Exploring Public Acceptance of Direct Air Capture with Carbon Storage: Analyzing the Role of Knowledge and Risk Perception

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Abstract

Negative emission technologies, such as Direct Air Capture with Carbon Storage (DACCS), are crucial for meeting climate goals. Despite its potential to remove large quantities of CO_2, public acceptance of DACCS is relatively low and understudied. This study examines how knowledge and risk perception affect public acceptance toward DACCS. It was hypothesized that people who learn more on the technology would perceive more risks (due to hint of risk bias), which in turn would decrease public acceptance. Participants recruited through convenience sampling were randomly assigned into two conditions, either reading basic information, or reading additionally about pros and cons. Contrary to expectations, risk perception and public acceptance did not differ significantly between conditions. However, a strong negative correlation was found between risk perception and public acceptance, emphasizing that perceived risks play a critical role in shaping public acceptance. These findings challenge the assumption that providing more information has an effect on acceptance. Instead, initial emotional reactions and risk perception are pivotal in forming opinions about DACCS. This study contributes to the discourse on geoengineering acceptance, suggesting that addressing public concerns and a positive framing are essential for the successful deployment of DACCS in combating climate change.

Keywords: Climate change, decarbonization, Direct Air Capture with Carbon Storage (DACCS), negative emission technologies (NETs), geoengineering, public acceptance, risk perception, knowledge, hint of risk bias

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Navigating the Climate Crisis: The Urgent Call for Decarbonization and Innovative Solutions

Climate change represents one of the most critical challenges confronting society today, largely due to its extensive and global impact (Erans et al., 2022). Since the industrial revolution, greenhouse gas emissions, primarily carbon dioxide (CO_2) emissions, have been steadily increasing, leading to global warming (Friedlingstein et al., 2022; IPCC, 2022). Human actions are the primary drivers of increase in recorded global temperatures, exceeding the impact of natural influences alone. Without immediate decarbonization of the global economy, which involves cutting greenhouse gas emissions by half within the next decade, it is projected that the global average temperature will rise by at least 2°C by 2050 compared to the average between 1850 and 1900. This temperature increase is predicted to bring about unforeseeable changes. Consequences including more frequent intense rainfalls, prolonged periods of drought, and extreme heatwaves. Such trends lead to widespread flooding and the displacement of millions of people globally, especially in regions of the Global South, due to projected sea level rise (Kopp et al., 2017). The present thus marks a period of acute climate urgency, where current policies are inadequate in reducing greenhouse emissions to meet net-zero targets in the near future (IPCC, 2022).

In response, the IPCC report emphasizes the need for CO_2 reduction (e.g. by switching to renewables) but also highlights the critical role of removing the remaining CO_2 from the air through negative emission technologies (NETs) (IPCC, 2022). NETs, or greenhouse gas removal techniques, involve extracting CO_2 and other greenhouse gases from the atmosphere to complement existing mitigation strategies (Cobo et al., 2023; Fankhauser et al., 2022). An example is Direct Air Capture with Carbon Storage (DACCS), which purifies the air by removing CO_2 and then releasing the CO_2-free air back into the environment, while the extracted CO_2 is stored underground in a liquefied form (Satterfield et al., 2023). DACCS is generally considered as a promising and efficient technology by experts, as it requires minimal land use and can operate on non-arable lands. The prospect of permanently storing liquefied CO_2 suggests a long-term solution to atmospheric CO_2 reduction. Despite its potential, DACCS faces challenges including risks of CO_2 leakage and high energy demands; it must operate on renewable energy to truly function as a negative emission technology (Satterfield et al., 2023). Moreover, the cost of DACCS remain higher than for most other NETS such as afforestation, creating a hurdle to its widespread adoption (Gambhir & Tavoni, 2019; Fuss et al., 2018; IPCC, 2022).

Exploring Public Acceptance of DACCS

To successfully integrate and implement new technologies in the society, public acceptance is crucial (Huijts et al., 2012). Demonstrations of public opposition to technology implementations, such as against carbon capture and storage (CCS), highlight the crucial role of social acceptance, as the lack of public support presents significant risks to the deployment (Arning et al., 2020).

The public is largely unfamiliar with DACCS, resulting in a lack of clear opinions about the technology. This pattern is also seen with other geoengineering concepts like solar radiation management and carbon dioxide removal, where public knowledge and perceptions are similarly limited (Cox et al., 2020; Raimi, 2021). When introduced to DACCS, few people view it as compatible with a sustainable future. Low acceptance of DACCS is mainly thought to be due to high costs, high energy demands, high level of interreference with nature, and high risk perception. Additionally, moral considerations include concerns about burdening future generations with waste, hindering the energy transition, and maintaining dependence on fossil fuels if DACCS does not employ renewable energy resources (Cox et al., 2020; Raimi, 2021; Satterfield et al., 2023). Positive reactions to DACCS are often attributed to its capacity to quickly absorb and store large amounts of CO_2 permanently. Furthermore, the implementation of DACCS could foster job creation, providing new employment opportunities for individuals formerly working in the oil and gas industries, which in turn supports the broader goal of energy transition (Satterfield et al., 2023).

