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Productive in disagreement: stakeholder deliberation insights on carbon dioxide removal in Germany

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Attention to carbon dioxide removal (CDR) in climate policy is growing, and many CDR methods such as direct air carbon capture and storage (DACCS) are controversial. As such, broadening knowledge creation to include stakeholder perspectives upstream of policy is important. This exploratory study provides insights into the stakeholder engagement process of a transdisciplinary research project and its findings regarding co-creative CDR policy design and evaluation. It analyzes the views of participants in a stakeholder engagement workshop on CDR and an online survey. In all instances, experts highlighted the importance of the context in which these technologies are deployed. Workshop participants' views of DACCS, including its risks and opportunities, evolved throughout the process, indicating that learning took place. We also present stakeholders' reflections on their own role in knowledge creation and policy design. The qualitative experience and joint exploration of topics reaffirm the relevance of proper engagement on controversial, wicked problems such as the scaling of CDR as exemplified for DACCS. A nuanced discussion of the deployment context matters for stakeholders' perception of DACCS. Our results underscore the importance of deliberative and adaptable policymaking in the current formative phase of CDR policy in Europe. Additionally, they highlight the need for policies to proactively address tradeoffs between climate mitigation efficiency and other goals. They advocate for government-backed CDR research and development (R&D) as a basis for future deployment alongside a fossil fuel phaseout to maintain a clear carbon budget and avert mitigation deterrence.

KEYWORDS

CDR methods, DACCS, stakeholder engagement, co-creation, transdisciplinary, knowledge creation

1 Introduction

Carbon dioxide removal (CDR) has been receiving increased attention by the policy community. Many CDR methods, however, are mired in controversy, in part due to uncertainties about their mitigation potential and co-benefits, as well as concerns they distract from emissions reduction priorities. Considering stakeholder perspectives in knowledge creation in the spirit of responsible research and deployment (Bellamy, 2022), transdisciplinary approaches are viewed as essential for legitimate, fair and effective scaling of CDR. Importantly, stakeholder engagement moves away from one-way communication ("science transfer") and

simple consultation processes toward interactive approaches of co-creation (Kujala et al., 2022). This procedural turn is particularly important for wicked problems, where there is disagreement not only on empirical facts, but also on values and norms. Characterized by complexity, interdependency, uncertainty, and a divergence of views and values, CDR prompts important science-policy challenges in climate policy design (Low and Honegger, 2020; Kowarsch et al., 2016). Where both values and knowledge are disputed, intellectual and political struggles easily blend (Hoppe, 2010), necessitating engagement at the science-policy interface to proactively move from "problem to policy" (Beck, 2011, 304; also: Reinecke, 2015). Engagement of relevant publics and stakeholders on different policy levels (including community) is essential to enable deliberative policy learning (Kowarsch et al., 2016) and responsible policy development (Waller et al., 2020), while avoiding unproductive polarization (Colvin et al., 2020). Engagement prevents simplified modelling projections from creating or maintaining exaggerated expectations (Low and Honegger, 2020). Following the example of energy policy research and practice (Sovacool, 2014; Köhler et al., 2019), transdisciplinary, humanities and social sciences-led research can help CDR-policy futures avoid controversy around CDR research (McLaren and Markusson, 2020).

Decades-long theoretical and empirical work in Science and Technology Studies suggests that stakeholder-led processes provide much more salient, credible and socially robust approaches to address the "political load" of disputed matters of relevant knowledge from assessments to policy recommendations (Bauer et al., 2016; Cash et al., 2003; Hoppe, 2010; Wesselink and Hoppe, 2011; Reinecke, 2015), particularly in local contexts (Beck, 2011; Gorg et al., 2010; Koetz et al., 2012; Spierenburg, 2012). Stakeholder engagements allow exploring the specific socio-political and institutional contexts that influence the feasibility, desirability and acceptability of a given policy approach while revealing different ways of knowing, including values (Failing et al., 2007; Gorg et al., 2010). The need for greater demand-side orientation in the process of policy planning and deliberation itself (Cox et al., 2020) and the need for critical self-reflection by researchers and stakeholders in such processes is increasingly being highlighted (Hoppe, 2010; Wesselink and Hoppe, 2011). Engagement processes are valuable in gathering insightful information on general perceptions about CDR technologies. This was illustrated already in the case of stakeholder engagement regarding novel CDR techniques in the Global South (Hilser et al., 2024).

Various options of engagement processes exist, though often involving case-specific design and focus on individual stakeholder engagement opportunities (e.g., plenary discussions, station talks, breakout groups). Generally speaking, engagement process design is expected to tangibly affect outcomes. However, while dedicated deliberative processes on CDR methods (e.g., in Switzerland, the UK, and Nordic countries) have begun offering some of the required ingredients (representation, empowerment, capacity building, and spaces for deliberation), experience with deliberative policy learning for CDR policy design is still limited, particularly in Germany. While high on the German policy agenda, there have to date been few engagements with stakeholders on CDR (Boettcher et al., 2023).

This article shares experience from active stakeholder engagement and passive consultations on direct air carbon capture and storage (DACCS) as a particularly controversial CDR method. Discussions during the in-person workshop are reflected against results from an online survey by interpretative and statistical means so as to understand stakeholder perceptions on the challenges of DACCS, climate policy instruments, and assessment criteria. In this regard, DACCS is a particularly salient CDR method, as it features prominently in both expert and societal discussions that could thus far not resolve whether and how much the method should play a role in countries' climate responses (if at all). Along those lines, the intention of the engagement was also to reveal to what degree stakeholders and researchers reflect on their role in shaping policy and future CDR application in society or engage during discussions on political and ethical questions, and not only technicalities, of DACCS. In this effort, the study first delivers valuable insights into the role and design of co-creative and deliberative processes for political debates on highly contested CDR methods. It also provides empirical substantiation of the actual political and ethical concerns and expectations that different stakeholders have regarding a future deployment of DACCS.

2 Materials and methods

Our exploratory approach is a combined interpretative and statistical analysis of data generated via participant observation of a workshop and a subsequent online survey. The qualitative data were generated via observation of a stakeholder workshop that the authors conducted in Berlin with stakeholders who represented government agencies; pro-removal, anti-removal and removal-neutral non-profit organizations; climate and environmental policy think tanks; climate consultancies; universities; carbon removal private companies; private insurance companies; and federal ministries. The survey generated qualitative and quantitative data on stakeholders' views and allows comparison of responses from workshop participants and additional stakeholders who did not participate in the workshop.

The mixed method approach applied here serves the purpose of drawing detailed conclusions about the different (more or less controversial) positions and attitudes towards CDR within and in-between the targeted stakeholder groups and to also assess potential engagement impacts. Qualitative methods were important considering the limitations of statistical methods to gain a deeper understanding of the nuances between perceptions and attitudes as well as "why" exactly a position is held or changed on a novel and complex topic like CDR. Regression analysis was employed for testing if some of the key qualitative findings also hold statistically.

2.1 Data collection

For the stakeholder workshop, the CDR-PoEt research consortium[1] brought together 16 stakeholders to explore their

1 The Carbon Dioxide Removals: Policies & Ethics (CDR PoEt) research consortium is funded by the German Federal Ministry of Education and Research (BMBF) and has the objective to analyse possible policy instruments for carbon dioxide removals (CDR) and their fairness implications. Specifically, the project examines the economic, socio-cultural and institutional feasibility of CDR in five work packages. These serve as the basis for policy recommendations at local and (inter-)national levels.

views on CDR generally (including bioenergy with carbon capture and storage (BECCS), agroforestry and nature-based solutions more broadly) and DACCS specifically, in normative and practical terms.

