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LETTER

Learning increases both acceptability and scrutiny of carbon dioxide removal methods: quasi-experimental evidence

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Abstract

Carbon dioxide removal (CDR) technologies are increasingly recognized as necessary complements to decarbonization efforts; however, public acceptance remains a critical implementation challenge. This study investigates the impact of educational exposure on perceptions of CDR methods among individuals with a pre-existing interest in climate solutions. We conducted a quasi-experimental study with pre- and post-surveys of participants ($n = 366$ pre-survey, $n = 83$ post-survey, $n = 29$ matched pairs) enrolled in a six-week online CDR curriculum. Baseline comparisons with previous studies confirmed that participants were more knowledgeable about CDR and held more positive environmental attitudes than nationally representative population samples. Following the educational intervention, participants demonstrated significant increases in self-reported CDR knowledge and more favourable risk-benefit assessments across all CDR technologies, with the largest gains for enhanced weathering and biochar. Qualitative analysis revealed that, rather than simple endorsement, education fostered more nuanced evaluation capabilities, with participants developing greater appreciation for both benefits and method-specific limitations. Notably, participants shifted away from technology-specific preferences and towards more portfolio-based thinking, recognizing the complementary roles of different CDR approaches. These findings suggest that informed engagement with CDR technologies produces sophisticated rather than uncritical assessment frameworks, with implications for how CDR communication and engagement strategies might be designed to support constructive public dialogue about these emerging technologies.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) emphasizes the need to develop carbon dioxide removal (CDR) capacity in conjunction with global decarbonization efforts (Babiker *et al* 2022). CDR encompasses various methods at varying levels of technology readiness, ranging from established practices, such as afforestation, to novel, engineered approaches, such as direct air capture (Minx *et al* 2018, Smith *et al* 2024). Besides the technical, environmental, and economic challenges associated with these methods (Cobo *et al* 2023), social scientists underscore the importance of societal acceptance and legitimacy (Cox *et al* 2020), particularly in establishing a social license to operate (SLO). For the establishment of an SLO for CDR, scholars stress the importance of investigating attitudes and perceptions towards CDR methods, which can have a crucial influence on CDR development and deployment more broadly (Cox *et al* 2024).

Public perceptions of CDR are shaped by a range of factors, including environmental values, perceived naturalness, moral hazard concerns, affective responses, and trust in institutions (Huijts *et al* 2012, Pidgeon and Spence 2017, Bertram and Merk 2020).

Some studies suggest that exposure to CDR information can weaken support for climate change mitigation (Campbell-Arvai *et al* 2017), while others find it may heighten risk perception and strengthen concern about climate change (Merk *et al* 2016, Hart *et al* 2022). These mixed findings suggest that the relationship between knowledge and public acceptance of CDR is highly context-dependent. While general climate literacy often correlates with stronger support for mitigation (Rosenthal *et al* 2023), the impact of CDR-specific knowledge is less consistent. Increased familiarity may lead to greater acceptance or, conversely, to heightened scepticism, depending on factors such as individuals' prior attitudes, political worldviews, and the way information is framed, especially regarding its naturality (Kahan *et al* 2015, Wolske *et al* 2019, Kerner *et al* 2023, Sloot and Bostrom 2024).

The objective of this study is to examine the dynamic between perceptions and levels of knowledge more closely. This dynamic will become increasingly important as publics engage with CDR deployment.

Building on a global CDR educational program, we have developed a unique dataset that reflects pre- and post-intervention perspectives. The participants self-selected into an educational curriculum hosted by AirMiners (AirMiners, 2025), an online community of people interested in CDR. In this program, participants engage in book-club style discussion groups that facilitate self-paced learning over a six-week period. During these six weeks, participants cover topics including the general role of CDR in climate change mitigation, the voluntary carbon market, measurement/ reporting/ verification (MRV), and nature-based and engineered CDR methods (a complete outline of the course and its modules can be found in the *appendix)*. Besides education, frequently cited motivations for participating in the course include networking, career transitions, and personal environmental impact.

This setting's generalisability is limited since we expect this self-selected sample to be both more knowledgeable and hold more positive attitudes regarding CDR. Nevertheless, this setting presents a unique opportunity to explore how perceptions change with greater exposure to CDR.

