly finance BECCS projects and subtract those negative emissions from their own emissions [36,37].
Reverse auctioning	The traditional role of buyers and sellers is inversely so that the reverse auctioning differentiates between one buyer (here the government) and many sellers (here actors that offer negative emissions through BECCS). Normally, the lowest bidder wins the auction and receives a differentiated guarantee price for storing CO ₂ from biogenic sources. Overall, the purpose of a reverse auctioning is to serve as an investment aid for BECCS operators [31,36–38].

reverse auctioning [31,36–38]. Table 3 shows the explanations of the various policy instruments, which were also outlined to the experts during the survey. The expanded set of questions in the second questionnaire also included items on whether the respondents' assessment of the policy instruments would change if they had to differentiate between a global context and their country of residence. In addition, participants were asked to assess these policies in the context of net-zero emissions targets compared to net-negative emissions targets. In those cases where assessments changed with the context, participants were asked to explain the differences.

In addition to the suitability of policy instruments, the questionnaire included a set of questions related to subsidies, reverse auctions, and the need for a policy mix to support BECCS. Since subsidy schemes can take on a variety of forms, we included a question about the suitability of five specific flat-rate subsidies for BECCS, i.e., for (1) biomass production, (2) bioenergy, (3) BECCS investment, (4) emissions stored with BECCS (i.e., a results-based payment), and (5) emissions stored with CCS (with no distinction between fossil and biomass sources) [32,49]. Furthermore, we asked about the likelihood of the respective subsidies being implemented by policymakers in the future. This allowed us to contrast the assessment of the subsidy schemes' suitability with the assessment of the likelihood of their implementation. Also, the core set of questions included questions about the experts' views on reverse auctioning, whether they felt it was an appropriate measure, and the reasons for their response.

In the extended questionnaire, we asked experts to agree or disagree with statements concerning BECCS as a suitable measure to address global warming, its contribution to meet the well below 2 °C goal, its contribution to mitigation actions in their country of residence, and last but not least, whether or not BECCS should be incentivized by means of policies. The response scales for questions that asked about the experts' views on specific topics were four-point Likert scales ranging from

“disagree strongly/very unsuitable/very unlikely” to “agree strongly/very suitable/very likely.”

4. Results of the expert survey

4.1. Perceptions of BECCS

To obtain a picture of how the experts perceived the potential of BECCS, they were asked to agree/disagree with four different statements, shown in Table 4. The respondents generally agreed that BECCS was both a suitable measure to address global warming and that BECCS should be incentivized by means of policies. The high level of agreement was especially true for experts from business and industry, of whom none disagreed with either of the two statements.

The responses of experts from research and policymaking were also overall positive, and only a small share of experts disagreed with at least one statement. For the statements about BECCS's contribution to meeting the well below 2 °C target globally and its contribution to mitigation actions in the respondents' country of residence, the responses were mainly positive. However, the level of agreement with these two statements was markedly lower compared to the level of agreement on the suitability of BECCS to address global warming in general, and the support for policy incentives. We find again that experts from business and industry tend to agree more with the statements on BECCS's contribution to the 2 °C target and to domestic mitigation actions in comparison to experts from research and policymaking, as shown in Table 4. While for both statements the response pattern diverged slightly between experts from business and industry compared to experts from research and policymaking, the Kruskal-Wallis test¹ revealed that the differences were not statistically significant ($p: 0.1147$

Table 4
Mean agreement with BECCS statements by working sector (Scale: 1 disagree strongly; 2 disagree slightly, 3 agree slightly, 4 agree strongly).

	Research		Business and industry		Policy		Total	
	Mean	N	Mean	N	Mean	N	Mean	N
BECCS is a suitable measure to address global warming. ^a	3.18	11	3.50	8	3.00	4	3.26	23
Globally, BECCS is likely to contribute substantially to meeting the well below 2 °C goal. ^b	2.64	11	3.50	8	2.50	4	2.91	23
In my country of residence, BECCS is likely to contribute substantially to mitigation actions. ^c	2.73	11	3.14	7	2.00	4	2.72	22
BECCS should be incentivized by policies. ^d	3.45	11	3.87	8	3.00	4	3.52	23

Note: “Don't know” answers and seven experts who indicated multiple working sectors were excluded.

Applied Kruskal-Wallis test: $H_0 =$ No difference in responses between working sectors.

^a $p: 0.3681$, ^b $p: 0.1147$, ^c $p: 0.1517$, ^d $p: 0.1126$.

¹ The Kruskal-Wallis H test was used to detect statistically significant differences in the response patterns among experts from research, business and industry, and policymaking, as well as among experts with different locations of their primary work. The Kruskal-Wallis test is a nonparametric procedure used to determine whether the tendencies of a variable differ between two or more independent samples [50].

for BECCS's contribution to the 2 °C target, and p : 0.1517 for BECCS's contribution to domestic mitigation actions).