In a sequence of three sessions that took place from April 18–19, 2023, stakeholders engaged in deliberations on three different thematic areas: 1—CDR policy instruments and instrument design; 2—Assessment criteria for CDR policies; 3—Policy instruments and regulations for DACCS (see Table 1).

While the first two sessions consisted of presentations by CDR PoEt researchers and moderated discussions with the workshop participants, Session 3 was more interactive and focused on DACCS to allow for more in-depth and tangible exchange. For instance, participants were first invited to use color-coded sticky notes to comment on a shortlist of six policy instruments for the development and incentivization of DACCS in Europe, indicating preferences: European Union emission trading system (EU-ETS) (cap-and-trade), direct state funding (e.g., via reverse auctioning), tax cuts, Paris Agreement Article 6 cooperation, research and development (R&D) funding, and no incentive system at all.

Second, participants were invited to indicate their (dis)agreement with a number of theses on DACCS (Table 2) before splitting into four breakout groups for a deepened exchange. Results were reported back to the plenary followed by a closing discussion.

The stakeholder engagement workshop was designed for an audience with strong expertise in climate and environmental policy and with experience with CDR generally and DACCS specifically, with individuals representing a diversity of views and actor types. The 16 participants had a good understanding of European climate policy and most were involved in German climate policy.

The workshop was held under the Chatham house rule and moderated as a largely open conversation in three half-day sessions. Sessions included switches between plenary discussion, some seeded with individual participants' prepared remarks, and active brainstorming sessions. The co-moderators repeatedly sought to mobilize less-vocal participants to ensure interweaving all views rather than defaulting to the most active. Some of the sessions made use of visualizations (see, e.g., Figure 1).

Data were derived in neutral facilitation and moderation, capturing the expressions of participants directly (e.g., sticky notes expressing opinion) or shortened by the facilitators and agreed upon by participants. Each breakout session had 1–2 notetakers per group and plenary sessions had 3–5 notetakers at all times. The investigators involved have also each captured the group discussion content in own independent notes based on their participatory observations.

After the workshop experience, the workshop participants – as well as a control group that did not attend the workshop – were invited

TABLE 1 Structure of stakeholder engagement CDR workshop.

Duration	Topic	Format
1 h	Session 1.1 • Ongoing CDR policy developments • The DACCS technology landscape • Normative dimensions of CDR policy • Carbon storage obligation: crowding-in funding for storage	Panel discussion
1 h	Session 1.2 Policy instruments & instrument mixes for CDR	Presentation
1 h	Session 1.3 What are the challenges of fair & effective CDR incentivization?	Moderated discussion
1.5 h	Session 2 Assessment criteria for CDR policies	Presentation & moderated discussion
2.75 h	Session 3.1 Policy instruments & regulations for DACCS in the European Union & Germany	Interactive design & breakout group discussion
1 h	Session 3.2 DACCS: Reflections & plenary discussion	Reflections & plenary discussion

TABLE 2 Theses on DACCS discussed by workshop participants.

Theses	Outcome
Emission trading systems are not suited to provide sufficient financial incentives for DACCS without accompanying measures	Majority approval with two opposing votes
Tax cuts for DACCS providers will lead to serious fairness/distribution issues	Mixed opinions between participants
DACCS implementation is fair if paid for by and implemented in countries with high present and/or past emissions	Majority approval with two opposing votes
DACCS requires low-carbon excess power and/or heat—high incentives can lead to an inefficient allocation of renewable energy capacities for DACCS instead of decarbonization/electrification	Unanimous approval by participants
DACCS as the ultimate backstop technology – an enabler for a carbon removal obligation?	Mixed opinions
Policy required designed specifically for DACCS (and other CDR methods respectively), vs. one general – technology neutral – CDR policy	Mixed opinions

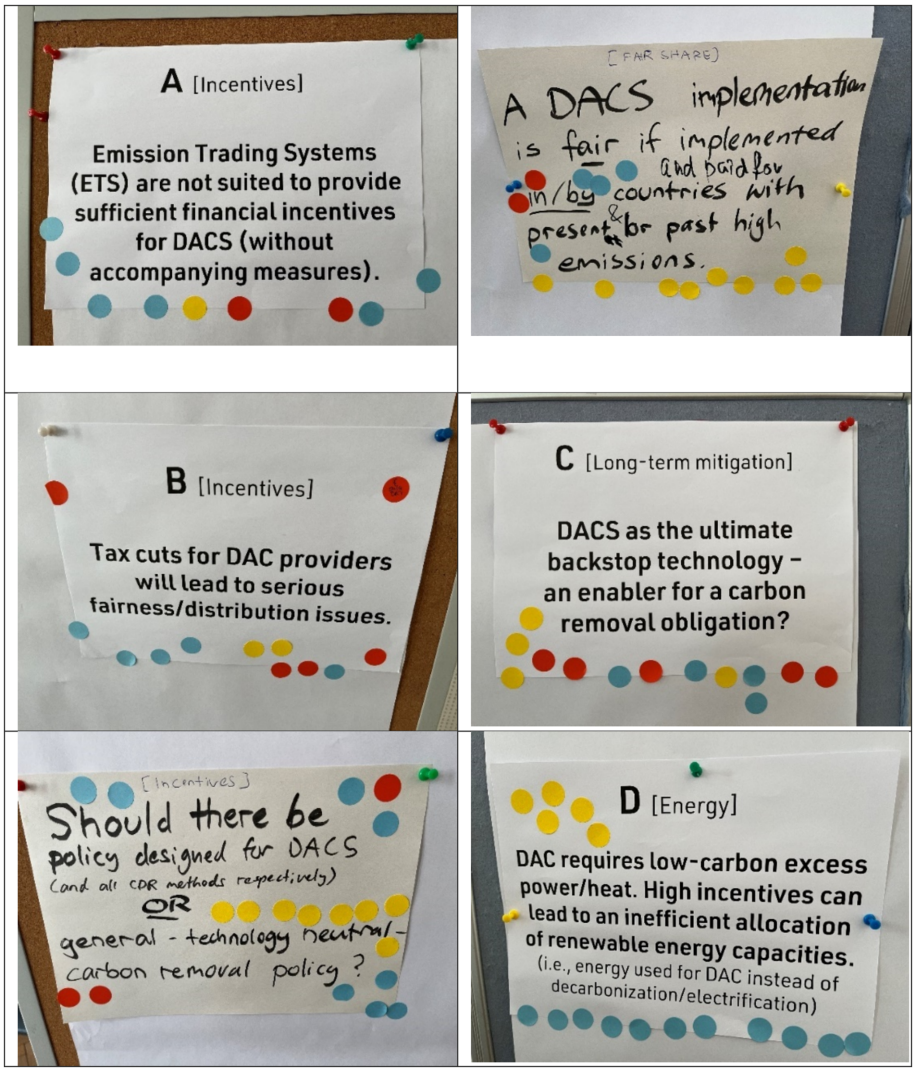

FIGURE 1
Visualizations used in DACCS theses discussions. Blue: I agree to theses. Red: I disagree to thesis. Yellow: I want to discuss this thesis and implications/solutions/etc. in a breakout group.

