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Factors Shaping Public Support for More Carbon Capture and Storage Projects in the United States

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Abstract

This study contributes to the literature examining public acceptance of carbon capture and storage (CCS) projects in the US. The examination of factors that shape public support for CCS projects provides policymakers with insights to address public concerns, balance CCS development with public sentiments, and make informed decisions about optimal locations and timing. Based on a nationally representative survey on 1850 respondents, the study finds that in the US, there is very low familiarity (6.4%) regarding CCS technology and some limited opposition (11.5%) to increased CCS development. Regression results suggest that support for increased CCS projects in the US is influenced by perceptions of technical and social risks (leakage and community danger, respectively) but not cost of living risks, perceptions of environmental and economic benefits, familiarity with the technology, confidence in government regulations, and a desire for the US to lead in CCS. We fail to find the 'Not-in-My-Backyard' effect, and individuals supporting the development of more CCS in their states also support it at a national level. Understanding these factors helps policymakers anticipate challenges in implementing CCS initiatives and allows for the development of strategies to address concerns.

Keywords NIMBY · Public perception · Technology · Ordered probit · National survey · Economic benefits

Introduction

Addressing climate change through the transition to a low-carbon economy is a globally recognized imperative. In this context, several studies argue for the emerging role of Carbon Capture and Storage (CCS) (Wennersten et al. 2015; Shu et al. 2023). While CCS processes, from capture to storage, have been in existence for some time (Freund and Ormerod 1997), their application in the context of a low-carbon economy brings a renewed focus, with varying perspectives on effectiveness and feasibility. While some studies highlight the role of CCS in facilitating decarbonization goals in hard-to-abate sectors (Paltsev et al. 2021), others emphasize uncertainties and constraints related to technical applications and large-scale adoption rates (Lane et al. 2021).

On the policy front, several jurisdictions and states are designing legislative frameworks and new policy incentives to encourage net zero emissions through eco-friendly production and carbon abatement processes (Psarras et al. 2017; Global Carbon Capture and Storage Institute 2022; Bowser et al. 2022). For instance, in 2022 the US enhanced tax credits for facilities that capture and manage carbon dioxide under Section 45Q of the Internal Revenue Code (International Energy Agency 2023; McLaughlin et al. 2023; Beck 2020a).[1] Individual US states also encourage power generators (e.g., coal and gas-fired plants) to adopt CCS for carbon management in the form of direct financial incentives, off-take agreements, cost recovery, tax incentives, and state assumption of long-term liability (Medlock et al. 2023; Center for Climate and Energy Solutions 2022;

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[1] The tax credit under Section 45Q was originally enacted in 2008 providing \$10 and \$20 for each ton of carbon stored via enhanced oil recovery (EOR) and geological formations, respectively. This was expanded in 2018 to broaden eligibility (e.g., lowering capture capacity, increasing value to \$50 and \$35 per ton respectively for storage and EOR, etc.) (Beck 2020). In 2022, 45Q tax credit was further enhanced to provide higher tax credit (\$60/ton for EOR and \$85/ton for storage) and reduce capacity requirements (International Energy Association 2022).

Great Plains Institute 2022). States such as Indiana and Wyoming are actively enacting legislation to shift certain long-term liabilities and risks associated with CCS projects to the state. Osazuwa-Peters and Hurlbert (2020) compare different types of CCS regulatory supports and find that while most existing frameworks focus on regulating technical aspects (e.g., permits for injection and storage site, liability, decommissioning, etc.) there are fewer provisions for the financial aspects of the technology (e.g., emission trading, monetization sources other than grants and tax credits, etc.) and public engagement (e.g., benefit sharing, providing information, etc.).