Particularly experts located in Sweden, the UK and the USA agreed that BECCS would contribute substantially to mitigation actions in their country of residence, while experts in other European countries mostly disagreed (e.g., Germany, Belgium and Austria), which is according to the Kruskal-Wallis test significant (p : 0.0216).² When asked what motivated their response, one expert argued that there was no room for BECCS in densely populated regions. Other experts also stated that a few countries (e.g., the UK, Sweden and Finland) had substantial potential for implementing BECCS because industrial plants already in place used biomass at scale and were suitable for a BECCS retrofit. Further, several experts indicated that meeting the targets would be difficult without CO₂ removal and that BECCS was one of the most advanced technologies for carbon removal. On the other hand, they also argued that BECCS was unlikely to contribute to climate change mitigation on a global scale due to challenges regarding upscaling, and that its contribution to reaching the 2 °C target would therefore be limited:

“BECCS is one among many solutions for climate change mitigation. There are many challenges to scaling up BECCS so it will likely not be a substantial contributor to climate change mitigation on a global scale, although it could contribute on a local and national level.”

Challenges for the large-scale deployment of BECCS include the conditions for long-term CO₂ storage and land-use implications (e.g., resource competition for land and water) due to the increased biomass use that would result from upscaled BECCS. Here, several experts emphasized the importance of ensuring the sustainability of biomass production:

“BECCS is part of the tools to reach carbon neutrality, but it cannot be used to compensate inaction. First the priority is to tackle fossil emissions, with CCS as last resort. Secondly, to ensure sustainable biomass production. Only then, BECCS should have role to play.”

On average, especially researchers agreed that BECCS was a suitable method to address global warming, but were more skeptical as to whether it would substantially contribute to meeting the well below 2 °C goal. 6 of 17 researchers agreed less with the second statement compared to the first (see Table 4). In contrast, among respondents from business and industry, only 1 of 10 gave different answers on the two statements. Despite being skeptical about the scope of BECCS's contribution to global climate change mitigation, most experts agreed that it needed to be incentivized by means of suitable policy instruments:

“There has been a significant volume of independent academic and third-party research over recent years that indicates that BECCS will play a critical role to address residual emissions in hard-to-abate sectors across the global economy. Whilst over the long-term a liquid market for carbon removals should provide developers with the revenue streams and price signals required to develop BECCS projects, in the short-term some form of policy intervention will be required given the capital and operational costs of carbon capture technology.”

4.2. Suitability of policy instruments for supporting BECCS

Fig. 1 shows that most experts ranked a carbon tax combined with a refund scheme as the most suitable option for supporting BECCS, followed by a general subsidy. The level of agreement on the suitability of a carbon tax combined with a refund scheme was fairly high and only a few experts ($N = 3$) felt the policy was unsuitable. The assessments of the integration in a cap-and-trade system, a quota obligation, and reverse

auctioning were more diverse. The majority of experts indicated that an integration in a cap-and-trade system or a quota obligation would be suitable means of supporting BECCS, although nearly one third of the experts felt these policies were unsuitable. Looking at reverse auctioning, it is striking that one third of experts responded “Don't know” – indicating that they felt that they did not know enough to assess the option's suitability. The remaining experts considered reverse auctioning to be a suitable policy ($N = 25$). If the “Don't know” answers were excluded from the analysis, reverse auctioning would be the second most suitable instrument after a carbon tax together with a refund scheme in the ranking.

In the open-text answers, several experts indicated that reverse auctioning was a suitable instrument for supporting BECCS at an early stage because it would enable government to support projects at the lowest possible cost and provide predictable financial flows for the operators. Nevertheless, from an operator's point of view, reverse auctioning bears the risk of putting considerable time and effort into the preparation of a bid, only to have it rejected:

“If the purpose is for the government to achieve low-cost BECCS then reverse auctioning probably is an appropriate instrument. For me as an actor it's a matter of reducing risks and with reverse auctioning I have to be very sure [to] have counted in all those risks that might appear to leave an offer. That requires a lot of knowledge and investment in time and effort and the possibility that my offer might be refused.”

Reverse auctioning could support the market entry of BECCS, but the experts also emphasize that it could only be effective for a limited time because of the limited opportunity to use public finance to create a sufficiently large market for upscaled BECCS. If a reverse auction were not combined with a quota obligation, a tax or a similar instrument to generate government revenues for financing the auctions, it would be costly for taxpayers in the long run. Therefore, reverse auctioning was often supported as part of a policy mix, an aspect that we will discuss in detail below.