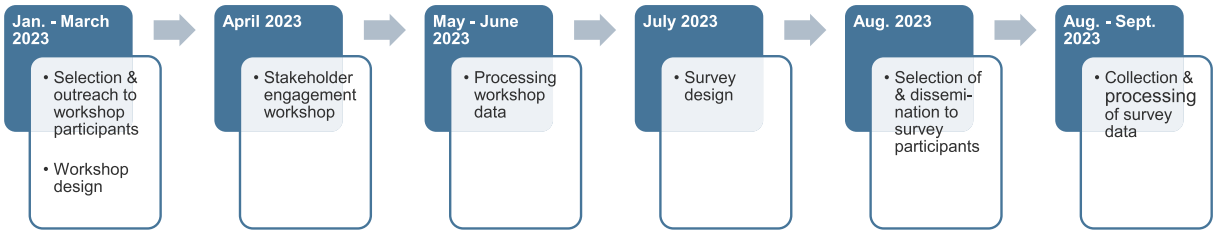

FIGURE 2
Data collection activities and timeline.

to respond to an online survey structured around the themes of the workshop sessions. Figure 2 describes in detail the data collection activities and timeline.

Workshop participants were chosen from the network of CDR PoEt consortium members based on their expertise in CDR and DACCS in a German and/or EU context as well as with the intention to include representation from a variety of sectors and positions on CDR. Where there was an existing relationship between a consortium member and a potential participant, the consortium member in question moved forward with recruitment. For participants without an existing relationship to the consortium, a designated CDR PoEt colleague engaged in their outreach using publicly available contact details.

The non-workshop survey respondents were similarly selected from the CDR PoEt consortium network as well as from their

participation in other stakeholder engagement activities of the broader CDRterra consortia. Selection was based on purposeful sampling to ensure comparable professional and expertise profiles in both the workshop and control group. For each workshop participant, two to seven individuals with similar backgrounds and roles were identified (based on professional criteria such as sector, geographical focus, and thematic expertise; age and gender were disregarded).

All 16 workshop participants and 78 other individuals received an invitation to the survey four months after the workshop. 37 responses were recorded, including 13 workshop participants and 24 non-workshop participants. 21 additional answers were disregarded as incomplete.

The survey consisted of three sections and a mix of multiple- and single-choice as well as Likert-scale (1–5) and open-ended questions. The first section addressed general background information, including age, gender, field of work, years of professional experience and experience with CDR and DACCS. The second section concerned the perception of CDR methods generally and DACCS specifically, climate policy instruments and assessment criteria, as well as the individual's role as a stakeholder in shaping decisions on CDR methods. The third section was only available to workshop participants. It asked about the perception of DACCS technologies before and after the stakeholder engagement workshop and the impact of the workshop on this perception. This section also evaluated the participants' overall perception of the workshop itself and their comfort participating as a stakeholder (see Appendix A for a complete questionnaire). An additional open question was added to any Likert-scale based evaluation question inviting respondents to elaborate on the reasons behind their choices.

2.2 Data analysis

The interpretative content analysis conducted rested in – and therefore was able to triangulate – a set of different sources of relevant content (Roller, 2019) including independently collected content from different investigators. It covered combined notes taken during the workshop by different facilitators based on focus group discussions and observation as well as key workshop products, like concept maps illustrating participant views and results of discussions, voting results or individual participant comments captured on sticky notes by participants or facilitators.

Researchers jointly reflected on the observations in the weeks following the workshop, transforming them into a detailed workshop summary. For this, the material was jointly structured in an abductive fashion along broader categories ("core themes") that pooled discussion content (Graneheim et al., 2017; Roller, 2019) roughly around the pre-defined themes of sessions and maintaining the order of the sessions, while leaving room to add new categories for left-over data. The summary report served as both a debrief on as well as a means to contrast the different impressions and interpretations of five different investigators, captured in their individual and independent notes (Roller, 2019).

To trace a possible evolution of views over the course of the workshop, researchers compared individual position statements from the beginning of the workshop (Session 1) with the views expressed on the same topics after (i) exposure and in-depth discussion of concepts and results of a CDR research project (Session 2) and (ii) interactive engagement with other stakeholders on contested aspects (Session 3). The captured insights were interpreted and further contrasted with the impressions of the observers using the same code tree that was elaborated based on the key takeaway that observers shared (see Table B.1). The interpretative data were then further contrasted with the qualitative responses of the survey and the results of the regression analysis of the survey data.

The survey data build an important cornerstone of triangulation contrasting the interpretative data with the results of quantitative analysis. This approach addresses the possible bias in observation that may be guided by the observers' expectation to identify specific views. In addition, combining quantitative statistics with interpretative methods allows to not only detect relevant positions and values of stakeholders on CDR, but also to explore their deeper meaning and to compare the views of those stakeholders who engaged in the deliberative process of the project on the contested method (considerably after the engagement) with those that had no such experience.

For the content analysis, the condensed notes and discussion material from the workshop were coded using the four overarching categories and respective (sub)-categories (codes/code groups) that were inductively derived based on the five team members' observations and key highlights (Table B.1). The overall categories serve as a structure for presenting the key findings in this paper. The same approach was followed in the course of interpreting the qualitative survey responses.

Regression analysis was applied to the quantitative survey data so as to empirically validate statistically relevant differences between participants in terms of background characteristics and previous workshop participation. A number of OLS regression models were estimated (Equation 1).

$$Y_i = \beta_0 + \beta_1 Workshop_i + \beta_2 X_{i2} + \ldots + \beta_k X_{ik} + \varepsilon_i \quad (1)$$

Y_i is the dependent variable that describes different opinions on the implementation of CDR and particularly DACCS technologies for survey respondent i, as well as on opinions for different climate policies and assessment frameworks for survey respondent i.

$Workshop_i$ describes whether the respondent i participated in the stakeholder engagement workshop. This is a binary variable, coded as 1 if the respondent participated in the workshop and as 0 if not.

$\beta_2 X_{i2} + \ldots + \beta_k X_{ik}$ include a number of background characteristics of survey respondents (see Appendix C for a detailed description of included variables). For dichotomous dependent variables, the above is a linear probability model. For all models, a significant positive coefficient for $\beta_1 + \beta_2 + \ldots + \beta_k$ implies that the respective respondent characteristics had a positive effect on the measure in question (and vice versa).

A potential problem of the chosen estimation is the potential existence of unobserved heterogeneity. This occurs when there are omitted variables that are associated with the dependent and independent variables. This potential bias is addressed through the mixed methods approach that we deploy that permits the corroboration of our results.

3 Results

3.1 Interpretative findings from the workshop

The workshop identified and explored several partly well-established, partly novel and contested thematic fields, which seemed to merit greater attention in policy deliberations. They represent themes with the strongest observable dynamics in the discussion in

terms of relative share in discussions and/or evolution in comparison to initially expressed positions. The core themes are also backed by observer interpretation and scope or breadth in the documentation material (meaning they took up considerable room in the discussion).

3.1.1 Context matters for CDR and DACCS deployment

The discussion primarily centered around whether CDR – and DACCS in particular – is needed in climate policy and to what extent. Conversations focused on a local German context as well as at the EU level, with reference to how deployment in these jurisdictions could have broader spillover effects in other countries. Consensus emerged that both support of and opposition to DACCS were less rooted in the technology *per se* but rather highly dependent on the context in which it would be deployed and its role in discourses on climate policy. Mitigation deterrence and the role of DACCS as a possible backstop technology in the future were the key discussion points. A commonly shared idea was that DACCS may only be acceptable for unabated "residual" emissions in a future scenario (and not necessarily in the near-term). This idea was predicated, however, on further mitigation ambition and precise, quantifiable figures on residual emissions. It was highlighted as one key learning in the engagement that the approval of present day incentivization of DACCS depends on trust in long-term emission reduction pathways (and policy commitment) for near-term DACCS deployment not to be perceived as mitigation deterrence. This also holds for CDR in general.