2. Method

2.1. Sample and survey items

A total of 366 individuals participated in a pre-survey, henceforth referred to as the *full pre-group*. The sample consisted of 50.8% females, 47.8% males, and 1.4% other, with a mean age of 35.1 years (range: 19–74). Participants were highly educated, with 76.7% holding at least a bachelor's degree. Respondents were predominantly based in the United States (44.6%), with additional representation from the United Kingdom (10.3%), Canada (6.8%), India (6.2%), Germany (3.5%), and a diverse set of 35 other countries (complete demographics in the *appendix)*.

The participants were asked to complete the study's pre-survey (see table 1, which lists all items in the *appendix*) during their onboarding process before the curriculum hosted by AirMiners. Eighty-three participants from the same sample completed the post-survey after finishing the course (referred to as the full *post-group*). The post-survey contained the same items, except for those that alluded to personal values, demographics, and environmental attitudes, which were intended to be matched using each participant's unique identifier. The post-survey also includes a specific question after the risk-benefit rating of the CDR methods, allowing participants to share what changed in their perception. An external link to this study's survey was provided, and participants were asked to complete it upon signing up for the educational program. Data gathering began in June 2024 and concluded in January 2025. Besides age, gender, and education level, no personal questions were asked, making the survey anonymous for participants.

To understand if this survey's participants are in fact more knowledgeable and positive about CDR, we compared them (pre-group) to different CDR perception studies where applicable, namely Campbell-Arvai *et al* (2017), Merk and Pönitzsch (2017), Wolske *et al* (2019), Cox *et al* (2020), and Baum *et al* (2024). We tested the same measures as these studies to examine significant differences between our sample and these representative studies (as complete data were available). The results can be found in figure 1 and group difference tests and the full table of variables can be found in the *appendix*.

The study participants overall demonstrated distinct environmental attitudes compared to those in representative studies. Political orientation skewed more left-leaning with reduced variability ($M = 3.27$, SD $= 1.18$) relative to Campbell-Arvai *et al* (2017) ($M = 3.94$, SD $= 1.59$) and climate mitigation support exceeded US/UK sample levels ($M = 5.88 \pm 1.31$ vs $M = 5.44 \pm 1.18$). Climate concern was exceptionally high, with strong agreement on climate change severity ($M = 6.60$) and personal worry ($M = 6.03$), although perceived personal impact was moderately lower ($M = 5.49$). Environmental scepticism remained minimal, as evidenced by a firm rejection of statements that claim an exaggeration of the ecological crisis ($M = 1.99$).

Technological attitudes revealed moderate scepticism toward nature-dominance paradigms. Participants showed moderate agreement that technological environmental solutions underestimate risks ($M = 3.95$) and expressed preference for minimal human-nature interference ($M = 4.30$), closely aligning with representative survey values ($M = 4.48$) from Merk & Pönitzsch (2017) and Wolske *et al* (2019). Anthropocentric viewpoints received low

Table 1. Constructs tested in the survey administered to the sample. Full list of measures in the appendix.

Dimension	Questions	Sources
Demographics	Age, gender, country of residence, education	—
Political orientation, values	Left vs right, Schwartz values	*Adapted from* Campbell-Arvai *et al* (2017), Jobin and Siegrist (2020)
Environmental attitudes	Naturality, human interventions in nature	*Adapted from* Wolske *et al* (2019), Merk and Pönitzsch (2017)
Climate change threat	Personal worry and affectedness, problem perception	*Adapted from* Cox *et al* (2020)
Climate change mitigation support	Support for international treaties, taxes, targets	*Adapted from* Campbell-Arvai *et al* (2017)
Trust in institutions	Science, government, companies	*Adapted from* Merk and Pönitzsch (2017)
CDR familiarity	Knowledge about CDR	*Adapted from* Baum *et al* (2024)
CDR attitudes	General CDR affect, fairness, moral hazard	*Adapted from* Cox *et al* (2020), Jobin and Siegrist (2020), Baum *et al* (2024)
CDR-method perceptions & acceptability	Risk/benefit perception, acceptability, and naturality assessment	*Own*
CDR framing	What opportunity does CDR present?	*Own—see appendix for details*