Public opinions towards the implementation of DACCS tend to be neutral or negative, though there is noticeably higher support for conducting laboratory research on it rather than its full-scale deployment (Raimi, 2021). However, due to the current climate urgency, full-scale implementation of DACCS is needed. Therefore, understanding the factors that increase public acceptance is crucial.

The Impact of Knowledge on Technology Acceptance

Technology acceptance research has shown that knowledge positively correlates with acceptance (Huijts et al., 2012). The knowledge deficit model states that greater awareness increases the likelihood of accepting a controversial technology (Parkins et al., 2018). This model has been supported by studies on various technologies, such as CCS and renewable energies (Duan, 2010; Molin, 2005). A study investigating the public perception of CCS in China, introduced all participants to CCS with a small paragraph, including the workings of the technology, different storage options and potential risks. Results of the regression analysis indicated participants are more likely to accept CCS when they had a better understanding of the workings of the CCS, its advantages and drawbacks (Duan, 2010). Similarly, a study on hydrogen acceptance, analyzing survey data, found people are more likely to accept hydrogen when they know more about how it works, its emissions and applications (Molin, 2005).

Nevertheless, other studies have found that more detailed knowledge can sometimes decrease acceptability. For example, the same study on hydrogen acceptance as mentioned above, found that providing clear information about how the technology works can improve its acceptability, whereas details about its risks and benefits tend to reduce acceptance and heighten risk perception (Molin, 2005). Furthermore, a study showed that people who received comprehensive information about the advantages and drawbacks of multiple carbon removal technologies (i.e., bioenergy with carbon capture and storage, DACCS, afforestation, and reforestation) significantly reduced their support in all three technolgoies, compared to those who only received basic factual knowledge (Wolske et al., 2019).

Hint of Risk Bias

The effect of knowledge on technology acceptance may vary depending on the amount of information participants receive. Participants who were more informed about the risks of geoengineering tended to perceive the technology more negatively than those who only knew the basics of what the technology is for and how it works (Sütterlin & Siegrist, 2017). In their study, Sütterlin and Siegrist (2017) included three experimental conditions: a control group that only learned the technology is used to combat climate change, a group that received additional information about the technology, and a third group that also learned about its risks. The control group rated the technology more positively compared to the experimental groups, with the group informed about the risks showing the most negative perception. Similarly other research found that providing participants with detailed pros and cons, compared to just basic information, decreased their acceptance of geoengineering measures (Braun et al. 2017; Wolske et al., 2019).

But why is it that when presenting more information people tend to decrease their acceptance of a technology? Previous research shows that when acceptance decreases with increased information provision, it’s often because researchers provided not only neutral details on how the technology works but also highlighted its risks and benefits (Braun et al. 2017; Wolske et al., 2019). A possible explanation is the phenomenon known as the 'hint of risk' effect. Suggesting that detailed discussions, whether positive or negative, can trigger a bias towards negative perceptions (Gregory & Lichtenstein, 1994; Rozin & Royzman, 2001; Satterfield et al., 2023). This bias towards negativity and increased risk perception likely stems from the adaptive advantages of being on the lookout towards negative events. It is thought to be a predisposition, since it can also be observed in animals and is linked to the greater danger posed by negative events, which can have fatal consequences. Neurological studies also showing that negative events often elicit stronger responses than positive ones of similar intensity (Ito et al., 1998).

Risk perception is vital for assessing public acceptance of DACCS, as resistance often arises from perceived risks (Arning et al., 2020; Dütschke, 2011). Risk perception involves the subjective evaluation of the potential of negative outcomes and significantly influences attitudes toward technology (Leiserowitz, 2006). Theory of Planned Behavior and frameworks concerning the acceptance of sustainable technologies both highlight the pivotal role of individual attitudes in the successful deployment of technology (Huijts et al., 2012).

A comprehensive meta-analysis on the public perception of CCS, incorporating findings from 26 studies, concluded that risk perception is consistently negatively correlated with public acceptance (Seigo et al., 2014). A study on geothermal energy acceptance in Sicily found that perceived risk on water pollution technical uncertainty, and economic feasibility influenced acceptance of geothermal energy negatively (Pellizzone et al. 2015). Similarly, a study examining public perceptions of renewable energy technology in South Korea, found risk perception to be a significant factor negatively affecting acceptability (Park & Ohm; 2014). Moreover, Yagoot et al. (2016) found risk perception, such as concerns about performance, reliability and past project failures, negatively affecting acceptance of renewable energy.

Current Study

Public acceptance of DACCS has received little attention in the literature, largely due to its status as a new technology. Given the potential of DACCS for large-scale CO_2 removal, it is crucial to investigate the factors that influence its acceptance. To bridge the gap in research specifically addressing DACCS, this study applies insights from previous technology acceptance research.