Table 5 summarizes the respondents' views on the suitability of different policy instruments by working sector. The response patterns diverge slightly between working sectors: experts from business and industry categorized most policies as suitable, whereas those from research and policy were more reserved, particularly regarding a quota obligation and a cap-and-trade system. However, the Kruskal-Wallis test did not identify significant differences in the responses of experts from the three different working sectors for any of the policies (see Table 5 for p -values). Considering all respondents, the Wilcoxon signed-rank test³ revealed that a carbon tax and refund scheme was significantly preferred over a cap-and-trade system (p : 0.0021) or quota obligation (p : 0.0184). Comparing the sectors shows that this result was mainly driven by researchers. According to the Wilcoxon signed-rank test, researchers significantly preferred a carbon tax with refund scheme over a subsidy (p : 0.0104), cap-and-trade system (p : 0.0023) or quota obligation (p : 0.0086). Furthermore, they significantly preferred reverse auctioning over a quota obligation (p : 0.0263) or cap-and-trade system (p : 0.0263). In contrast, experts from policy and business and industry did not show a significant preference for any policy measure (p : 0.0918–1 for experts from policy, p : 0.1585–1 for experts from business and industry).

As mentioned above, one set of questions concerned the experts' opinions on specific subsidies. Fig. 2 presents the assessment of their suitability and the likelihood of their implementation for the various

² For the other statements and policy instruments, the experts' assessments did not differ significantly based on their location. Therefore, we did not explore it any further in this study.

³ The Wilcoxon signed-rank test was used to detect differences in the response patterns among experts from the same working sector. This allowed us to determine whether the response patterns for the suitability of two policy instruments were significantly different among experts from the same group. The Wilcoxon signed-rank test is another nonparametric test used to determine whether the main tendencies of a variable differ between two or more independent samples [51].

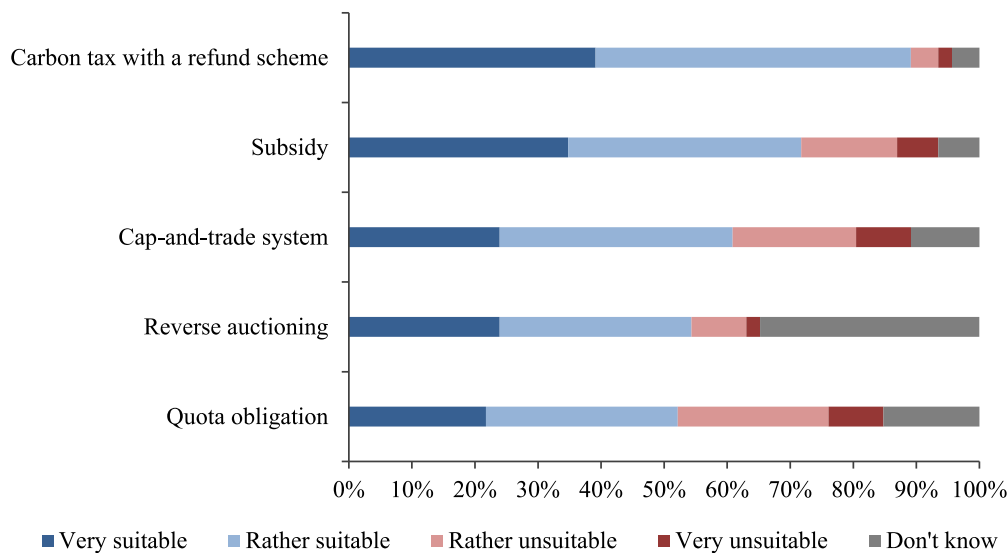


Fig. 1. Results of the assessment on the suitability of different policy instruments for supporting BECCS.

Table 5

Mean assessment of the suitability of policy instruments for supporting BECCS by working sector (Scale: 1 very unsuitable; 2 rather unsuitable, 3 rather suitable, 4 very suitable).

	Research		Business and industry		Policy		Total	
	Mean	N	Mean	N	Mean	N	Mean	N
Carbon tax with a refund scheme ^a	3.50	22	3.30	10	2.75	4	3.36	36
Subsidy ^b	2.95	22	3.44	9	3.25	4	3.11	35
Cap-and-trade system ^c	2.71	21	3.25	8	2.25	4	2.78	33
Reverse auctioning ^d	3.29	14	3.14	7	2.50	2	3.17	23
Quota obligation ^e	2.63	19	2.87	8	2.00	4	2.61	31

Note: “Don't know” answers and seven experts who indicated multiple working sectors were excluded.

Applied Kruskal-Wallis test: $H_0 =$ No difference in responses between working sectors.