It was noted that concerns and hesitations by some participants regarding the scale-up of different CDR methods are (much) less related to the methods and technologies themselves or their direct side-effects, but about the role, effectiveness, and (cost/resource) efficiency of CDR in systemic contexts, such as climate discourses (e.g., on mitigation deterrence), climate policy and strategies, and particularly (and linked to all of the above) the transformation of the energy system. Having to increase the renewable energy basis to cater to CDR activities (for unabated emissions) rather than utilizing renewables directly as the major vehicle for a climate neutral transformation (avoiding residual emissions) was portrayed as highly problematic.

This led to the discussion of several related policy recommendations. Government-supported deployment of CDR, with a key focus on R&D, should co-exist with a fossil fuel phaseout in order to have a precise carbon budget to be removed. In those efforts it is also critical to establish clear and ambitious definitions of key terms (for example residual emissions and hard-to-abate emissions) in order for CDR strategies or international cooperation on CDR to be successful. Clear terms would help prevent CDR from being used as mitigation deterrence and help ensure its responsible and precise deployment in the eyes of stakeholders. Specifically, it is important to ensure that DACCS is not used for enhanced oil recovery. In the course of the discussions the stakeholders agreed that DACCS implementation would be fair if paid for by and deployed in countries with high current or historical emissions and in line with the polluter pays principle, which the researchers also discussed as one possible way of assessing the methods.

Another key learning regarding the context of CDR and DACCS deployment was the importance of the timeline. The concrete timeline of DACCS incentivization on the path to net-zero emissions was considered highly relevant. Here, participants who initially expressed strong opposition to DACCS – due to the risk of mitigation deterrence and preference for other mitigation options – accepted that the technology could have a desirable role in the future if there was trust (now) in ambitious emission reduction pathways that led to actual reductions in net emissions.

3.1.2 Decisive nuances in support or opposition conditions for DACCS

Some participants, mainly from civil society and public administration, expressed overall doubt about the desirability of DACCS and its role for climate mitigation regardless of its deployment context, as they said it is an unproven technology. This sentiment was especially strong at the beginning of the workshop. Nature-based solutions (NbS, such as afforestation or agroforestry) were – especially initially – highlighted by some as a far less problematic CDR method. As a "no regret" option, NbS is not only readily available at reasonable costs (Griscom et al., 2017), but also has minimal and known risks and limitations as well as numerous co-benefits (especially if applied at scale, Fargione et al., 2018) including in ethical and social terms. Still, their role as immediate CDR deserves cautious consideration in terms of mitigation deterrence (Lenzi, 2018) or land competition (Caldecott et al., 2015). In the discussions, it received acceptance right away, explicitly excluding BECCS.

We interpreted the hesitation towards DACCS as possibly a lingering consequence of previous narratives of civil society organizations that strongly opposed the overarching idea of CDR (Otto et al., 2021), even though many of the reasons underpinning those narratives have since changed (Boettcher et al., 2023).

Novel CDR methods can upset existing narratives, or not. BECCS, for instance, still evokes the same concerns around human rights and forest ecosystem loss that many NGOs successfully raised in the context of subsidized biofuel production in the global South in the past. A representative from a major environmental NGO, for example, remarked that BECCS is completely off limits, citing vivid memory of the fights on biofuels. DACCS, however, is not tainted by that history (*paraphrased by researchers*). Therefore, despite the current evidence that several forms of BECCS may not exhibit the same problems, a somewhat categorical rejection seems to persist based on deeply held moral grounds.

On the other hand, a considerable number of the workshop participants strongly supported DACCS deployment – especially under certain conditions (discussed previously). DACCS as a technology is seen as potentially important against the backdrop of an undeniable need to pursue CDR overall, not least in light of problems of permanence with afforestation (and associated scandals in the recent past). It was suspected that these views also rest in a broader shift towards acceptance of carbon capture and storage (CCS) technology in Germany vis-à-vis the failure of the government to meet its climate goals and the ongoing development of a carbon management strategy for the country, which led to a "softening" of opposition or even active support (Blanchard et al., 2024).

Another source of disagreement between workshop participants was the time horizon for DACCS incentivization and implementation, as there was disagreement as to whether it should be a near-term or a long-term priority. Some participants supported early action to accelerate innovation (through forceful R&D) and cost reductions, whereas others cautioned against incentivizing DACCS at the current

stage to avoid mitigation deterrence. DACCS, in their view, could play a role in the future when it is a mature technology.

Although trust in ambitious emission reduction pathways was portrayed as a precondition for accepting investment in DACCS, some participants saw an immediate need to invest in R&D and timely (pilot) deployment to have a scalable technology like DACCS available as a backstop option should the long-term net-zero target be unattainable. Both divergent views hinge on similar assumptions, e.g., regarding long-term resource efficiency and scalability of DACCS that need to be proven first but also the current impression that political action lagged far behind in ambition.

3.1.3 Diversity, interlinkages and tradeoffs between policy (assessment) approaches

There was a common understanding that no singular policy measure exists to deal with the challenges deriving from the complexity of DACCS (as well as other CDR) methods, vis-à-vis the social and economic burden and corresponding justice and equity implications (both nationally and internationally), and that public support was needed for the significant anticipated costs. Participants agreed that the voluntary carbon market (VCM) or other market approaches alone will not be sufficient to incentivize large-scale CDR. Considering that a broad set of criteria are relevant for assessing "good" – e.g. climate effective, efficient, or socially just – policies, participants saw a necessity to employ a full mix of policy instruments for satisfactory performance, especially for incentivization. Still, except for public support to fund and push R&D for DACCS deployment, which was seen as unproblematic, participants could not agree on the exact mixture or preferred policy instruments to implement DACCS at scale.

It was noted how strongly interrelated the assessment criteria of policies are and how they influenced each other with considerable tradeoffs (e.g., between efficiency and other targets like ecological effectiveness). This rendered clear policy choices even more complicated.

3.1.4 Deliberative learning experience

Although not a key focus of the workshop discussion as such, the engagement seemed to spark dynamics that allowed stakeholders to exchange on the highly controversial matter at a "higher" level. When comparing the arguments brought up after the initial technical presentations, i.e., when participants could "react" or "comment" and share their own (or their organization's) stance, with the positions shared during the deliberations in the second half of the workshop there was a clear evolution.

While participants had rather rigid "yes-or-no" positions at the outset, the different formats of engagement (small group deliberations, silent placing of sticky notes, open face-to-face discussions in extended breaks) seemed to nudge even actors who tended towards passive listening into more active interaction. With the engagement designed explicitly around direct and more comfortable small group human-to-human interactions (including extensive breaks), various opportunities were installed for peaceful and respectful exchanges of arguments.

Many nuances of DACCS implementation became salient for workshop participants in their evaluation of DACCS deployment. Stakeholders who were interested, active and increasingly informed on the topic seemed open for nuanced discussions around CDR policymaking and did not stand by their initial yes-no positions. Discussions quickly moved in the direction of exchanging arguments about what is useful and desirable in which context. The room given in the workshop for in-depth deliberations allowed for a certain level of joint sense-making and positioning.