Research on technology acceptance shows mixed results regarding the impact of knowledge on public acceptance. This study seeks to establish a causal link between knowledge and public acceptance, as most existing research relies on correlational data (Huijts et al., 2012). It is hypothesized that people with less knowledge are more likely to accept DACCS than people with more knowledge (H1). This is anticipated due to the 'hint of risk' bias, leading to the second hypothesis (H2), which suggests that increased knowledge elevates risk perception. Building on previous findings, we hypothesize that high risk perception is associated with lower acceptance of DACCS (H3). Integrating these hypotheses, we propose a mediation effect (H4), where risk perception mediates the relationship between knowledge and public acceptance. In other words, it is expected that providing pros and cons may heighten risk perception, which in turn, reduces public acceptance of DACCS.

Overall, the inconsistencies and lack of causational research, underscore the need for investigation. By employing a causal research design, this study aims to address the research gaps and methodological limitations. The findings are expected to inform policy and decision-making processes to tailor strategies that effectively integrate DACCS into broader climate initiatives.

Methods

Procedure

This cross-sectional study was approved by the Ethical Committee of the Faculty of Behavioral and Social Sciences at the University of Groningen (EC-BSS), after which sampling was commenced. The data collection was conducted over the course of 11 days in May 2024. Participants were invited from the researchers' social networks and social media circles to participate in this study. This was done by sharing the link to the online questionnaire administered through Qualtrics survey software. The online survey was available in English, Dutch, and German, and it took around 10- 15 minutes to complete and can be found in appendix A. Participation in the study was completely voluntary for every participant.

Participants

An a priori power analysis, based on the methodology outlined by Fritz and MacKinnon (2007), determined that a sample size of at least 148 was necessary to achieve a power of 80% and a medium effect size of $\alpha = .26$ and $\beta = .26$ for both the first (α path) and second (β path) phases of the mediation design.

In total, 203 participants took part in the study. People withholding their consent or failing the attention or manipulation check were excluded, leaving a sample of a size of 150 participants. The sample consisted of 100 women, 46 men, one preferred not to say and three participants identifying as nonbinary. The age range of participants was between 18 and 87 years old ($M = 31.39$, $SD = 16,13$). Among them, 22 participants were Dutch, 61 were German, and 29 were British. 38 participants identifying as another nationality, for example Bosnian, Spanish, Austrian, and Portuguese.

Material

The questionnaire consisted of eight subsections, starting with a section outlining the purpose of the study, including an explanation that study participation is voluntary, information about data privacy, and contact information of the research team. After the informed consent, we asked participants for their background information, such as age, gender, and nationality.

Participants were randomly assigned to one of two conditions. In the low knowledge condition, participants read a brief introduction of how DACCS works; in the high knowledge condition, participants additionally read a list of pros and cons. The infographics were taken from the study by Lee et al., 2023 (see Appendix A). The survey continued with questions regarding risk perception of DACCS, followed by questions about acceptability of DACCS. The survey also included questions regarding personal values and perceptions, including political orientation, environmental values of their political group, environmental identity, perceptions of climate change, perceived effectiveness and benefit perception of DACCS. Since these variables were out of the scope of this study, they were not included in the following analysis.

At the end, a debriefing was provided, informing the participants that they had been assigned to one of the two knowledge conditions. Participants had to consent again to participate in the research and allow us to process their data. Lastly, contact details of the research team and a text field for general comments were provided, giving the participant the opportunity to contact the research team for any further questions or concerns.

Measures

Attention and manipulation checks

An attention check was included amongst the risk and benefit perception questions. It was designed to assess participants' attention to the content, asking them to: "Please select 'disagree' as your answer" (1 = *strongly disagree,* 6 = *strongly agree*). 28 participants selected an answer other than 'disagree', and therefore were excluded from data analysis.

Additionally, a manipulation check was included. The item prompted participants to recall previously introduced information on DACCS: "Without going back to check, please answer the following question: What have you read about in previous descriptions? (selecting multiple answers is possible)". Options included "How DACCS works", "Pros of DACCS", and "Cons of DACCS". People in low knowledge condition should only select the option "How DACCS works" and people in the high knowledge condition should select all three answer options ("How DACCS works", "Pros of DACCS", and "Cons of DACCS") In total 25 people failed to select the correct options regarding their knowledge condition[1].

Furthermore, a timer tracked how long participants spent reading the provided information to evaluate the manipulation's effectiveness. After excluding those who failed the manipulation and attention checks, the average reading time (in seconds) differed between the knowledge conditions ($M_{low\ knowledge}$ = 33.18, $SD_{low\ knowledge}$ = 72.17; $M_{high\ knowledge}$ = 54.01, $SD_{high\ knowledge}$ = 45.00). This difference was statistically significant (t (148) = -2.13, p = .04).

Independent and Dependent Variables

Risk perception was measured by using six modified questions out of the questionnaire by Arning et al., 2020. Participants were asked to indicate their level of agreement on statements like "I think CO_2 pumping during the process of DACCS is risky" or "I am concerned that a certain amount of CO_2 may come back to the atmosphere even if it is stored on a deep seabed." on a 6-point Likert scale ranging from strongly disagree (1) to strongly agree (6) (Cronbach's α = .72, M = 3.61, SD = 0.69).