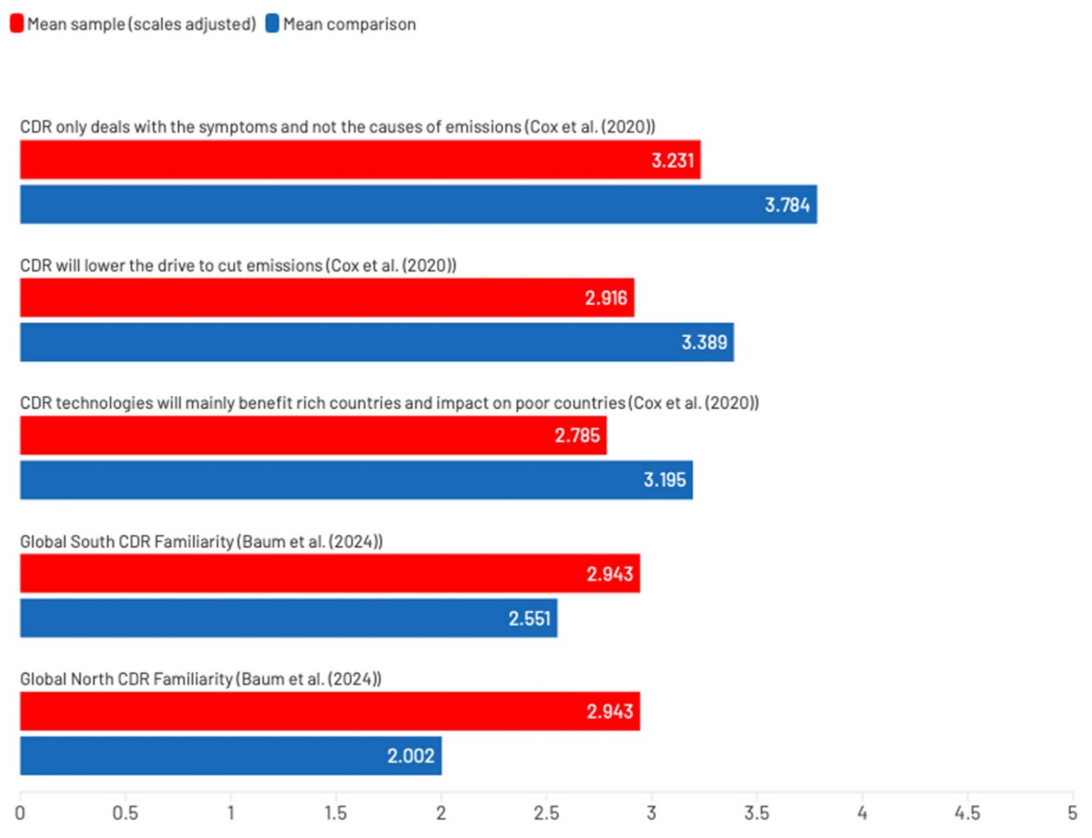

Figure 1. Ratings of this sample (pre-group N = 366, in red) regarding knowledge and CDR attitudes differ significantly from studies conducted by Cox *et al* (2020) and Baum *et al* (2024). Participants rate themselves as more familiar and more positive regarding CDR. Used independent samples t-tests (Welch's) and effect sizes calculated using Cohen's d. All scales rescaled to 1–5 for comparability (full information in the appendix).

endorsement, with significantly lower agreement that humans should rule nature ($M = 2.14$ vs $M = 2.92$) and similar scepticism regarding human capacity to control nature through scientific understanding ($M = 2.89$ vs $M = 2.92$). These patterns indicate a more biocentric and environmentally cautious orientation compared to broader population samples, suggesting participants represent an environmentally engaged demographic with nuanced perspectives on technological climate interventions.