^a p : 0.2743, ^b p : 0.3771, ^c p : 0.1856, ^d p : 0.8346, ^e p : 0.3147.

flat-rate subsidies. The experts ranked a results-based subsidy based on emissions stored with BECCS as the most suitable option, followed by an investment subsidy. The Wilcoxon signed-rank test indicated that subsidies on emissions stored with CCS (p : 0.0 for subsidy on BECCS/CCS, p : 0.0003 for subsidy on investment/CCS), and on bioenergy (p : 0.0 for subsidy on BECCS/bioenergy, p : 0.0 for subsidy on investment/bioenergy) or biomass production (p : 0.0 for subsidy on BECCS/biomass production, p : 0.0 for subsidy on investment/biomass production) were considered significantly less suitable.

It is interesting to note that roughly half of the respondents felt that subsidizing CCS alone would not be sufficiently effective to support the implementation of BECCS. Only 47 % of the experts considered this subsidy to be suitable, while nearly 90 % considered a subsidy on emissions stored with BECCS to be suitable. In comparison, the experts claimed that an investment subsidy was most likely to be implemented, followed by a subsidy on emissions stored with BECCS, although for the latter the assessment of the likelihood was lower than that of the instrument's suitability. However, a Wilcoxon sign-rank test showed that, in these cases, there was no significant difference between the responses on suitability and likelihood of implementation (p : 0.2406). Furthermore, the assessments of a subsidy on biomass production and a subsidy

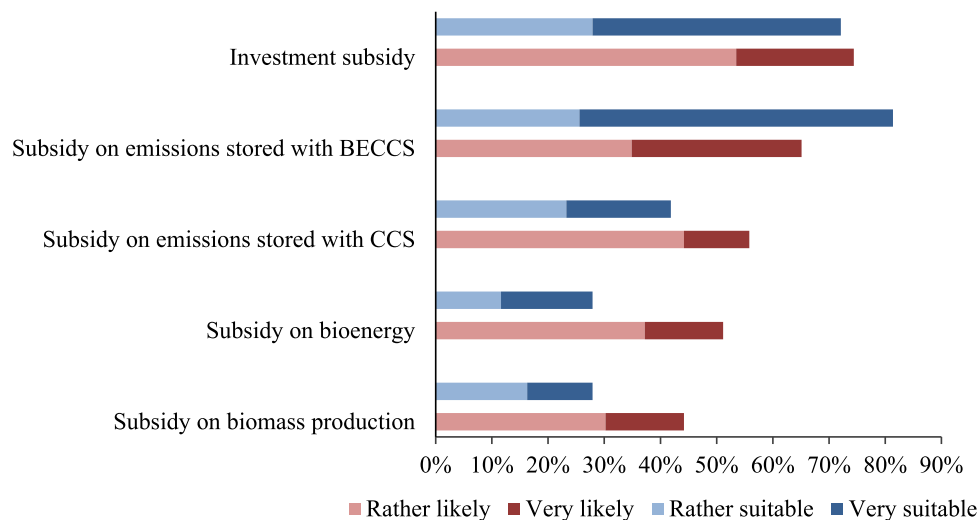


Fig. 2. Comparison of the suitability of different subsidies (blue bar) and the likelihood of their being implemented by policymakers (red bar) (“Don't know” responses excluded). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 6

Mean suitability of different subsidies by working sector (Scale: 1 very unsuitable; 2 rather unsuitable, 3 rather suitable, 4 very suitable).

	Research		Business and industry		Policy		Total	
	Mean	N	Mean	N	Mean	N	Mean	N
Investment subsidy ^a	2.90	20	3.80	10	3.33	3	3.21	33
Subsidy on emissions stored with BECCS ^b	3.30	20	3.70	10	3.00	5	3.37	35
Subsidy on emissions stored with CCS ^c	2.57	19	2.50	10	2.40	5	2.53	34
Subsidy on bioenergy ^d	2.00	21	2.55	9	2.50	4	2.21	34
Subsidy on biomass production ^e	1.95	21	1.77	9	3.20	5	2.08	35

Note: "Don't know" answers and seven experts who indicated multiple working sectors were excluded.

Applied Kruskal-Wallis test: H_0 = No difference in responses by working sector.

^a p : 0.0727, ^b p : 0.1963, ^c p : 0.9326, ^d p : 0.2959, ^e p : 0.0553.

on bioenergy diverged slightly. As mentioned above, the subsidies were considered to be less suitable than the other suggested subsidies. Despite this assessment, roughly half of the experts considered both subsidies likely to be implemented by policymakers. Here as well, we employed the Wilcoxon sign-rank test, which revealed that the likelihood of the subsidies' implementation was considered to be significantly higher than their suitability (p : 0.0124 for suitability/likelihood of subsidy on biomass production, p : 0.0064 for suitability/likelihood of subsidy on bioenergy).