Moving forward, more nations are expected to consider improving the regulatory framework to reduce investment barriers and facilitate the deployment and adoption of CCS technologies to address the nations' net zero carbon emission goals. Governments worldwide are significantly increasing their funding for CCS projects. For instance, the US and Europe made over $20 billion available to CCS projects in 2023 alone. This trend is evident in various countries, including the Netherlands, Denmark, and others, indicating a global commitment to CCS. Likewise, in the US national efforts are underway to provide financial assistance to carbon-emitting industries in the form of tax credits, R&D funding, loan programs, etc. Moreover, countries are not only developing their own CCS strategies but also collaborating on cross-border CCS projects. The creation of new initiatives like the Carbon Management Challenge and the signing of cross-border arrangements under the London Protocol demonstrate a collective effort to accelerate CCS deployment. These actions signal a strategic shift towards a more integrated and cooperative approach to CCS, further encouraging its adoption (Budinis et al., 2023). However, despite generous policy support and the technical readiness of CCS applications, there are several barriers that hinder the development of CCS projects. Barriers discussed in the literature include high investment costs (Budinis et al. 2018), the absence of market-based monetary returns (Zapantis et al. 2019; Azure et al. 2023), and uncertainty towards future policy support (Gibbins and Chalmers 2008; Davies et al. 2013). Furthermore, negative public perception and opposition towards CCS projects is a major factor identified as a key barrier to the large-scale adoption of CCS technology (Pianta et al. 2021; Boyd et al. 2017; Tcvetkov et al. 2019).

The goal of this study is to use a national survey to examine what factors influence the support for developing more CCS projects in the US. These factors, largely derived from a literature review, encompass perceptions of risks and benefits (Krause et al. 2014; Danne et al. 2021), familiarity with CCS technology (Pianta et al. 2021), concerns about government regulation (Yang et al. 2016), and aspirations for national CCS technology leadership (Beck 2020). Additionally, we study the 'Not-in-My-Backyard' (NIMBY) versus 'Yes-in-My-Backyard' (YIMBY) effects, examining whether and to what extent individuals who have general support for CCS projects will or will not hold the same level of support for projects in closer proximity (Wallquist et al. 2012). Understanding public perceptions of CCS would allow policymakers to consider public acceptability in designing policies for decarbonization.

This study contributes to the existing literature in the social, economic, and decision-sciences domain, particularly within the realm of carbon capture public perceptions in the US. The research builds upon the foundation laid by recent survey-based studies (e.g., Whitmarsh et al. 2019) and tests hypotheses based on data collected from the US. While there is a growing body of survey research on carbon capture perceptions and public support in various countries, including Canada (Boyd et al. 2017), the UK (Perdan et al. 2017), Germany (Arning et al. 2019), and Switzerland (Wenger et al. 2021), the US context has remained relatively understudied. Moreover, existing survey-based studies in the US are focused on a single state and not performed at a national level (e.g., Krause et al. (2014) in Indiana and Moon et al. (2020) based in Texas). This research expands the scope to a national level, providing a more comprehensive understanding of the US market. Unlike previous state-specific studies (Krause et al. 2014; Moon et al. 2020), this research conducts a nationally representative survey which allows for a more accurate and holistic view of public perceptions and support for carbon capture across the entire country, rather than being limited to a single state. This broad perspective, combined with insights from previous state level studies (Krause et al. 2014; Moon et al. 2020) is crucial for informing policy decisions and strategies at a national level.

A thorough examination of the literature reveals that the majority of carbon capture and storage (CCS) public perception studies are concentrated in regions outside the United States. For instance, a literature review by Tcvetkov et al. (2019) covering studies conducted between 2002 and 2018 underscores this geographical discrepancy. Only 12 studies (out of a total of 135) during this period were based on data collected from the US, and only a handful of other cross-country studies included the US in their comparisons. Furthermore, existing studies within the US context often exhibit limitations such as a narrow focus on individual states, as observed in research concentrating on areas with high potential for carbon capture like Indiana (Krause et al. 2014). Alternatively, some studies exclusively explore the political feasibility of scaling up CCS without providing a comprehensive assessment of public perceptions and support (Pianta et al. 2021). This study offers a more holistic understanding of public perceptions by adopting a nationally representative approach. By doing so, the research enriches the literature with valuable insights into the dynamics of carbon capture acceptance and public sentiment within a context that has been notably under-represented in previous scholarly endeavors.