The sample also exhibited significantly more positive attitudes toward CDR, showing less concern about moral hazard effects (2.92 ± 1.14 vs 3.39 ± 0.87, $p < 0.001$, $d = -0.52$), criticism on CDR being merely about treating symptoms instead of underlying problems (3.23 ± 1.13 vs 3.78 ± 0.91, $p < 0.001$, $d = -0.58$), and equity issues (2.79 ± 1.03 vs 3.20 ± 0.90, $p < 0.001$, $d = -0.45$) compared to US/UK populations (Cox *et al* 2020). Notably, CDR technology familiarity was substantially higher than both Global North (3.92 ± 1.42 vs 1.86 ± 0.57, $d = 1.72$) and Global South samples (vs 2.42 ± 0.63, $d = 1.17$) (Baum *et al* 2024).

2.2. Analysis

We employed a quasi-experimental design with pre- and post-surveys to examine the change in perceptions that participants experience as they progress through the curriculum. The pre-survey included 366 participants, and 83 participants completed the post-surveys.

First, we examined the acceptability of specific CDR methods for the pre-group, as their level of familiarity differs significantly from that in other CDR perception studies. Here, we performed multiple regressions to examine the predictive power of familiarity, naturalness perceptions, and other variables related to the CDR method-specific acceptability.

Second, we examined the effect of the educational intervention. Here, due to participant identifier limitations, only 29 participants could be matched between surveys, creating another group: the *matched pre- and post-group*. To address potential selection bias in the matched subsample, we conducted comparative analyses between matched participants ($n = 29$) and the broader pre-survey sample ($n = 366$) across all measured variables. Independent samples t-tests revealed significant differences on only two environmental attitude variables: 'The so-called 'ecological crisis' facing humankind has been greatly exaggerated' ($p = 0.004$, Cohen's $d = 0.35$) and 'There may be negative impacts of CDR on the environment' ($p = 0.025$, Cohen's $d = -0.38$). Given the small effect sizes ($d < 0.4$) and the limited number of significant differences, we considered the matched subsample sufficiently representative of the broader population for further analysis.

Pre-post changes were analysed using paired t-tests for the *matched pre- and post-groups* ($n = 29$) across knowledge, acceptability, and risk-benefit assessment. Effect sizes were calculated using Cohen's d to assess both practical and statistical significance. We employed the same analysis for the full *pre- and post-groups* to validate perception changes.

To contextualize quantitative changes, participants provided open-ended responses to the question 'Please comment on your risk/benefit ratings. What changed?'. Post-survey responses were analysed using inductive thematic analysis following established protocols. Initial codes were developed through line-by-line coding, then organised into overarching themes through iterative refinement.

3. Results

3.1. General acceptability levels for CDR methods

Acceptability ratings varied substantially across CDR methods, revealing a hierarchy of public preferences. Nature-based solutions received the highest acceptability ratings, with afforestation ($M = 5.54$, $SD = 1.41$) and soil carbon sequestration ($M = 5.50$, $SD = 1.36$) scoring above the midpoint of the seven-point scale. Engineered solutions demonstrated moderate acceptability levels: biochar and bio-oil production ($M = 5.19$, $SD = 1.35$), bioenergy with carbon capture and storage (BECCS) ($M = 5.02$, $SD = 1.34$). Enhanced weathering received somewhat lower acceptability ($M = 4.91$, $SD = 1.38$), while ocean-based CDR methods showed the lowest acceptability ratings: ocean alkalinity enhancement ($M = 4.66$, $SD = 1.42$) and other ocean CDR approaches ($M = 4.75$, $SD = 1.39$). The most important predictive variables for the multiple regressions are shown in figure 2 (a full table can be found in the *appendix)*.

Method-specific risk/benefit assessments emerged as the strongest predictor category for CDR acceptability. The correlations between risk/benefit perceptions and acceptability for corresponding methods were substantial: enhanced weathering risk/benefit perceptions correlated most strongly with enhanced weathering acceptability ($r = 0.598$, $R^2 = 0.358$, $p < 0.001$), followed by DACCS risk/benefit perceptions with DACCS acceptability ($r = 0.571$, $R^2 = 0.326$, $p < 0.001$), and biochar risk/benefit perceptions with biochar acceptability ($r = 0.542$, $R^2 = 0.294$, $p < 0.001$). Notably, cross-method relationships were also significant but demonstrated weaker correlations, suggesting that while risk/benefit perceptions show some generalization across CDR technologies, method-specific assessments remain the strongest predictors of acceptability.