Table 6 compares the assessment of suitability between experts from research, business and industry, and policy, and we can see that the responses differ slightly. In particular, the assessment of a subsidy on biomass production diverges, with experts from policy considering it to be substantially more suitable compared to experts from research and business and industry. However, the Kruskal-Wallis test indicated no significant variation between experts from the different working sectors (see Table 6 for p -values). The Wilcoxon signed-rank test revealed that experts from research and business and industry significantly preferred an investment subsidy and a subsidy on emissions stored with BECCS over the three other subsidies (p : 0.005–0.0872 for experts from research, p : 0.0066–0.0276 for experts from business and industry). Further, experts from research significantly favored a subsidy on emissions stored with CCS over a subsidy on bioenergy (p : 0.0112) or biomass production (p : 0.0274), while experts from business only

Table 7

Mean likelihood of different subsidies being implemented by working sector (Scale: 1 very unlikely; 2 rather unlikely, 3 rather likely, 4 very likely).

	Research		Business and industry		Policy		Total	
	Mean	N	Mean	N	Mean	N	Mean	N
Investment subsidy ^a	2.85	20	3.22	9	3.25	4	3.00	33
Subsidy on emissions stored with BECCS ^b	2.89	19	3.37	8	2.75	4	3.00	31
Subsidy on emissions stored with CCS ^c	2.84	19	2.75	8	2.50	4	2.77	31
Subsidy on bioenergy ^d	3.05	19	2.71	7	1.75	4	2.80	30
Subsidy on biomass production ^e	2.85	20	2.00	9	2.25	4	2.56	32

Note: "Don't know" answers and seven experts who indicated multiple working sectors were excluded.

Applied Kruskal-Wallis test: H_0 = No difference in responses by working sector.

^a p : 0.4246, ^b p : 0.2831, ^c p : 0.5187, ^d p : 0.0216, ^e p : 0.0521.

preferred such a subsidy over a subsidy on biomass production (p : 0.0276). Comparing the assessment of the likelihood of implementation between experts from the different working sectors, Table 7 shows that the response patterns diverged significantly for a subsidy on bioenergy (p : 0.0216). Additionally, the assessment of the likelihood of a subsidy on bioenergy being implemented differed significantly between experts from business and industry and those from policy (p : 0.0283), as well as between experts from research and those from policy (p : 0.0126).

We also asked the experts if they would change their ranking of the suitability of policy instruments to support BECCS depending on whether the target were net-zero emissions or net-negative emissions. Only six experts (N = 30) across all three working sectors indicated that they would change their ranking. While 17 experts claimed they would not rank the suitability of the policy instruments differently, seven selected the response "Don't know." Those experts who would change their ranking mainly argued that achieving net-negative emissions would require more ambitious measures and that policies would therefore have to be more stringent:

"BECCS for offsetting residual emissions is structurally different from BECCS for providing net negative emissions. All of the above schemes, if appropriately adjusted, can in principle incentivize CDR [CO₂ removal] at no additional costs for tax-payers if CDR only balances residual emissions. None of the schemes, however, are suitable for net negative emissions without consideration of intertemporal financial transfers/ intertemporal emission trading."

Given how heterogeneous the adjusted rankings were, it is difficult to make conclusive remarks on the rankings of the different policy instruments for achieving net-negative targets compared to net-zero targets.

4.3. Need for a policy mix

Further, the experts were asked if they felt that a policy mix was necessary to support the implementation of BECCS. Roughly 83 % of experts from all working sectors agreed to this. Those experts who supported a policy mix were subsequently asked, in an open-ended question, to suggest which policy mix they considered to be most suitable for supporting BECCS.

As Fig. 3 shows, most experts proposed a policy mix containing the above-mentioned policies and including policies with direct financial support from the government, e.g., a carbon tax (if combined with a refund scheme), a general subsidy, or reverse auctioning. They included market-based instruments as complementary policies, especially cap-and-trade and a quota obligation. Interestingly, a quota obligation was mentioned comparatively often even though it had been categorized as the least suitable instrument in the previous questions (see Fig. 1). The most frequently suggested policy mix combines a carbon tax with a quota obligation and a carbon tax with a refund scheme, followed by reverse auctioning with either a quota obligation or a cap-and-trade system.

A few experts also suggested a sequencing of the policy mix. One expert proposed a subsidy combined with public procurement as a suitable mix for an early phase of BECCS deployment, followed by a market-based mechanism once BECCS technology and the corresponding market were more mature. Another example: introduction of reverse auctioning at the beginning, followed by a cap-and-trade system or quota obligation. Furthermore, some experts called for other measures such as public procurement, government-funded research, mechanisms for CCS (including infrastructure build-up and regulations), as well as regulations for guaranteeing sustainable biomass production. In general, several experts claimed that the ideal policy selection depended on the government's preferred scale and scope:

	Reverse auctioning	Subsidy	Carbon tax	Cap-and-trade	Regulation on biomass sourcing	Investment funds
Carbon tax	1	0	0	0	0	0
Cap-and-trade	2	1	1	0	0	0
Quota obligation	2	1	3	2	0	0
Market-based mechanism	0	1	1	0	0	1
Refund scheme	0	0	3	0	0	0
Public procurement	0	1	0	0	0	0
Price stabilization mechanism	0	0	0	1	0	0
Strategies for CCS	0	1	1	0	1	0
Research	1	0	1	1	0	0

Fig. 3. Overview of the frequency of proposed combinations of different policies and/or other mechanisms. The rows and columns respectively show proposed policies/mechanisms to be combined by the experts.