Section "Conceptual Framework and Hypothesis Development" presents a literature review based on which six hypotheses are developed. Section "Survey Design and Methods" presents a discussion of the survey design and implementation as well as a summary of the empirical approaches used to test the hypothesis. Section "Results and Discussion" presents regression results and discusses findings. Section "Conclusion" concludes with a summary and policy implications.

Conceptual Framework and Hypothesis Development

The goal of this study is to understand factors that shape public acceptance of carbon capture and storage (CCS) projects in the US. We test for the impact of the following six factors on the level of support/opposition for the development of more CCS projects in the US. These factors are (1) *perceptions* of CCS risks/benefits, including the cost-of-living impacts, (2) *familiarity* with CCS technology, (3) *concerns* about the effectiveness of government regulation due to perception of industry influence and regulatory effectiveness, and (4) *aspirations* regarding national CCS technology leadership. These factors are largely compiled from a review of existing survey-based studies (Tcvetkov et al. 2019; Wong-Parodi et al. 2011) and each of these factors is formulated as a hypothesis for the US context. We also develop hypothesis testing for the 'Not-in-My-Backyard' (NIMBY) effect where individuals that support CCS nationally would not hold the same level of support when projects are proposed in closer proximity, versus the 'Yes-in-My-Backyard' (YIMBY) effect where individuals that support CCS nationally are also likely to support CCS in their vicinity (e.g., due to perceived benefits).

Risk/Benefit Perceptions

Perceptions of risk and benefit refer to the subjective judgments that people make about the attributes and consequences of a given technology (Seigo et al. 2014). Terwel et al. (2009) find that perceptions about risks and benefits influence the acceptability of new technologies. According to Tokushige et al. (2007), in Japan, individuals who perceive greater benefits compared to risks, are more likely to accept CCS projects. One potential source of risk is concern about the level of safety of carbon storage processes which are often perceived to be still relatively newer. For example, Tokushige et al. (2007) find that in the context of Japan, individuals may be concerned about unknown risks. Gough et al. (2002) studied public reaction to geological and ocean sequestration of carbon dioxide and found expressions of general concerns regarding the safety of carbon storage among focus group participants. Other causes of concern for CCS risk include uncertainty regarding the technology, risk of leakage from the storage facilities and pipelines, and fear of earthquakes, accidents, or explosions (Itaoka et al. 2014) (*technical risks*).

In addition, studies show that individuals may be more concerned about *socioeconomic risks* than technical risks. For instance, in the context of Switzerland, Wallquist et al. (2011) found that residents may be concerned about economic and welfare impacts. The study also revealed respondents' concern about CCS technologies crowding out renewable energy technologies. Perceptions of CCS risk are most often discussed in the context of carbon leakages, risk of failure, continued use of fossil fuels, ecological risks, and risk to residents and communities (e.g., health risk) where CCS projects are implemented (Krause et al. 2014).

Krause et al. (2014) show that in the state of Indiana (where over half of electric power source is coal), residents' level of acceptability or opposition to CCS projects is shaped by their beliefs about local economic impacts as well as their concern about the safety of the technology. Perceived benefits include economic benefits from a CCS project in terms of jobs, employment, and additional tax revenues (Krause et al. 2014). Based on a literature review of existing studies Tcvetkov et al. (2019) categorize perceptions of CCS benefits as those benefits that accrue to societies (economic benefits such as job creation and investment) and the environment (reducing greenhouse gas emission or reducing climate change effects). Thus, the source of perceived risks can broadly be viewed as technical or socioeconomic, whereas the source of perceived benefits is either economic or environmental.