[1] only counting participants who have passed the attention check mentioned prior

Participants rated their acceptance regarding the use and implementation of DACCS on a four-item scale (Cronbach's $\alpha = .93$). For instance, they responded to the statement, "I find the use of DACCS technology acceptable," using a 6-point Likert scale ranging from strongly disagree (1) to strongly agree (6) ($M = 4.27$, $SD = 0.85$).

Data Analysis

Assumption checks

As part of the statistical analysis, independent sample t-tests, regression analysis, and mediation analysis were performed, using SPSS (version 28.0). For the mediation analysis the PROCESS model (written by Andrew F. Hayes, Ph. D.) was used[2]. We checked the assumptions of normality, homogeneity of variance, multicollinear, and independence of observations. Q-Q plots for the independent variables appeared to be approximately normal. Although the Shapiro-Wilk test indicated significant p-values for both variables ($p_{acceptance} < .001$, $p_{risk\ perception} = .01$), suggesting a violation of the normality assumption. Nevertheless, the large sample size justified proceeding with the planned analyses. Furthermore, Levene's test for equal variances confirmed that the assumption of homogeneity of variance was satisfied ($p_{acceptance} = .32$, $p_{risk\ perception} = .28$). The assumptions of linearity and homoscedasticity were assessed through scatter plots, which showed no violations of these assumptions. In the mediation analysis, it was checked for multicollinearity by examining the variance inflation factor, which revealed no issues with multicollinearity. 10 significant outliers were determined by applying the 1.5*IQR rule. Since outliers do not represent measurement errors, but rather more extreme but valid opinions of participants, we decided to include them in the sample for further analysis.[3]

[2] Number of bootstrap samples for percentile bootstrap confidence intervals: 5000

[3] For explorative purposes the analysis was performed twice, ones including and another time excluding the outliers. Results did not show different patterns.

Results

Hypothesis Testing

Effect of Knowledge on Public Acceptance of DACCS

The first hypothesis states that people in the low knowledge condition show higher acceptance of DACCS in comparison with people in the high knowledge condition. Independent samples t-test results showed no significant difference in DACCS acceptance between the low and high knowledge conditions t (148) = 0.81, p = .21. The low knowledge condition had a slightly higher group mean compared to the higher knowledge condition ($M_{low\ knowledge}$ = 4.33, $SD_{low\ knowledge}$ = 0.75; $M_{high\ knowledge}$ = 4.21, $SD_{high\ knowledge}$ = 0.94), nevertheless they do not differ significantly. This suggests that additional information about the benefits and drawbacks of DACCS did not influence participants' overall acceptance of the technology.

Effect of Knowledge on Risk Perception of DACCS

For H2 it was hypothesized that more knowledge leads to higher risk perception. Again, after running an independent samples t-test, the results showed that there is no significant difference in risk perception between knowledge conditions, t (148) = 0.61, p = .27. We found the mean risk perception of the high knowledge condition to be slightly lower than the low knowledge condition ($M_{low\ knowledge}$ = 3.36; $SD_{low\ knowledge}$ = 0.54; $M_{high\ knowledge}$ = 3.30, $SD_{high\ knowledge}$ = 0.59), nevertheless they do not differ significantly. Therefore, additional information did not influence participant's risk perception of DACCS.

Correlation between Risk Perception and Public Acceptance of DACCS

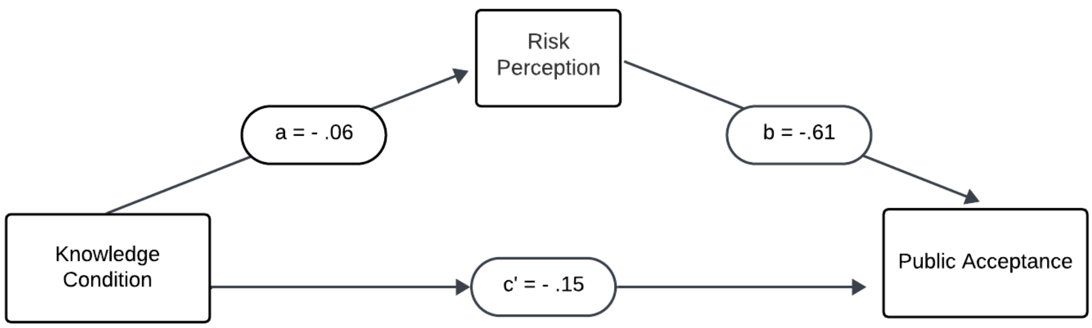
H3 states that risk perception negatively correlates with public acceptance of DACCS. This was tested by running a regression analysis. Results of simple linear regression showed that the higher the risk perception, the lower public acceptance of DACCS (b = - 0.60, R^2 = .16, F (1, 148) = 28.08, p < .001).