“All of the policies listed above could have a role in supporting the implementation of BECCS, but the mix of policies that are most relevant vary by national and regional context.”

5. Discussion

In this expert survey, a carbon tax with a refund scheme received the highest agreement among experts to be a suitable option for supporting the commercial deployment of BECCS, followed by a general subsidy. Looking more closely at subsidies, the experts preferred technology-specific subsidies, since they considered subsidizing BECCS directly to be much more suitable than subsidizing CCS in general. On the one hand, Bellamy et al. [36] argue that deciding on the technology specificity of a subsidy reveals a dilemma of incentives, as in this case a subsidy for BECCS alone would undermine the exploitation of possible synergy effects between BECCS and fossil fuels with CCS. On the other hand, a general CCS subsidy might more effectively promote the deployment of fossil CCS, as BECCS is less mature than CCS and therefore associated with higher investment risks. Another very likely explanation for a preference to subsidize BECCS and not fossil CCS is provided by Fridahl et al. [30], who show how BECCS and CCS differ in two principal ways. First, BECCS provides a public good. This motivates support policy that rewards deployment. In contrast, fossil CCS should be incentivized by policies that penalize fossil emissions, so as to internalize a negative externality into the cost of production. Second, since fossil CCS is already at least partially incentivized by means of various instruments such as carbon taxes and cap-and-trade systems, attention should be directed towards technology-specific BECCS policies. If not, the chances that BECCS will complement fossil CCS as a mitigation option are low. It is likely that our participants share this view of the existing policy landscape and concerns regarding the competitiveness of BECCS compared to fossil CCS. This would also help those governments aspiring to develop technology-specific supply-push policies for BECCS to advance CO₂ removal.

With regard to reverse auctioning, we found a lack of knowledge about, and experience with, this instrument. On the one hand, one third of the experts selected the “Don't know” response and did not assess the instrument at all. On the other hand, the remaining experts mostly ranked it as suitable. Some participants commented that reverse auctioning was particularly suitable for the early implementation phase, which they justified by the fact that costs are minimized through competitive bidding. In addition, long-term contracts could reduce operators' uncertainty about financing the BECCS plants. These statements

are in line with Lundberg and Fridahl [38], who argue that reverse auctioning is a suitable interim policy for BECCS market entry, as cost efficiency and stable revenues provide robust planning horizons for the operators and investors. In our survey, some experts claimed that reverse auctioning was not a long-term policy due to the high cost borne by governments and, ultimately, taxpayers. Zetterberg et al. [37] stress this argument and highlight a sequential policy approach as a potential solution. They suggest that, after an early stage of reverse auctioning alone, the policy portfolio could be extended by quota obligations for scaling up BECCS, and for generating revenues to finance additional reverse auctions. This sequential policy mix was also proposed by some experts in our survey.

While the survey participants considered a quota obligation as a stand-alone measure to be less suitable compared to other policies, roughly half of them suggested policy mixes that include quota obligations, most often together with a carbon tax and reverse auctioning. A plausible explanation for these seemingly contradictory views is that quota obligations are considered problematic when used as a stand-alone instrument, whereas they can work well if combined with other instruments. Take publicly funded flat-rate subsidies or reverse auctions, for example: quota obligations could mitigate the problem of raising long-term public finance for subsidies, regardless of whether they are flat-rate subsidies or subsidies allocated via reverse auctions. Sectors with hard-to-abate emissions, such as agriculture and international aviation, could be obligated to buy and surrender BECCS certificates generated from the auctions, so as to comply with an annual BECCS quota specified as a share of their total emissions. As such, the quota obligation would reduce demand for emissions-intensive goods and services, such as meat and dairy products or flights, and would help to raise private finance for BECCS. A similar policy option is explored by Jenkins et al. [52], who argue that extractors of fossil carbon should be obliged to demonstrate long-term storage of CO₂ corresponding to a quota of the fossil carbon they extract. The quota would increase over time, and regulators could require that a share of the quota be delivered through BECCS. However, Zetterberg et al. concede that while in general a sequential policy approach would be promising, it would also be highly complex to set up.