Especially discussions' deep dive into the concrete challenges but also possible policy measures to address them helped to enable a nuanced exchange on the details. Working jointly on the details of development, deployment and policy measures built important bridges, even between supposedly opposing positions. The possibility to explicate essential pre-conditions to be able to agree was the foundation for actual agreement. The discussion of different assessment criteria, including explicitly those relating to fairness, sparked novel framings among participants when reassessing DACCS in terms of the role that deployment may have for unlocking new possibilities to enforce polluter pays policies.

The team put an effort in trying to make sense of when exactly in the engagement the positions moved and which of the engagement methods were particularly successful in enabling the mutual learning, including the face-to-face exchanges in numerous breaks. However, while we could not really identify this flipping point, it is undoubtful that a certain level of learning occurred among the stakeholders through the engagement. Deliberation allowed discovering new potential landing zones for political compromise. Minor paradigmatic shifts of positions created new overlaps, with one concrete example being that if DACCS is used to operationalize the highly valued polluter-pays principle with clear limitations and safeguards for CDR use, it would avoid that CDR would be seen as just an "easy way out" through empty promises of future action.

3.2 Survey results

3.2.1 General observations

Overall, most survey respondents have worked on CDR and DACCS. Respondents generally do not oppose CDR and DACCS methods. However, their support tends to be conditional in most cases (see summary statistics Tables C.1, C.3, C.4).

3.2.2 Comparison to identified themes from the workshop

3.2.2.1 Opinions regarding general support for or opposition to DACCS and CDR

As also seen in the workshop discussions, there was a certain notion that some CDR methods face a higher level of acceptability or support than others. On a scale from 1–5, reflecting how prominently methods should feature in climate policy according to the respondents (1 = should have no role at all, 5 = should have a very central role), agroforestry as a NbS, for instance, receives on average more support (3.36) compared to BECCS (3.05) and to DACCS (3.06). Although support for agroforestry is higher, survey respondents are still on average not opposed to CDR and DACCS methods (Figure 3).

When controlling for respondent characteristics, workshop participants scored on average at a lower level – i.e. 1.499 lower on a five-point scale – in their view on how prominently DACCS should feature in climate policy (1 = should have no role at all, 5 = should have a very central role), compared to non-workshop participants

(this effect is statistically significant at the 0.05 significance level) (Table 3). Men tend to support DACCS more. The same applies to those who have worked in the promotion of DACCS. Although we have no proof of what causes this larger skepticism from the workshop participants for DACCS, one possible explanation would be that the workshop deliberations may have increased the salience of some nuanced takes regarding the role of DACCS and the importance of context for its deployment. This finding is in line with the results of the qualitative analysis on the presence of deliberative learning.

When looking at how workshop participants rated different methods in comparison to non-workshop respondents, no significant difference could be seen between the two groups for agroforestry and BECCS. Importantly, agroforestry and BECCS were not a core focus of workshop discussions. Agroforestry was subsumed under NbS. Overall, support for agroforestry tends to be stronger from those who work in research and administration and civil society.

In line with the participatory observations on context, the support for CDR and DACCS tends to be conditional in most cases. Only 14% of survey respondents thinks that DACCS deployment is relevant in every context. Here time-scale and hindering emission reductions are also highlighted. 70% of respondents thinks that DACCS is acceptable to address climate change as long as its deployment does not hinder emission reductions, and 32% of respondents thinks that DACCS deployment depends on the time-scale, as it is not an appropriate solution for the short-term (Figure 4).

While there are hardly any differences in opinion between workshop participants and other survey respondents regarding questions on contexts for DACCS (Table 4) when controlling for different characteristics, male respondents whose work relates to promoting DACCS with many years of relevant professional experience tend to rather support the idea that DACCS should be deployed as long as it does not hinder emission reduction efforts.

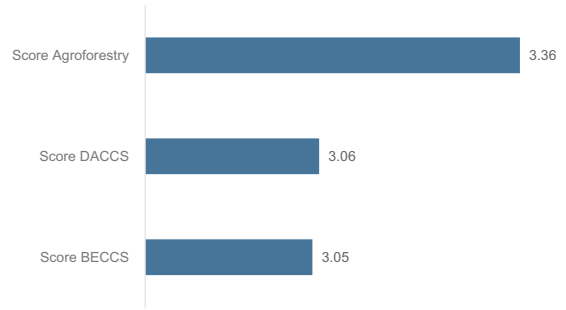

FIGURE 3
Survey respondents mean scores for different CDR technologies (36 Respondents). Score agroforestry: mean value, Ordinal, scale 1–5, according to how prominently respondent thinks agroforestry should feature in climate policy (1 = should have no role at all, 5 = should have a very central role). Score DACCS: mean value, Ordinal, scale 1–5, according to how prominently respondent thinks DACCS should feature in climate policy (1 = should have no role at all, 5 = should have a very central role). Score BECCS: mean value, Ordinal, scale 1–5, according to how prominently respondent thinks DACCS should feature in climate policy (1 = should have no role at all, 5 = should have a very central role).

3.2.2.2 Opinions regarding policy instruments and assessment criteria

When interpreting the results on the different policy measures and respective preferred assessment criteria, survey respondents favored regulation over other policy instruments, followed by direct

TABLE 3 Regression results for survey respondents scores of different CDR methods (DACCS, BECCS, and agroforestry).

Variables	Score DACCS	Score BECCS	Score Agroforestry
CDR workshop	−1.499** (0.563)	−0.568 (0.727)	0.0332 (0.633)
Male	1.200*** (0.381)	0.468 (0.445)	−0.537 (0.487)
Work EU	0.925 (0.588)	1.212* (0.685)	−0.880 (0.722)
Work Germany	0.00402 (0.667)	0.431 (0.550)	0.668 (0.576)
Policy	0.0785 (0.610)	−0.710 (0.588)	−0.418 (0.792)
Research	0.555 (0.775)	0.271 (0.760)	1.348** (0.605)
Administration	1.013 (0.656)	−1.558* (0.879)	1.357* (0.771)
Private sector	0.710 (0.752)	0.449 (0.725)	1.040 (0.606)
Civil society	0.00409 (0.710)	−0.702 (0.702)	0.977* (0.511)
Years experience	−0.0392 (0.0374)	−0.0645** (0.0308)	0.0490 (0.0373)
Work CDR	0.544 (0.845)	−0.0173 (0.748)	1.149 (0.998)
Work DACCS	−0.517 (0.481)	−1.439** (0.617)	−1.132* (0.599)
Promo DACCS	1.293* (0.648)	0.696 (0.642)	0.604 (0.552)
Constant	2.249 (1.562)	4.757*** (1.408)	1.708 (1.418)
Observations	36	36	36
R-squared	0.545	0.547	0.484

All models are OLS. Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Score DACCS: ordinal, scale 1–5, according to how prominently respondent thinks DACCS should feature in climate policy (1 = should have no role at all, 5 = should have a very central role). Score BECCS: ordinal, scale 1–5, according to how prominently respondent thinks DACCS should feature in climate policy (1 = should have no role at all, 5 = should have a very central role). Score agroforestry: ordinal, scale 1–5, according to how prominently respondent thinks agroforestry should feature in climate policy (1 = should have no role at all, 5 = should have a very central role).

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funding. There was a stronger support for climate effectiveness and feasibility compared to other assessment criteria like economic performance, equity and fair process (Table C.4).