Mediation Effect of Risk Perception

It was expected to find a mediation effect (H4), namely the relationship between knowledge and acceptance of DACCS was thought to be mediated by risk perception. As illustrated in Figure 1, the effect of knowledge on public acceptance (direct effect; Path c') was found to be statistically non-significant ($\beta = -.15$; $p = .25$; *95% CI* [-0.40; 0.10]). The effect of knowledge on risk perception (Path a) was shown to be non-significant ($\beta = -.06$; $p = .55$; *95% CI* [- 0.24; 0.13]). Furthermore, the effect of risk perception on public acceptance (Path b) was shown to be significant ($\beta = -.61$; $p < .001$; *95% CI [*- 0.83; - 0.38*]*). The indirect effect of knowledge through risk perception on acceptance (path a*b) was insignificant ($\beta = .03$, *95% CI* [-0.08; 0.15]). It seems that, while risk perception independently affects public acceptance of DACCS, the amount of knowledge provided in this study did not alter risk perception sufficiently to influence acceptability.

Figure 1

Mediation model



*Note: Indirect effect: a*b = (- .06) * (- .61) = .03; Direct effect = c' = - .15*

Discussion

Overview of Key Findings

This study aimed to investigate factors influencing public acceptance of DACCS, specifically, the role of knowledge on public acceptance and the mediating role of risk perception. The study tested the following four hypotheses: Basic knowledge of DACCS results in higher public acceptance of DACCS compared to a more comprehensive understanding including pros and cons (H1); higher knowledge results in greater risk perception of DACCS (H2); and people with higher risk perception are less likely to accept DACCS (H3); and finally, the effect of knowledge was expected to be mediated by risk perception (H4). Results revealed that knowledge did not significantly affect public acceptance and risk perception, therefore H1 and H2 were rejected. As hypothesized, risk perception was negatively associated with public acceptance. The indirect effect of knowledge through risk perception on public acceptance was not significant, suggesting no mediation effect. This indicates that the type of knowledge provided in this study did not alter risk perception sufficiently to influence acceptability. Given the none-significant results of H1 and H2, nonsignificant mediation results were to be expected.

Explanation of Results

Contrary to earlier studies that highlighted the significant role of knowledge in public acceptance of technologies (Ellis et al., 2007; Molin, 2005; Wolske et al., 2019), our results indicate that knowledge may play a less crucial role in shaping public attitudes towards DACCS. Looking at other research, it was found that in the context of CCS, knowledge was a relatively weak predictor of public acceptance (De Best-Waldhober et al., 2012). This notion is further supported by a review of CCS perceptions, which suggests that other factors might exert a stronger influence on technology acceptance (Seigo et al., 2014).

When dealing with complex and unfamiliar technologies like DACCS, trust in experts and institutions appears to be more influential than detailed knowledge about the technology (De Best-Waldhober et al., 2012; Seigo et al., 2014). Laypeople lack a deep understanding of the technical aspects of DACCS, such as the potential for CO_2 reduction, risks of leakage, and the safety of long-term storage. Therefore, they rely on the credibility and trustworthiness of experts and authorities who present this information and serve as agent to take responsibility of implementation (Seigo et al., 2014). NGOs and researchers are seen as the most reliable and trusted stakeholders, while energy companies and industry stakeholders are among the least trusted (Seigo et al., 2014; Siegrist, 2000). Trust in stakeholders is also affected by how similar people perceive themselves to be to those stakeholders (Ter Mors et al., 2010). Information from diverse, collaborating stakeholders is viewed as more trustworthy and balanced than information from a single stakeholder (Ter Mors et al., 2010).

The causal chain account of trust, supported by studies on gene technology acceptance, suggest that trust indirectly affects acceptance of technology by reducing perceived risks and increasing perceived benefits (Siegrist, 2000). A study specifically focusing on competence-based trust[4] in CCS acceptance research, having manipulated the level of trust, supported the notion that people show higher acceptance scores, due to lower risk and higher benefits scores when the competence-based trust in the fictional organization was high (Terwel et al., 2009). Furthermore, research on acceptance of nuclear power energy and the role of trust on risk perception supported this causal chain account of trust and found an indirect effect of trust on acceptance through reduced perceived risks (Ryu et al., 2018). Hence, it is assumed that trust is an influential factor when it comes to public acceptance of DACCS, potentially more influential than knowledge. Future research could replicate findings from CCS, gene technology and nuclear energy acceptance research and extend them investigate how acceptance of DACCS differs over different sources with varying levels of perceived credibility (e.g., researchers, NGOs, or energy companies).

Next to trust, another potential factor explaining the results may be the affect heuristic. The affect heuristic suggests that people's assessments of risks and benefits are heavily influenced by their immediate emotional responses rather than a detailed analysis of pros and

[4] Competence-based trust is defined as trust based on organizational experience and expertise (Terwel et al., 2009).

cons (Finucane et al., 2000; Slovic et al., 2007). A study on a geoengineering technology found that participants' initial reactions to introductory information about the technology significantly shaped their risk perceptions (Sütterlin & Siegrist, 2017). When people initially perceived the geoengineering technology negatively (e.g., tampering with nature), additional knowledge had only a small effect on altering their risk perception. When informed about the risks, perceived risk and acceptance remain almost unchanged between conditions.