General CDR knowledge constituted the second strongest predictor category. Basic CDR knowledge ('Know CDR Basics') showed consistently strong relationships across all CDR methods, with correlations

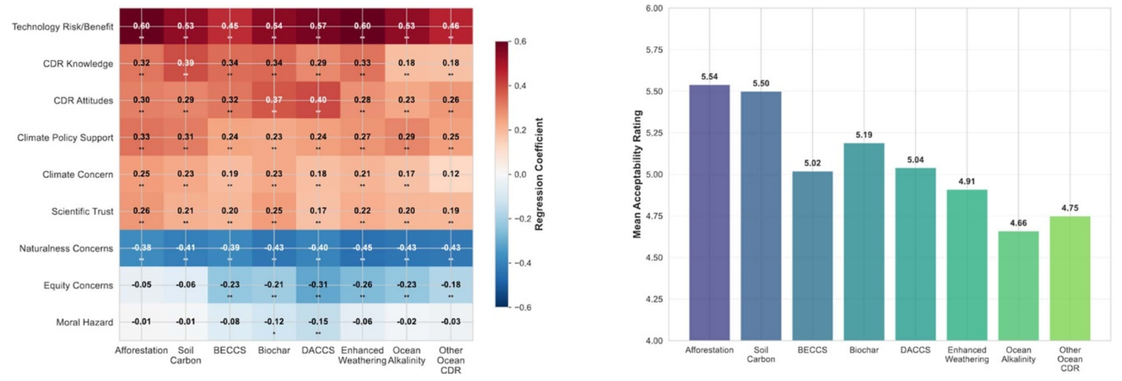

Figure 2. Participants prefer more natural CDR methods (right, measure: using [method] to combat climate change is acceptable (1: strongly disagree, 7: strongly agree). Perceived naturalness of the method, CDR attitudes, as well as method specific risk/benefit ratings have a strong impact on the method's acceptability (left). *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. Full regression table in the appendix.

ranging from $r = 0.178$ to $r = 0.392$ (all $p < 0.001$). The strongest knowledge-acceptability relationship was observed for soil carbon sequestration ($r = 0.392$, $R^2 = 0.154$), suggesting that basic CDR understanding supports acceptance of established nature-based approaches. Similarly, general *positive attitudes* toward CDR ('Positive About CDR') demonstrated robust correlations with all methods ($r = 0.230$–0.397, all $p < 0.001$), with the strongest association found for DACCS acceptability ($r = 0.397$, $R^2 = 0.158$).

Naturalness perceptions demonstrated significant negative associations with CDR acceptability across most options. Perceptions of unnaturalness showed the strongest negative correlations with acceptability for corresponding CDR technologies: enhanced weathering unnaturalness perceptions correlated negatively with enhanced weathering acceptability ($r = -0.446$, $R^2 = 0.199$, $p < 0.001$), and biochar unnaturalness perceptions showed similar negative associations with biochar acceptability ($r = -0.434$, $R^2 = 0.188$, $p < 0.001$). These findings confirm the importance of naturalness framings in shaping public acceptance of CDR technologies.

Concerns about CDR implementation revealed mixed patterns across methods. The concern that 'CDR mainly benefits rich countries' showed significant negative correlations with most engineered CDR methods ($r = -0.178$ to -0.310, all $p < 0.001$), with the strongest negative relationship observed for DACCS acceptability ($r = -0.310$, $R^2 = 0.096$, $p < 0.001$). Other specific concerns about CDR showed weaker or inconsistent relationships with acceptability measures, suggesting that equity concerns may be more salient than technical or environmental concerns for this sample.

Demographic variables demonstrated mixed and generally weaker predictive power compared to attitude and knowledge measures. Geographic location showed strong but inconsistent effect sizes across methods (Cohen's $d = 0.67$–0.95 for significant relationships), suggesting regional variation in CDR preferences that warrants further investigation. Gender effects were moderate for nature-based and some engineered solutions (Cohen's $d = 0.18$–0.44). In contrast, age showed minimal relationships with CDR acceptability, yielding only one significant correlation across all methods (biochar: $r = 0.124$, $p < 0.05$).