In addition to these risk/benefit factors discussed in the literature, we examine whether support/opposition to CCS technology is affected by the perception that the technology would ultimately affect consumer prices and increase the cost of living. Although several discrete choice experiments estimate the maximum incremental price households would be willing to pay for energy from different energy technologies (Van Rijnsoever et al. 2015; Danne et al. 2021), this additional risk factor (cost of living impact on consumers in the form of increase in the price of energy) has not been extensively studied in shaping public support for US-based CCS projects (Merk et al. 2023). Individuals may be concerned about the high initial and operational costs of adopting a CCS project (e.g., construction, technology development, developing storage sites, building pipeline, etc.) which may ultimately be passed on to consumers (e.g., higher energy prices). For example, a recent study by Azure et al. (2023) finds that the adoption of CCS among fossil-based power generators could potentially increase the price of electricity when tax credits are not sufficient to cover costs. Based on an international experimental study, Whitmarsh, et al. (2019) find that costs of deploying CCS can lead to lower support among the general public. On the contrary, in Saskatchewan, Canada, Osazuwa-Peters et al. (2020) observed that the cost and technical risk associated with innovative energy technologies were not the primary concerns for people. These factors were less influential in shaping people's risk perceptions and tolerance towards these technologies. Instead, their past experiences with energy use and consumption played a more significant role.

Hypothesis 1 (Perceived benefits): Holding other factors constant, support for the development of more CCS projects will increase when individuals perceive more benefits in the form of addressing climate change and positive economic impacts.

Hypothesis 2 (Perceived risks): Holding other factors constant, support for the development of more CCS projects will decline when individuals perceive higher risks in the form of danger to local communities (social risk), higher cost of living for consumers (economic risk), and leakage risks (technical risk).

Familiarity with CCS

The second factor hypothesized to shape support for more CCS projects in the US is familiarity about the technology. Familiarity addresses the extent to which individuals are informed about the nature of the technology, its purpose, and its consequences. Most studies examining public perception of CCS highlight the role of familiarity in driving the acceptance/rejection of CCS technologies (Pietzner et al. 2011; Sala and Oltra 2011). In Spain, Sala and Oltra (2011) find that individuals who have a low level of self-perceived knowledge of CCS are more likely to have a negative opinion of CCS, compared to individuals who have a high or very high level of perceived knowledge. The study also finds that individuals who believe they have a very high knowledge of CCS have a very positive view of CCS. Pianta et al. (2021) show that the level of familiarity about CCS is positively correlated with positive perceptions of the technology. On the contrary the study by de Best-Waldhober et al. (2011) suggests that even after being provided expert level information on CCS, the general public may still have concerns around the safety of CCS and hence not support the technology. In Switzerland, Wallquist et al. (2011) find that individuals who are more knowledgeable about carbon dioxide (its physical and chemical properties) have a lower perception of CCS risks and benefits and so the study suggests that more knowledge about carbon dioxide might ease down concerns about risk but at the same time leads to less confidence about the benefits. Hurlbert et al. (2020) conducted a study in Saskatchewan, Canada, and suggested that the reason for the support for CCS projects and the lower perceived risk in some communities could be due to the lack of information within these communities (Wallquist et al., 2010).

Hypothesis 3 (Familiarity): Holding other factors constant, support for the development of more CCS projects will increase when individuals are more familiar with the technology.

Trust in Government

Previous studies show that trust in institutions could shape the level of public support/opposition to novel low-carbon technologies (Terwel et al. 2009). Gough et al. (2002) studied public reaction to geological and ocean sequestration of carbon dioxide and found expressions of concern regarding trusting the ability of companies and other institutions to oversee carbon sequestration processes in the long term. In China, Yang et al. (2016) find that trust in stakeholders that implement CCS technology (including project developers and governmental institutions) has a positive influence on support for CCS projects because trust can increase expected benefits while minimizing concerns about risk. Midden and Huijts (2009) study the role of trust in influencing attitudes towards carbon dioxide storage.