Since DACCS is a relatively new and unfamiliar technology, people might not have an immediate emotional response to it but are likely to relate it to familiar technologies to understand it better (Gentner & Smith, 2013). For some, DACCS might evoke comparisons to renewable technologies or other NETs like afforestation and reforestation, leading to a positive initial reaction (Raimi, 2021). Others might associate DACCS with nuclear waste or, due to its underground storage aspect, with hydraulic fracturing, which is perceived negatively (Satterfield et al., 2023; Raimi, 2021). Cox et al. (2021) found that negative public attitudes towards hydraulic fracturing often transfer to other technologies, especially NETs, possibly including DACCS. This transfer of attitudes is known as the ripple effect, where perceived risks extend from one technology to another due to the mental imagery associated with the first technology (Cox et al., 2021).

Regardless of the specific comparisons, people's evaluations of DACCS are based on their initial emotional reactions caused by comparisons to other technologies and their attitudes towards them. This initial emotional response tends to overshadow subsequent information about risks and benefits, leading to initial emotions dominating over later information. In this study, the affect heuristic, combined with comparisons to other technologies and the ripple effect, might have led to consistent acceptance scores across different knowledge conditions. Those who initially viewed DACCS positively perceived it as acceptable, while those with negative initial reactions saw it as less acceptable, regardless of the pros and cons provided.

As the affect heuristic shows, the emotional response towards a technology (or the technology compared to) might play a more important role than knowledge provision when it comes to public acceptance of DACCS. More specifically, this research also showed that risk perception is a significant predictor of public acceptance of DACCS. Our study confirmed that higher risk perception is significantly linked to lower public acceptance of DACCS. Participants who viewed DACCS as riskier were less likely to find its implementation acceptable. These findings align with previous research indicating that risk perception negatively impacts public acceptance of technology. A review paper on public perceptions of CCS suggests that perceived risk is a critical predictor of how people view new technologies (Seigo et al., 2014). Studies on various technologies, including geothermal energy, CCS, and renewable energy, have consistently shown that higher perceived risks reduce acceptance (Chung & Kim, 2018; Seigo et al., 2014; Park & Ohm, 2014).

In our study, risk perception accounted for around 16% of the variance in public acceptance of DACCS, underscoring its significant influence. Comments from participants highlighted several concerns, for example, some worried that DACCS represents excessive human interference with nature; others mentioned the concerns about high costs. Additionally, concerns about the long-term storage and potential leakage risks were prevalent.

This research enhances the growing body of evidence regarding public attitudes towards DACCS, emphasizing that initial emotional responses and perceived risks play a crucial role in shaping public acceptance. Furthermore, participant's comments add to the understanding of why risks are perceived as important. Research could expand on risk perception by exploring participants concerns about its interference with nature, explore economic concerns, conducting a cost-benefit analysis, as well as conducting long term risk assessments, investigating potential leakage. More general, future research could investigate how positive versus negative framing affects the initial affective response towards DACCS and in turn how it influences public acceptance.

Methodology Limitations and Future Research

Several limitations need to be addressed in future research. The convenience sampling method, limit the generalizability of the findings as most of our participants were young (*M* = 31.39) and the predominantly from Western Europe. Future studies should include more diverse samples, both geographically and culturally, to explore potential differences in perceptions of DACCS across various contexts. Another limitation of our study was the weak manipulation of the knowledge variable and the limited amount of information provided to participants. Participants were only exposed to an infographic and a brief overview of three pros and three cons of DACCS, lacking the depth and detail that could have elicited stronger emotional responses or a more thorough understanding. Participants may not have experienced the hint of risk because of the lack of engagement. Many participants reported feeling inadequately informed, with some even leaving answers blank due to discomfort from insufficient information. The manipulation check showed that 25 participants could not accurately recall the provided information, indicating that our manipulation might not be strong enough to engage participants meaningfully.

Given these methodological constraints, future research should consider employing more robust and engaging methods for information delivery. Incorporating multimedia formats, such as videos could enhance participants' engagement and comprehension and creates a stronger manipulation (Kayser et al., 2010) Moreover, exploring the use of virtual reality, the use of focus groups or workshops could help create more immersive experiences that elicit stronger emotional responses (Susindar et al., 2019). This would enable a more nuanced investigation into how different types of information and presentation formats impact participants' risk perceptions and acceptance, offering valuable insights for both research and policymaking in the field of emerging technologies.