3.2. Quantitative changes in CDR knowledge, acceptability, and risk-benefit perceptions

Based on 29 participants who completed both surveys and were representative of the full baseline sample, the intervention produced significant changes in CDR perception as measured by their mean rating of the survey items.

The educational intervention produced statistically significant increases across knowledge, acceptability, and risk-benefit dimensions (figure 3). Knowledge gains were substantial, with familiarity scores increasing from 3.5 to 6.1 ($p < 0.001$), confidence in basic CDR understanding rising from 3.8 to 6.5 ($p < 0.001$), and advanced knowledge confidence improving from 2.6 to 5.4 ($p < 0.001$).

Risk-benefit assessments shifted positively for all CDR technologies examined. The largest improvements were observed for enhanced weathering ($5.97 \rightarrow 7.55$, $p = 0.009$) and biochar & Bio-Oil ($6.30 \rightarrow 7.83$, $p = 0.001$). Engineered solutions showed notable improvements: DACCS ($6.00 \rightarrow 7.45$, $p = 0.011$) and BECCS ($5.63 \rightarrow 7.10$, $p = 0.004$). Ocean Alkalinity Enhancement, despite remaining the lowest-rated technology, increased from 5.03 to 6.24 ($p = 0.041$).

Acceptability ratings similarly increased across technologies, with biochar & bio-oil showing the most substantial improvement ($4.77 \rightarrow 5.90$, $p = 0.001$), followed by enhanced weathering ($4.73 \rightarrow 5.59$, $p = 0.024$) and DACCS ($4.97 \rightarrow 5.83$,

Figure 3. Participants of the matched pre- and post-group ($n = 29$) rate themselves significantly more knowledgeable and perceive a selection of CDR methods as more beneficial and more acceptable (only significant changes depicted). Certain opportunities are more strongly attributed to CDR. This selection presents only $p < 0.05$ changes in participants' ratings. No significant changes were detected for perceived threats of climate change, climate change mitigation support, and general CDR attitudes (negative and positive). Full range of variables in the appendix.

$p = 0.022$). Participants also reported stronger agreement with CDR's role in climate mitigation and ecological restoration.

Notably, we did not detect significant changes in *matched pre- and post-groups* across different categories: perceived threats of climate change, climate change mitigation support, and general CDR attitudes (both negative and positive).

The significant changes reported above are corroborated by a cross-sectional comparison between the *full pre-study and post-study samples*, which showed similar patterns. In all measures where we detected a significant change in the ratings in the matched group, we found a significant change in the overall pre- and post-groups in the same direction.

In the *full pre- and post-groups*, we found significant changes in additional categories: increased support for climate change mitigation, increased worry about climate change, and increased scrutiny of CDR methods (unintended consequences, negative environmental impact). The full table of changes can be viewed in the *appendix*, but should be regarded with caution due to the difficulty in matching pre- and post-intervention answers.

3.3. Qualitative context for perceptual changes

Following the educational intervention, participants demonstrated substantial shifts in their risk-benefit assessments of CDR technologies, as revealed through thematic analysis of the responses to the post-survey ($n = 83$). Rather than simple directional changes in support, the intervention fostered more nuanced views.

The most pronounced change was *enhanced understanding*, reported by 41% of participants. Many explicitly contrasted their pre-intervention knowledge gaps ('Previously, I had no knowledge, so everything changed') with post-intervention confidence in their assessments ('my ratings are MUCH more informed'). This knowledge enhancement was accompanied by increased risk awareness (30% of responses), with participants developing a more nuanced understanding of technology-specific limitations, including permanence challenges, monitoring difficulties, and ecosystem uncertainties.

Ocean-based CDR methods emerged as the primary focus of open-ended responses to *changing perceptions*, mentioned in 30% of responses. Participants consistently expressed heightened concern about scientific uncertainties and potential ecosystem impacts, noting that ocean CDR 'seems relatively unproven' and expressing concern about 'what we do not know' regarding large-scale marine interventions. This increased caution was coupled with recognition of ocean CDR's scalability potential, reflecting participants' growing appreciation of the tension between scale requirements and risk management.