When it comes to trusting governmental institutions, we propose two related yet distinct hypotheses. First is the concern regarding the influence of the private sector on the governance of CCS technology where individuals may believe the government is influenced by industry groups or associations when it comes to advancing CCS technology. For example, Boyd et al. (2017) find that in Canada individuals who believe the government is not influenced by the coal and oil industry regarding CCS are more likely to support developing CCS projects as well as using government subsidies/funding to support the development of CCS. This can be framed as a regulatory capture effect which is the belief that the government is influenced by industry groups and hence may prioritize industry needs (Dal Bó 2006; Carpenter and Moss 2013).

Second, we focus on individuals' beliefs regarding regulatory effectiveness which reflects concerns about whether there is enough regulatory infrastructure to facilitate the safe application of CCS technologies irrespective of whether there is a private influence on government bodies or not. In the study by Boyd et al. (2017), the authors find that individuals who believe the government will adequately regulate CCS are more likely to support CCS projects and they combine these two effects to present a proxy to measure trust in government. Terwel et al. (2009) present trust to be in the context of trusting the competence and the integrity of CCS stakeholders. In a similar study, Terwel et al. (2011) show that public trust in CCS stakeholders affects their acceptance of CCS projects. For example, the public may have more trust for information provided by environmental NGOs than industrial stakeholder. There may also be other aspects of trust in institutions and stakeholders such as trusting the information provided on expected CCS benefits and risks.

Hypothesis 4 (Trust for the government): Holding other factors constant, support for the development of more CCS projects will increase when individuals are *less concerned* about (i) the influence of carbon-emitting industries on the governance of CCS, and (ii) the adequacy of government regulation on the safe operation of CCS.

Aspiring Technological Leadership

Beck (2020) discusses several factors as to why the US is best positioned to lead commercial-scale CCS at a global level and these factors include the availability of resources/wealth, favorable political and economic conditions, as well as the existence of innovation-driven manufacturing activities. Likewise, Stephens (2009) discusses the US context that enabled the nation as a CCS technology leader in terms of investing more resources in CCS development than any other country and the nation's contribution to global greenhouse gas emissions. According to data compiled by the Global Carbon Capture and Storage Institute, about 35% of CCS facilities worldwide are found in the US making the US the top nation with the most CCS-adopting facilities.

When people believe their country should be a leader in cutting-edge technological solutions for climate change, this sentiment is often described as an aspiration or an expression of national ambition. In such cases, individuals may be more willing to invest in technology advancement and adoption. For instance, if individuals aspire the US to be a technology leader in the CCS space, they may be more willing to support more CCS projects.

In Saskatchewan, Canada, Hurlbert and Osazuwa-Peters (2023) suggest that the phrase 'world energy leader' could serve as an effective communication strategy by shifting perception of CCS from a risk to an opportunity, emphasizing Saskatchewan's leadership in sustainable energy security and climate change mitigation. This framing positioned Saskatchewan as a standard-bearer for CCS technology, differentiating its deployment from other projects. Furthermore, the authors find that other information framings such as 'managed risk' contributed for the successful implementation of CCS because it aligned well with the local community's values, beliefs, and norms.

Hypothesis 5 (Aspiring technological leadership): Holding other factors constant, support for the development of more CCS projects will increase when individuals have a higher aspiration and national ambition for CCS technology leadership.