Practical implications

Our research challenges the assumption that providing sufficient information will automatically increase acceptance of new technologies. Contrary to previous studies, our findings suggest that balanced information alone does not necessarily influence public acceptance or trigger a risk bias. This research highlights that it is not just about the information provided, but how it is perceived and who presents it. Simply giving more information about DACCS may not be enough to change opinions, though it does not cause harm. Transparency about DACCS, including its risks and benefits, remains important. However, our research indicates that knowledge plays a less significant role in public acceptance compared to trust and initial affective responses. Creating a positive initial association with DACCS is more crucial than providing extensive knowledge. Policymakers should aim to link DACCS with other positively perceived technologies and use positive framing to highlight its benefits and potential in fighting climate change. Once a positive first impression is established, a more nuanced view can be presented. Furthermore, communicators and policymakers should prioritize building trust. This can be done by collaboration between industry, scientists, and NGOs.

Conclusion

In conclusion, this study investigated the factors influencing public acceptance of DACCS. Our results revealed that giving more information does not significantly alter acceptability or risk perception, but risk perception alone plays a pivotal role in shaping attitudes towards DACCS. These findings challenge the assumption that more information naturally leads to a change in acceptance or perceived risks. Future research is suggested to focus more on other factors such as trust between policymakers and public, addressing emotional responses and risk perception.

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Appendix A

Qualtrics Questionnaire

Introduction of Negative Emission Technology and Practices

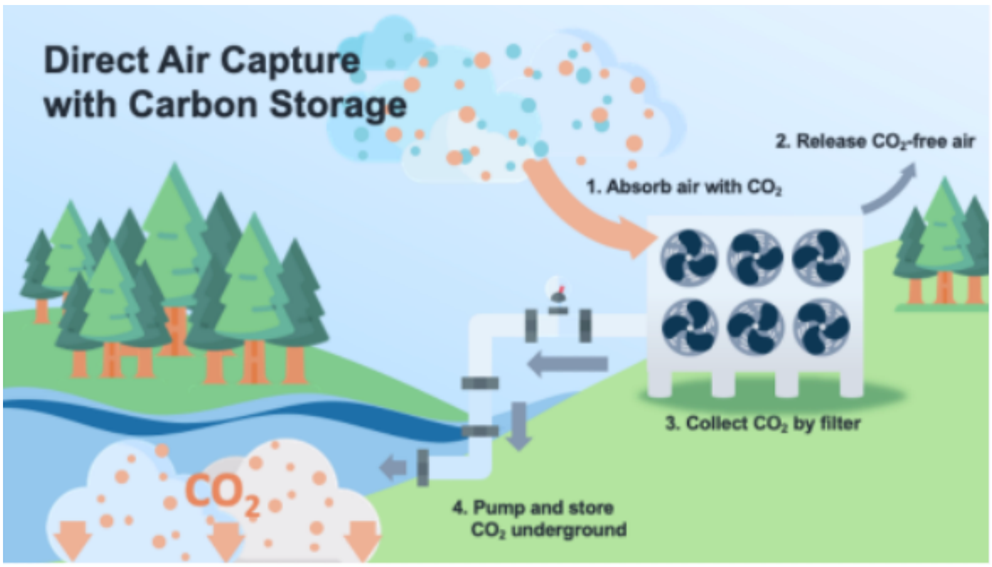
The impact of climate change and how do we reduce it?

Climate change has severe consequences around the world, such as more heat waves, wildfires, floods and rising sea levels. To limit climate change, we need to reduce the concentration of greenhouse gas emissions in the atmosphere, such as carbon dioxide (CO_2). CO_2 mostly comes from burning fossil fuels, such as coal, oil and gas. We can reduce CO_2 emissions by using less energy and switching to renewable energy sources, such as solar and wind energy. However, some greenhouse gas emissions will continue to be emitted, and CO_2 concentrations in the atmosphere need to be reduced over time. CO_2 in the air could be removed and stored underground or in the ocean by the technology called direct air capture with carbon storage (DACCS).

In the next page, we will provide a brief description of DACCS and ask your opinion about it.