Generally, the response patterns of experts from research, business and industry, and policy were similar and we observed significant differences only for a few questions. One difference emerged for the assessment of an integration of BECCS in a cap-and-trade system. While respondents from business and industry and from policy did not feel that any policy instrument was more suitable than the others, researchers preferred a carbon tax combined with a refund scheme, and reverse

auctioning over a cap-and-trade mechanism. One reason could be that some researchers might be critical towards including BECCS in a cap-and-trade system before the technology has matured and become cost-competitive. One potential solution to this problem is explored by Rickels et al. [53], who suggest that a central institution — potentially a carbon central bank — could be mandated to procure removals at an early stage, including from BECCS, to facilitate learning and associated cost reduction in negative emissions. The institution would also serve as a clearinghouse between providers of carbon removal and the European cap-and-trade market, allowing the institution to supply removal credits to the allowances market in the future, if deemed necessary to stabilize prices.

Additionally, we asked whether experts would give different rankings for net-zero and net-negative targets. The reason is that current Nationally Determined Contributions (NDCs), even if fully implemented, are likely to result in global warming of >1.5 °C, and the lack of sufficient mitigation ambitions in the NDCs would also severely limit opportunities to stabilize warming at $+2$ °C. Thus, the need to implement net-negative targets to compensate for temperature overshoots is increasingly being discussed [2–4]. Generally, net-negative emissions can be achieved if the deployment of NETs exceeds annual residual emissions, requiring a higher reliance on NETs and thus more stringent policies guaranteeing intertemporal financial transfers [41]. Therefore, it is striking that only six experts would change their ranking, which indicates that most experts concentrate on a general establishment of a market for BECCS and trajectories for achieving near-term targets. It seems that a market for BECCS beyond 2050 is out of sight. This is in line with Babiker et al. [4], who claim that so far, most countries have focused on achieving net-zero targets and only very few (e.g., Finland, Sweden, Germany and Fiji) have adopted long-term mitigation strategies that factor in net-negative emissions. Babiker et al. and the respondents in our survey alike stressed the need for further research on the importance of net-negative emissions for mitigating climate change; only then will it be possible to create suitable policy incentives for BECCS in line with achieving net-negative targets [4].

In general, most experts agreed that BECCS is a suitable method for addressing global warming, but they stressed that it should be seen as one measure in a portfolio of several CO₂ removal methods. It should be noted that the general agreement on the suitability of using BECCS to address climate change might result from the selection of respondents. We targeted a population of experts directly involved in BECCS projects, research, or policies. Fridahl and Lehtveer [29] posed similar questions about BECCS's contribution to climate targets to a more diverse audience of delegates attending UN climate change conferences and did not receive such optimistic results. Furthermore, it can be observed in the survey that a large share of experts from business and industry have a positive opinion about BECCS and rank most policy instruments as suitable, e.g., nobody disagreed that BECCS is a suitable measure to address global warming and needs policy incentivizes. It is difficult to find a reasonable justification regarding the extent to which the experts' working sector influences their preference for BECCS, as there are limited studies on this topic. This finding is in line with Fridahl [54], who also identified in his survey with UNFCCC delegates that business actors are slightly more positive towards BECCS. Most of the experts from business and industry in this survey are directly involved in BECCS or parts of the value chain. Therefore, it can be speculated that the experts have a vested interest in ensuring that BECCS is viewed as an appropriate measure and that implementation progresses through suitable policy incentives. On the other hand, researchers may think more skeptically about BECCS because they are trained by profession to emphasize trade-offs as well as potentials.

Additionally, we must acknowledge that this survey has an underrepresentation of the Global South, even though we screened for experts on a global level, most of the identified experts on this topic are from the Global North. This issue of underrepresentation of the Global South in the discourse on policies for NETs has also been addressed by Jaschke

and Biermann [55] and Sovacool [56]. Possible reasons could be that many countries in the Global South are run by authoritarian regimes, making it difficult for researchers to freely express their opinions on policy-related topics. Furthermore, it can be assumed that research in the Global South is limited by insufficient support for the training of scientists, as well as by the lack of resources, capacities or interest [56]. Although we include a respondent from Brazil, we must note that in general the responses are likely to be provided regarding the political and economic system of OECD countries. Considering the regions with the highest shares of modern bioenergy use in IAMs, Asia, and in particular China, are not represented by this survey [57]. Since the Chinese economic system is different to the one of the OECD countries, including Chinese experts to this review could have potentially made the interpretation of the results more difficult, due to the heterogenous economic backgrounds [58,59]. Generally, an important learning from conducting this survey is that for global distribution, it may be advisable to include partners with networks in different countries. Through their network in the respective country, they may easily distribute the survey and in the best case increase the number of responses from various experts located in different countries.