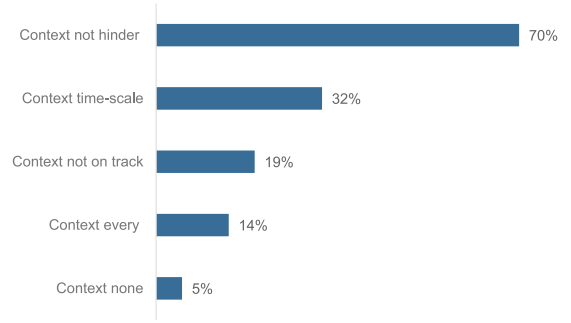

FIGURE 4
Survey respondents' opinion regarding the context by which DACCS should be deployed reported in percent of respondents supporting the different statements on context (37 Responses). Context not hinder: percent of respondents that thinks that DACCS is acceptable to address climate change as long as its deployment does not hinder emission reductions. Context time-scale: Percent of respondents that thinks that DACCS deployment depends on the time-scale, as it is not an appropriate solution for the short-term. Context not on track: Percent of respondents that thinks that DACCS is acceptable to address climate change only if we are not on track to achieve emission reductions without its use. Context every: percent of respondents that thinks that DACCS deployment is relevant in every context. Context none: percent of respondents that thinks that DACCS deployment is not relevant in any context.

As was highlighted in observations from the workshop, survey respondents see tradeoffs between assessment criteria as demonstrated by the negative associations of some of these criteria in the correlation matrix (Table 5). For example, *fair process* (referring to fair implementation and procedural justice issues) is negatively associated with *climate effectiveness* ($r = -0.38$), *feasibility* ($r = -0.42$) and *economic performance* ($r = -0.40$). This means respondents that would favor the assessment criteria oriented at impact, technical "do-ability" or efficiency, would lean less towards assessment criteria that relate to desirability and equity. It also suggests that respondents may perceive an incompatibility between a strong emphasis on process and the pursuit of efficient and effective results. Along those lines, economic performance was also negatively associated with equity (distributive justice) ($r = -0.49$), suggesting perceived tradeoffs between fairness and expediency.

Especially supporters of DACCS tend to favor carbon markets as well as *economic performance* as assessment criteria while they give less significance to fair process. Support for DACCS technologies is positively associated with a higher scoring of all policy instruments (r around 0.5), but the association is weaker with regulatory instruments (r = 0.36). This suggests that respondents do not view DACCS as a means to force – via regulation – hard-to-abate industries to counter their emissions.

In terms of opinions regarding policy instruments (Table C.6) and assessment criteria (Table C.7), there are no significant differences between workshop participants and other respondents. This suggests that the communicative process did not change the perceptions of policies and ethics. However, we see that a number of background characteristics of survey participants are significantly correlated with these opinions.

TABLE 4 Rergression results for survey respondents opinion regarding the different context to deploy DACCS.

VARIABLES	Context does not hinder	Context not on track	Context time-scale	Context none	Context every
CDR workshop	−0.0837 (0.195)	−0.00575 (0.185)	0.0296 (0.206)	0.219 (0.152)	−0.264 (0.205)
Male	0.315* (0.170)	0.0786 (0.171)	0.0118 (0.185)	−0.159 (0.103)	0.169 (0.132)
Work EU	−0.234 (0.179)	0.0596 (0.198)	−0.172 (0.289)	−0.123 (0.127)	0.180 (0.227)
Work Germany	0.00717 (0.169)	0.218 (0.151)	−0.114 (0.249)	0.104 (0.0816)	−0.172 (0.150)
Policy	0.267 (0.224)	0.221 (0.146)	0.164 (0.187)	−0.0888 (0.113)	0.0737 (0.162)
Research	−0.258 (0.207)	−0.0434 (0.195)	−0.0851 (0.264)	0.114 (0.101)	−0.131 (0.126)
Administration	0.222 (0.429)	0.00448 (0.229)	−0.293 (0.235)	−0.289 (0.176)	0.402 (0.334)
Private sector	0.284 (0.214)	−0.0534 (0.256)	0.107 (0.220)	−0.107 (0.0849)	0.105 (0.167)
Civil society	0.262 (0.208)	0.120 (0.197)	0.343 (0.279)	−0.0225 (0.0870)	0.0859 (0.185)
Years experience	0.0226** (0.00960)	−0.00855 (0.00777)	0.00850 (0.0145)	−0.00351 (0.00377)	−0.00244 (0.00597)
Work CDR	0.303 (0.450)	−0.588 (0.507)	−0.556 (0.389)	−0.0429 (0.153)	0.329 (0.271)
Work DACCS	0.0984 (0.279)	−0.267 (0.289)	0.418 (0.245)	0.0311 (0.128)	−0.109 (0.228)
Promo DACCS	0.282* (0.158)	0.0611 (0.188)	−0.107 (0.247)	−0.115 (0.0828)	−0.0246 (0.213)
Constant	−0.209 (0.496)	0.715 (0.445)	0.391 (0.487)	0.165 (0.177)	−0.0681 (0.289)
Observations	37	37	37	37	37
R-squared	0.437	0.205	0.315	0.318	0.223

All models are OLS. Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Context not hinder: binary, 1 = Respondent thinks that DACCS is acceptable to address climate change as long as its deployment does not hinder emission reductions. Context not on track: binary, 1 = Respondent thinks that DACCS is acceptable to address climate change only if we are not on track to achieve emission reductions without its use. Context time-scale: binary, 1 = Respondent thinks that DACCS deployment depends on the time-scale, as it is not an appropriate solution for the short-term. Context none: binary, 1 = respondent thinks that DACCS deployment is not relevant in any context. Context every: Binary, 1 = respondent thinks that DACCS deployment is relevant in every context.

TABLE 5 Correlations matrix of survey respondents opinions regarding DACCS, policy instruments and assessment criteria.

	Incentivization	Market generation	Direct funding	Regulation	Context does not hinder	Context not on track	Context time-scale	Context none	Context every	Score DACCS	Score BECCS	Score Agroforestry	Feasibility	Climate Effectiveness	Fair process	Economic performance	Equity
Incentivization	1.00																
Market generation	0.63***	1.00															
Direct funding	0.44***	0.32*	1.00														
Regulation	0.22	−0.08	0.51***	1.00													
Context does not hinder	0.32**	0.15	−0.02	−0.08	1.00												
Context not on track	−0.26	−0.30*	−0.04	0.19	−0.14	1.00											
Context time-scale	0.06	0.07	−0.14	0.00	0.20	−0.04	1.00										
Context none	−0.22	−0.37**	0.06	0.08	−0.37**	−0.12	−0.17	1.00									
Context every	0.12	0.26	0.23	0.01	−0.26	0.01	0.06	−0.09	1.00								
Score DACCS	0.52***	0.50***	0.52***	0.36**	0.17	−0.07	−0.12	−0.37**	0.35**	1.00							
Score BECCS	0.33**	0.46***	0.42**	0.15	0.12	0.08	−0.07	−0.37**	0.10	0.62***	1.00						
Score Agroforestry	0.29*	0.15	0.09	0.08	0.08	0.08	−0.20	0.31*	0.07	0.10	0.02	1.00					
Feasibility	0.17	0.12	0.34**	0.32**	−0.05	0.39**	0.05	−0.20	−0.01	0.21	0.06	−0.01	1.00				
Climate Effectiveness	0.18	0.21	−0.05	−0.16	0.07	−0.21	0.35**	0.00	0.14	−0.18	−0.33*	−0.14	−0.20	1.00			
Fair process	−0.35**	−0.41**	−0.38**	0.11	0.00	0.01	−0.07	0.11	−0.17	−0.28*	−0.18	0.11	−0.42**	−0.38**	1.00		
Economic performance	0.25	0.37**	0.15	−0.29*	0.24	−0.15	−0.35**	−0.26	0.13	0.41**	0.54***	−0.07	−0.14	−0.13	−0.40**	1.00	
Equity	−0.17	−0.22	0.02	0.00	−0.33*	−0.09	0.21	0.44***	−0.05	−0.24	−0.26	0.07	−0.18	0.09	−0.13	−0.49***	1

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3.2.2.3 Existence of nuances in support or opposition of CDR and DACCS

Regression results overall revealed a substantial difference in opinions on questions around support of CDR technologies, policies and assessment criteria between different groups of respondents (along the lines of previous referred distinctions, e.g., gender, professional experience), confirming the existence of a variety of opinions. This was also identified in the workshop deliberations.