Engineered solutions such as direct air capture received more favourable post-intervention assessments, with participants appreciating permanence characteristics despite cost considerations. Nature-based solutions (afforestation, soil carbon) were increasingly viewed through a dual lens recognizing both co-benefits and permanence limitations, with several participants specifically noting concerns about 'short storage timescale' and 'MRV difficulty.'

The intervention encouraged a shift from technology-specific preferences toward portfolio-based thinking. Participants increasingly recognized that 'a good mix of solutions will be most beneficial' and that risks are 'more about how each method is used/deployed rather than something inherent to the method itself.' This shift reflects growing appreciation for the scale of required CDR deployment and the complementary roles of different technologies. Though these results should be interpreted cautiously, we observe a transition towards a more nuanced view of CDR methods across the board.

4. Discussion

Our findings both confirm and extend existing literature on CDR attitudes, which are typically structured by environmental values, risk perceptions, and perceived naturalness of technologies. This existing literature mostly relies on representative studies. We do not claim that our results can be generalized to these general populations. Rather, they should be seen as indicative.

Baseline ratings across different methods follow expected patterns, with nature-based approaches receiving higher acceptability than technological or open-system solutions, consistent with established 'naturalness bias' research (Wolske *et al* 2019, Cox *et al* 2020).

The finding that CDR knowledge and positive attitudes constitute one of the strongest predictor categories indicates substantial potential for educational interventions to influence acceptance patterns. At the same time, it is important to recognize that this potential is demonstrated within a self-selected sample of participants who were motivated to engage with CDR. While this limits the generalizability of our findings, it also offers a distinctive angle: even among individuals predisposed to engage positively, views evolved in more differentiated ways as knowledge increased. Our sample of motivated individuals could be a proxy for stakeholders that are most likely to participate in public debates or decision-making.

Our results also illustrate how education reshapes initial patterns of evaluation, with enhanced rock weathering providing a particularly instructive case. Despite its character as a strong intervention in natural systems, enhanced rock weathering (ERW) showed the greatest improvement in risk–benefit assessment (5.97 $\rightarrow$ 7.55). Several dynamics may account for this shift. One possibility is that participants learned to interpret ERW as 'enhancing natural systems' rather than replacing them, consistent with Corner and Pidgeon's (2015) finding that natural framings can reduce psychological distance and perceived risk. Another is that the observed change reflects less about intrinsic features of ERW itself and more about the challenges of grasping the concept initially. For participants with limited prior knowledge, ERW may have been especially difficult to understand, and the marked improvement may therefore reflect a transition from little or no comprehension to a more informed grasp of the technology.

This is supported by the dramatic knowledge gains observed (familiarity increasing from 3.5 to 6.1), suggesting a transition from largely uninformed to informed opinions. Initially, many participants lacked sufficient knowledge to hold meaningful preferences. This aligns with Jobin and Siegrist's (Jobin and Siegrist 2020) finding that familiarity reduces perceived risk. Our results show a more complex dynamic. Education simultaneously increased both support and critical scrutiny, with participants developing more differentiated views rather than simply more favourable ones.

This pattern suggests that initial low acceptability may reflect uncertainty rather than informed opposition, such as in the case of ERW. As participants gained knowledge, they became capable of nuanced assessments that recognized both benefits and method-specific limitations. The concurrent rise in risk awareness indicates growing epistemic confidence. Well-informed individuals engage more constructively with technological complexity rather than defaulting to simple rejection or acceptance (Siegrist and Cvetkovich 2000).

4.1. Implications

Our findings suggest that informed stakeholders can serve as early sense-makers in contested technological domains, developing sophisticated assessment capabilities that transcend simple support or opposition (Scheer and Renn 2014, Bellamy and Lezaun 2017). The co-evolution of increased support alongside growing risk awareness indicates that deeper engagement produces more nuanced evaluation frameworks rather than uncritical endorsement.