Furthermore, we observed differences in the assessment of BECCS's global and domestic contributions in our survey. Some experts felt that a given country's geophysical potential played a role in connection with deploying BECCS and that the existing infrastructure could be beneficial, especially regarding established industries using biomass at larger scale. In contrast, densely populated countries may lack space for BECCS, an argument which was also brought up in the survey conducted by Bellamy et al. [60]. One country with high BECCS potential is Sweden, as it has a large forest area, abandoned land area and low population density [31,36,61]. Further, it already uses large shares of biomass for its heat and power sector and pulp and paper industry [9,36]. Besides geographical advantages in biomass production, other national characteristics can also play a role. Borchers et al. [62] mention that the availability of existing industries that can be retrofitted with BECCS can increase its attractiveness, e.g., Germany wants to phase out coal by 2030 and one option would be to retrofit coal-fired plants to burn biomass. Moreover, Smith et al. [63] argue that limited geological storage capacity might also be a challenge for certain countries, and thus national geology has an impact on countries' potential to deploy NETs. In this connection, it is also worth reflecting over the experts' tendency to be skeptical towards the global mitigation potential of BECCS. While experts see a role for BECCS in specific countries' mitigation portfolios, their survey responses also indicate caution against overly optimistic deployment rates in modelled emissions pathways for stabilizing global warming well below 2 °C. While policy leverage is crucial for BECCS deployment, other local contextual factors will also influence deployment rates, factors that are hard to capture in global integrated assessment models [57]. Incentivizing BECCS deployment through policy could provide an important supplement in the global response to climate change but must not be used as an excuse to avoid incentivizing other forms of CO₂ removals. Needless to say, this is obviously also true for emissions reductions, to avoid using future removal potentials to deter contemporary mitigation actions [64].

A number of experts raised concerns about the benefits and sustainability of BECCS. They argued that, before deploying BECCS at large scale, policymakers needed to be aware of the attributes that are necessary for BECCS to deliver the expected climate benefits. Scaling up BECCS would lead to higher demand for biomass for bioenergy production. In this survey, experts expressed their concerns regarding the trade-offs between BECCS and land use, if the land used for biomass production could also be used for food production. Several experts indicated the importance of sustainable biomass sourcing and claimed that, besides policies for the deployment of BECCS, policies to ensure the sustainable origin of biomass were crucial. In addition, a few experts pointed out that the BECCS process involves high water consumption, which could exacerbate water scarcity. These challenges might limit the

potential of BECCS and there is already an ongoing research focusing on potentials and trade-offs caused by BECCS (e.g., [15–17]). In addition, further expert surveys on incentivizing the deployment of BECCS should include the issue of guaranteeing sustainable biomass sourcing in connection with the large-scale implementation of BECCS.

Finally, as mentioned above, this survey only addressed experts on CCS and/or BECCS, which may have biased the results. To capture a bigger picture, questions on the suitability and feasibility of policies to support BECCS, and to support NETs in general, should also be posed to experts on other NETs and climate change mitigation technologies. Failing to exploit synergies between different NETs, and the inefficient allocation of policy support, are serious concerns that need to be addressed [65].

6. Conclusion

There is already an ongoing debate about suitable policy instruments for incentivizing a deployment of BECCS in the scientific literature, but a survey assessing the opinions of experts had hitherto been lacking. Thus, the objective of this paper was to analyze the different expert opinions from multiple working sectors regarding the suitability of various policy instruments to incentivize BECCS deployment. Generally, a major takeaway of this survey is that a number of policies are in principle considered suitable and most experts agree that BECCS is an appropriate climate change mitigation measure. The survey shows a strong consensus among the experts on the need for immediate publicly funded policy support to tap its near-term potential, and general agreement that a policy mix is necessary for scaling up BECCS deployment in the long term. However, several experts emphasized that BECCS's domestic potential differed from its global potential, and that it should therefore be seen as one measure in a portfolio of several CO₂ removal methods. In this context, trade-offs between BECCS and land and water use, as well as sustainable biomass sourcing and countries' unique geophysical characteristics, were highlighted. Therefore, on the one hand, further research addressing these issues is required. On the other, NETs are needed for climate change mitigation, and the implementation of BECCS in regions with suitable geophysical potential should be politically supported. As noted by Lundberg and Fridahl [38], a publicly funded instrument, such as a flat-rate subsidy or a subsidy allocated through competitive reverse auctions, would also allow governments to interrupt further development if unanticipated negative consequences emerged from BECCS deployment. Both approaches received considerable support in this survey. The experts' views on a sequential approach to building a BECCS policy mix, starting off with immediate but limited public support to initiate a technology push, align well with the approach called for by Lundberg and Fridahl. Also, accompanying policies to ensure biomass sustainability and minimize emissions from land use and forestry need to be defined and embedded in the policy mix.

Declaration of competing interest

The authors declare no competing interests.

Data availability

The data supporting the results of the study are not publicly available due to ethical reasons, but are available from the corresponding author upon reasonable request.

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