Moreover, a general divergence of opinions was observed regarding whether DACCS should be a long-term or short-term priority, as was also observed during the workshop.

Examples from responses to open-ended questions that invite respondents to elaborate further on their choices reveal that a number of survey respondents share the impression of urgency to start planning for deployment; however, others highlight the risk of mitigation deterrence seen in this effort:

> *"If we do not start now, high quality DACCS will not be available in time."*
>
> *"To scale-up to the necessary scale will take a long time, hence it needs to start today."*
>
> *"If DACCS is deployed at large scale too quickly it risks diluting emission reductions efforts by diverting energy and materials to a process which is highly inefficient (yet necessary to an extent)."*

3.2.2.4 Hidden deliberative learning experience

While we found some evidence of learning, there is no evidence that opinions between the workshop participants and non-participants diverge also in terms of the specific contexts in which DACCS should be used or on their opinion regarding the role of policies and assessment criteria.

Interestingly, workshop participants self-reported their perception of DACCS before attending the workshop (3.75) to have remained the same as their perception after attending the workshop (3.75) (on a scale from 1–5, with 1 meaning "very negative" and 5 meaning "very positive") (Table C.5). Although indicating that they did not perceive the workshop to have been a learning experience for them in regard to their general perceptions of DACCS, when invited to elaborate further, the answers indicate otherwise. Numerous participants provided statements signifying a learning experience in line with the interpretative observations, such us:

> *"I had engaging conversations with people who were opposed to DACCS and we found a good middle ground."*
>
> *"It made even more clear that climate policy and DACCS are nuanced subjects that require a lot of care and holistic understanding."*
>
> *"It made me aware of some additional points of discussion surrounding DACCS."*
>
> *"I learned new nuances to anti-DACCS arguments."*

3.2.3 Reflection on stakeholder roles and participation in stakeholder processes

The survey contained a section in which respondents were invited to provide open-ended statements on their role as stakeholders in shaping decisions on CDR methods. The co-authors analyzed and grouped these into thematic categories (see Table C.9). Both workshop participants and non-participants overlap in the following four categories in characterizing their roles as stakeholders in shaping the CDR policy process and the value of their opinions and expertise informing the discussion:

- *Avert negative side-effects from the promotion of CDR.*
- *Ensure sound implementation of CDR.*
- *General information provision.*
- *Affect the conversation about CDR.*

Interestingly the last theme, *Affect the conversation about CDR,* was predominantly mentioned by workshop participants and less so by non-workshop respondents.

Non-workshop respondents further indicated the following themes characterizing their role as stakeholders:

- *Promotion of the technology / CDR method.*
- *Policy design.*
- *Contribute to inclusive decision-making.*
- *Offering specific viewpoints.*

When comparing the thematic scope of responses by participants with those of non-participants, workshop participants do not see themselves as having a role in suggesting specific policy designs, CDR methods or viewpoints. This may be seen in light of the interpretative findings according to which participants achieved consensus during the workshop that they cannot agree on the "right" policies or CDR methods. They also experienced how in open conversations even different viewpoints may develop a shared ground for agreement when given room to elaborate on the possible contexts and conditions for deployment. However, we cannot be sure of a causal relationship. This finding could also indicate, for example, that experts interested in the general picture and in open communication are more likely to participate in such stakeholder engagement processes.

Another interesting result is that the self-reported likelihood to participate in a future DACCS workshop is not significantly higher for workshop participants (Table C.8). This means that participation in a stakeholder engagement workshop is not a determinant for future engagements. Respondents that are male tend to report a higher likelihood to participate in a future workshop, while respondents with more years of relevant professional experience report a lower likelihood to participate. Future stakeholder engagement workshops should take this into consideration to ensure balanced participation in such processes.

4 Limitations

This study comes with certain methodological limitations. One is the small sample size of both workshop and survey participants. Such small sample sizes relativize to a certain extent the results, especially those of the quantitative analysis and the significance found in the correlations including the comparisons between workshop and non-workshop survey participants. The small sample size could result in the failure to find significant relationships in the quantitative analysis, when such relationships exist. It also raises questions if the participant list was inclusive and representative enough to include the broad range of opinions surrounding CDR and DACCS technologies

as well as all relevant backgrounds of participating stakeholder. To mediate this, we sampled stakeholders with views both critical and in support of DACCS and representing different sectors. Moreover, expertise-focused studies in an emerging field can hardly move beyond a small- to medium-sized sample (due to the small number of experts). Also, workshop designs for engagement are usually not tailored to more than a few dozen participants.

Overall, and regardless of the sample size, there is some scope for selection bias in the data collection method. Invited participants were not selected randomly and in any case it may be possible that some could be more likely attend a stakeholder engagement workshop or to respond to a subsequent online survey invitation than others. Despite the employment of purposeful sampling to ensure some comparability between the profiles of workshop and non-workshop participants in the survey, one can observe stark differences between the two groups. To address this limitation, we controlled for respondent background characteristics in the statistical analysis.

However, we cannot exclude the possibility of the potential source of bias in the analysis that is induced by the presence of omitted variables, and the quantitative analysis cannot draw conclusions about causality. On the other hand, the mixed method approach employed allows us to corroborate our results to an extent and to offer possible explanations of the observed correlations also based on the findings of the qualitative analysis. Larger sample sizes and more sophisticated econometric and data collection techniques (e.g., the use of panel data) may be advisable to address these limitations in the future.

Another limitation is that the workshop proceedings were not recorded. Instead we relied on detailed note taking. We therefore do not have access to direct quotes of participants to include in the presentation of the interpretative workshop results. We acknowledge that the use of direct quotes would have benefited the analysis and enriched the presentation of the results. It would also have also been valuable to readers interested in the relevant discourses. The use of direct quotes derived from the open-ended survey responses helps to, at least in part, address this limitation.

5 Discussion

While CDR has become important on the German policy agenda (Geden and Schenuit, 2020), few engagements with stakeholders have happened so far (Boettcher et al., 2023) to address whether or not to deploy CDR methods. Our study is among the first of this kind for and in Germany and reaffirms that transdisciplinary stakeholder engagement matters – for both engaged stakeholders and researchers to gain important policy insights. Stakeholder deliberation processes are important in their own right for addressing wicked problems prone to a high value load, such as the implementation of CDR and DACCS.