Critically, participants' qualitative responses emphasized that acceptance depends on governance and deployment processes rather than the technologies themselves. Many noted that risks are 'more about how each method is used/deployed rather than something inherent to the method itself.' This suggests that resistance to CDR may stem less from technological concerns than from governance, fairness, and accountability dimensions (Sovacool *et al* 2023, Low *et al* 2024, Dörpmund *et al* 2025).

These insights have important implications for CDR communication strategies. Rather than focusing solely on technological benefits or seeking to persuade through information provision, effective engagement should enable critical reflection and negotiation of trade-offs. The transition toward portfolio-based thinking observed here suggests that informed stakeholders can move beyond technology-specific preferences to appreciate complementary roles of different approaches within integrated CDR strategies.

4.2. Limitations and future work

This study has several limitations. First, the sample ($n = 366$) consisted of self-selected individuals enrolled in an online CDR curriculum, many of whom likely held pre-existing interest in climate solutions. This introduces selection bias and may overrepresent favourable views on CDR. The subset used for longitudinal analysis was small ($n = 29$), limiting generalizability and statistical inference. Second, while the survey provided rich insights into perceptions and value orientations, its scope was constrained and did not systematically address governance, policy, or site-specific implementation contexts, factors known to shape CDR acceptance (Bellamy *et al* 2019, Wolske *et al* 2019). Third, knowledge was self-assessed rather than objectively tested, which may introduce bias, especially among less-informed respondents (Kruger and Dunning 2000). Finally, while the data highlight possible shifts in perception, the study design was exploratory and limited in terms of generalisability. Future research would benefit from representative sampling, controlled longitudinal designs, and integration of method-specific framings to more robustly link perception change with educational interventions (Campbell-Arvai *et al* 2017).

5. Conclusion

This study provides insights into how educational exposure affects perceptions of CDR technologies among individuals with existing environmental engagement. Our findings reveal that education produces more nuanced views of CDR, rather than simply more favourable views, challenging the assumption that information provision leads to uncritical acceptance or straightforward attitude change.

The dramatic knowledge gains observed (familiarity increasing from 3.5 to 6.1) reflect participants' transition from largely uninformed to informed assessment capabilities, at least in the context of the measures of this study. Importantly, this knowledge enhancement was accompanied by increased critical awareness of technology-specific limitations, suggesting that well-informed individuals develop more differentiated evaluation frameworks rather than defaulting to simple acceptance or rejection.

The concurrent improvements in risk-benefit assessments across all CDR methods, particularly for enhanced weathering and biochar technologies, indicate that initial skepticism may often reflect uncertainty rather than informed opposition. As participants gained technical understanding, they became capable of recognizing both the potential and limitations of different approaches, moving toward portfolio-based thinking that appreciates the complementary roles of diverse CDR strategies.

These findings have several implications for the development and communication of CDR. First, they suggest that resistance to CDR may stem less from technological concerns than from governance, accountability, and procedural justice dimensions. Second, they indicate that effective public engagement should facilitate critical reflection and negotiation of trade-offs rather than focusing solely on persuasion through information provision. Third, they demonstrate that informed stakeholders can develop sophisticated assessment capabilities that transcend polarized support or opposition.

Future research should address the limitations outlined above by employing representative sampling, controlled longitudinal designs, and objective knowledge assessments. Additionally, investigating how the changed perceptions of informed individuals translate into broader social influence patterns would strengthen the understanding of how educational interventions might contribute to constructive public dialogue about emerging climate technologies. Such research is crucial as CDR technologies move from laboratory scale toward potential large-scale deployment, requiring sustained public engagement and social legitimacy to succeed.

Data availability statement

The data cannot be made publicly available upon publication because they contain sensitive personal information. The data that support the findings of this study are available upon reasonable request from the authors.

Acknowledgment

We want to express our gratitude to AirMiners, its representatives, and community members for their openness to facilitate this study.

Ethical statement

The data for this study were collected with a non-academic partner (AirMiners) as part of their educational offering. In this setting, we collected implied consent. In the introduction to our survey, participants were informed about the intended usage of their anonymised data and how their participation in the survey implied consent to this use. Furthermore, participants were provided with contact details for any questions or requests, as well as an external link that led them to a document with more information on the study's scope and data usage.

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