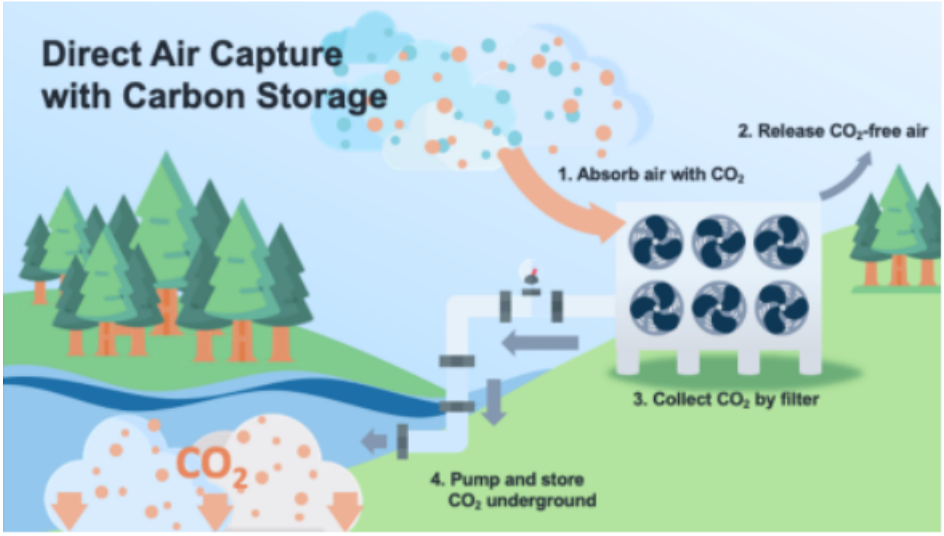
Introduction of DACCS

Low Knowledge Condition



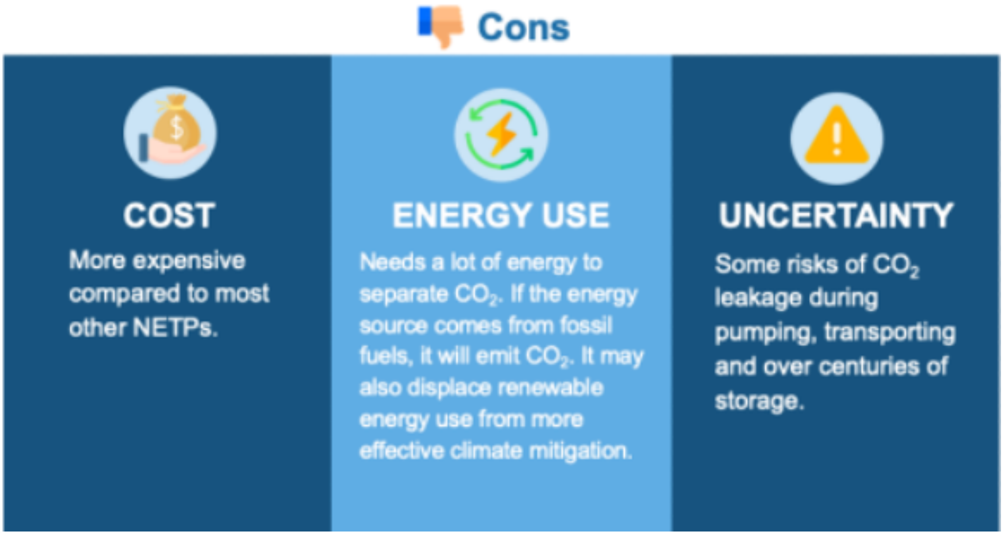
Direct air capture with carbon storage (DACCS) filters CO_2 out of the air so it can be stored. The air without CO_2 is released back into the atmosphere, just like a big air purifier. The captured CO_2 is then stored as a liquid in underground storages.

High Knowledge Condition



Direct air capture with carbon storage (DACCS) filters CO_2 out of the air so it can be stored. The air without CO_2 is released back into the atmosphere, just like a big air purifier. The captured CO_2 is then stored as a liquid in underground storages.

Below gives an overview of pros and cons of direct air capture with carbon storage.



Attention Check

Without going back to check, please answer the following question: What have you read about in previous descriptions? (selecting multiple answers is possible)

- o **How DACCS works**
- o **Pros of DACCS**
- o **Cons of DACCS**

DACCS – Risk and Benefit Perception

Your Opinions About Risk and Benefit of DACCS

Based on the information above, we are interested in how you perceive different risks and benefits of DACCS. Please read the statements below carefully and indicate your level of agreement on a 6-point scale from strongly disagree (1) to strongly agree (6)

	1 strongly disagree	2 disagree	3 somewhat disagree	4 somewhat agree	5 agree	6 strongly agree
I think CO2 pumping during the process of DACCS is risky.	o	o	o	o	o	o

This technology contributes to the fight against climate change.	o	o	o	o	o	o
The expansion of renewable energies will be delayed by investments in DACCS projects.	o	o	o	o	o	o
DACCS technology is an environmentally friendly technology.	o	o	o	o	o	o
This technology is merely a pretext to continue burning fossil energy sources.	o	o	o	o	o	o
DACCS decreases the current concentration of carbon dioxide in the atmosphere.	o	o	o	o	o	o
I'm concerned that a certain amount of CO2 may come back to the atmosphere even if it is stored on a deep seabed.	o	o	o	o	o	o
I'm concerned that we leave the risk to the future generation.	o	o	o	o	o	o
Please select 'disagree' as your answer.	o	o	o	o	o	o
I'm concerned about accidents during transportation of CO2 captured.	o	o	o	o	o	o

Acceptability of DACCS

We are interested in your opinion on how acceptable it is to implement DACCS. Please read the statements below carefully and evaluate them on a 6-point scale from strongly disagree (1) to strongly agree (6).

	1 strongly disagree	2 disagree	3 somewhat disagree	4 somewhat agree	5 agree	6 strongly agree
I find the use of DACCS technology acceptable.	o	o	o	o	o	o
I find it acceptable to implement DACCS technology in my country.	o	o	o	o	o	o
I find it acceptable to use DACCS technology in order to reach global climate goals.	o	o	o	o	o	o
I find it acceptable to use more DACCS technology in my country than is used now.	o	o	o	o	o	o