The evidence from both participatory observation and the survey suggests that, together with the focus on the policy dimension, the open communicative process in the workshops enables a generation of valuable insights and an evolution of perceptions regarding CDR and DACCS implementation. When compared to dynamics in workshop deliberations, surveys principally do not provoke the same reflection about arguments and self-positioning. Nonetheless, survey results confirmed many of the key findings of the workshop.

The focus of the deliberations on policy measures and on concrete political, social, ethical and technical aspects of a possible future deployment of CDR and DACCS built the basis for mutual understanding, joint sense-making and positioning and allowed for this evolution of perceptions regarding DACCS. With this focus, the workshop shifted the conversations related to CDR from "problem to policy" (Beck, 2011, 304) – thus avoiding unproductive polarization. The approach to express and further elaborate on value preferences in a hypothetical future deployment – reflecting on stakeholders' interventions – encouraged, in our view, stakeholders to articulate what conditions would need to be met in order for them to accept deployment. In joint reasoning stakeholders spelled out two major conditions deemed indispensable to accept CDR deployment: (1) no misuse for mitigation deterrence, (2) clear and quantifiable mitigation commitments and calculations of residual emissions.

In contrast, stakeholders agreed far less on appropriate policy measures and assessment criteria. However, a commonly shared expectation was that no single measure, like VCMs, will suffice and that R&D efforts, supported by policy, must be scaled today. Moreover, numerous survey respondents seemed to prefer regulatory policy instruments. When digging deeper into the criteria, climate effectiveness and feasibility were often preferred in a certain contrast to and even suggesting tradeoffs with fair processes (seen to perform less well *economically*).

Moreover, the evidence suggests that, through the CDR workshop as a communicative process, there was evolution of the perception of the participants' role as stakeholders in shaping decisions on CDR methods. Participants' responses revealed less advocacy for specific solutions and rather highlighted the broader picture and need to communicate openly, including on possible negative consequences as well as the scope for implementation. In a way, deliberation may also contribute to (self-)consciousness and acceptance of diverse views.

The different patterns in the responses regarding the own role in the further development of CDR in Germany aligns well with the idea that deliberation is not only a tool for exploring common argumentative grounds, but also to become conscious of and accept the diversity of views. Participants' responses advocated less for specific solutions but rather highlighted the broader picture and the need to communicate openly, including on possible negative consequences and scope for implementation. An interesting result is the evidence on hidden deliberative learning. Our study revealed that the self-reported indifference in opinion contradicted both the own (qualitative) responses and the observations and documentation of the workshop experience. This highlights that although learning takes place it is a complex process experienced potentially differently by different participants. It also emphasizes the strength of mixed method approaches to capture the nuances of such complex topics.

The study design employing mixed methods in engagement as well as data gathering and analysis was useful for tracing opinions on the highly controversial and complex issue of CDR and the rather intangible phenomenon of deliberative learning. Further, our dual-methodological approach reaffirmed the view that simple one-way consultation approaches (like our survey, or passive online consultations) may in fact be limited tools for exchange of views and deliberative learning. In this respect it may be a misperception to assume that CDR stakeholders simply must be better informed about the different methods, risks and benefits to form an opinion. The stakeholders in our process were highly knowledgeable on the technical aspects of DACCS. They benefited from joint sense-making on the value dimension of CDR, as confirmed by qualitative feedback in the survey.

Although CDR, and especially DACCS, is a highly controversial matter, this does not mean that policy action is unthinkable. In fact, under clearly identifiable conditions there is – already today – room to maneuver. A general willingness to accept early deployment exists when not used for mitigation deterrence. Stakeholders expect a clear definition of and roadmap for residual emissions to be removed in the overall carbon budget. To credibly avert the risk of mitigation deterrence, trustworthy pathways for fossil phaseout and tangible results in emission reductions need to be delivered. In light of the recent dynamics related to the energy crisis and public opinion, higher ambition may be the major hurdle for an active handling of CDR in German climate policies.

In this respect, our research confirms the role of deliberative learning for socially robust policy-making on wicked problems and issues prone to uncertainty and a high value load such as CDR. Engagement processes seem particularly relevant to help carve out concrete conditions under which stakeholders would be willing to accept deployment and to avoid further polarization into simplified yes/no or support/objection positions. Engagement is well placed already in early phases of policy development when stakeholders are still forming their own positions about the novel methods, as is the case of the European CDR policy development (Boettcher et al., 2023). Extending this further, adaptive policy-making is needed to also cater to different positions held regarding scaling today vs. future deployment. Although probably too early to direct political discussions on DACCS (or other methods) toward scaling as a backstop technology, it seems important to plan for the methods to become relevant in the future. Policy can (and in the view of some even should exclusively) already support (applied) R&D, and piloting to ensure resource efficiency (especially of energy, land-use, natural and financial resources) as a precondition for any acceptable backstop technology. This requires focus on potential tradeoffs between climate mitigation efficiency and other desirability assessment criteria of policies (not just methods). Policy measures may be as controversial for stakeholders as methods, or even the only controversial aspect left with "undisputed" CDR methods, like NbS. Policy is well advised to pro-actively open up deliberative spaces to exchange on the types and mixes of policy measures that will have to be in place for scaling. This may determine how quickly they can be implemented when needed without objection.

It remains to be seen how similar or different this process would be for BECCS, which was discussed with even more resolute objection by some stakeholders, or NbS approaches, like agroforestry, where controversies seemed broadly absent, but may still be revealed in terms of modes of implementation and the dealing with concrete risks (like non-permanence). Depending on how deeply rooted controversies are on these matters, stakeholder engagement on other CDR methods could help concretize the common ground for policy action. As with our DACCS workshop, it seems important to shift the focus and attention in engagement from pure problematization of the controversial method to the assumptions and requirements for mitigating risks and promoting desirable future outcomes of the methods. Moreover, similar research can shed light if our findings resonate beyond Germany and the European context that was the focus of this study.

Future engagements with stakeholders can shed light on stakeholder views on questions around CDR and DACCS in different contexts (both geographically and for different CDR technologies). The findings on policy instruments and criteria also call for further research to understand in more detail the dynamics between these different opinions and their implications for policy. More research will also be required in the future to understand complex learning processes and to identify how learning is generated and experienced by different participants and (or vs. publics).

In this respect, this study provides a compelling case for the strength of mixed methods approaches. Workshops with a similar structure that are interactive and dialogue-focused and employ a variety of formats (small group deliberations, silent placing of sticky notes, open face-to-face discussions in extended breaks, expert inputs and moderated discussions) will be conducive for an in-depth exchange and learning. While, we have highlighted the benefits of replicating a similar approach, the use of larger sample sizes and more advanced statistical techniques will help address some of the limitations of this study and to confirm causal relationships, especially on evolution of perceptions.

A remaining blind spot of this study is the engagement of broader, non-expert publics who may object to CDR deployment. While the public cannot be engaged in similar ways as in this study, classical approaches to public consultations may be too limited for the needed (deliberative) learning. More research and experimentation are needed around innovative ways of both informing and engaging publics.

Data availability statement

The datasets presented in this article are not readily available because of respondent anonymity considerations. Requests to access the datasets should be directed to apergi@adelphi.de.

Author contributions

MA: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. MHe: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. SE: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. MHo: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. SR: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. DT: Conceptualization, Funding acquisition, Writing – review & editing.

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Conflict of interest

MA, MHe, DT were employed by Adelphi Research GmbH. MHo was employed by Perspectives Climate Research gGmbH.

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

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fclim.2024.1465613/full#supplementary-material

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