NIMBY/YIMBY Effects

NIMBY refers to the resistance that individuals express when confronted with the prospect of a new project in their vicinity, even if they might support the project in general. According to the NIMBY effect, individuals who generally support the development of carbon mitigation technology such as CCS may not show the same level of support when the site is closer in proximity. Wallquist et al. (2012) find evidence for a NIMBY effect in the context of Switzerland where people consider the proximity of CCS pipelines and storage sites to their residency to evaluate their preference for CCS system elements. Likewise, based on a survey of one thousand Indiana residents, Krause et al. (2014) find that while 80% of residents support CCS projects in general, about 20% of these would switch to opposition when those projects were proposed closer to their proximity which illustrates the NIMBY phenomena. There are several reasons for the NIMBY effect such as perceived negative consequences on local economies (e.g., property values, environmental or health impacts, quality of life, etc.) and the desire to preserve the status quo. We test for the NIMBY effect of whether individuals who are opposed to more CCS projects in their state or closer proximity would support the development of more CCS in general. While individuals may recognize the overall need for having CCS projects, they may resist having such projects closer to home.

Hypothesis 6 (NIMBY): Holding other factors constant, support for the development of more CCS projects in general will be higher for individuals who do not want them in their states or closer proximity.

The alternative hypothesis would be the YIMBY effect where individuals who agree with the development of CCS projects in general are more likely to want them in their states and/or closer proximity (e.g., due to perceived benefits). Unlike the NIMBY perspective, individuals with a YIMBY perspective embrace projects in closer proximity due to opportunities for community growth and development as well as the benefits of achieving environmental goals.

Survey Design and Methods

This study is based on an online survey that was administered on a demographically representative sample of 1850 US residents recruited using services from Prolific Inc. Prolific Inc. is an online platform which connects survey respondents with researchers. Peer et al. (2017) and Palan

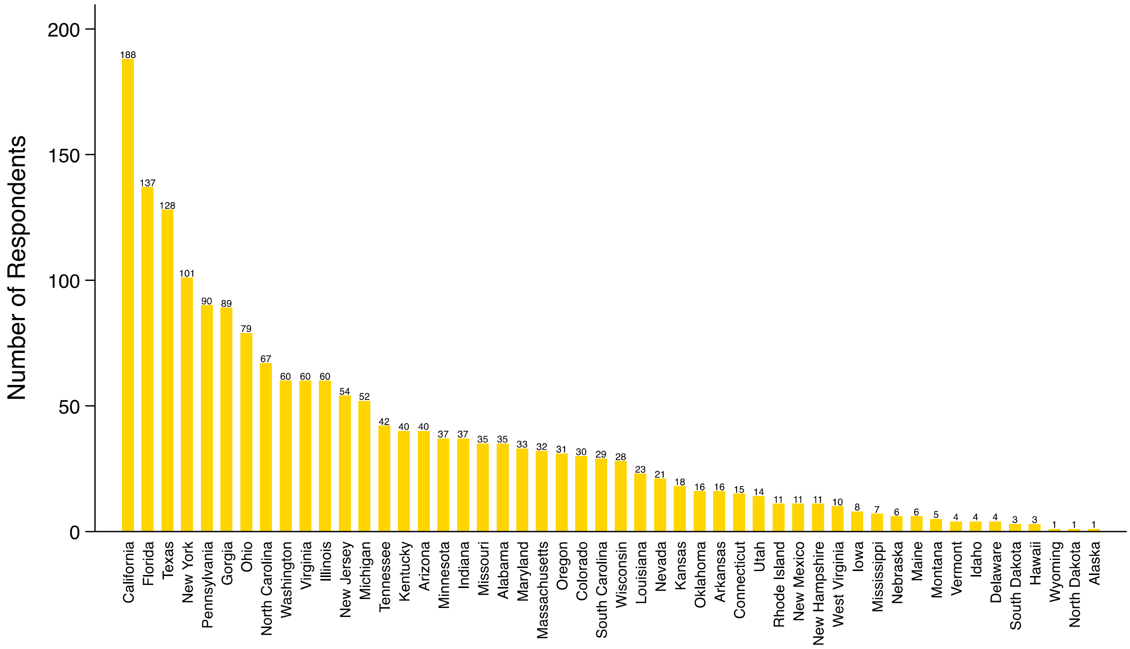

Fig. 1 Distribution of survey respondents by state ($N = 1833$)

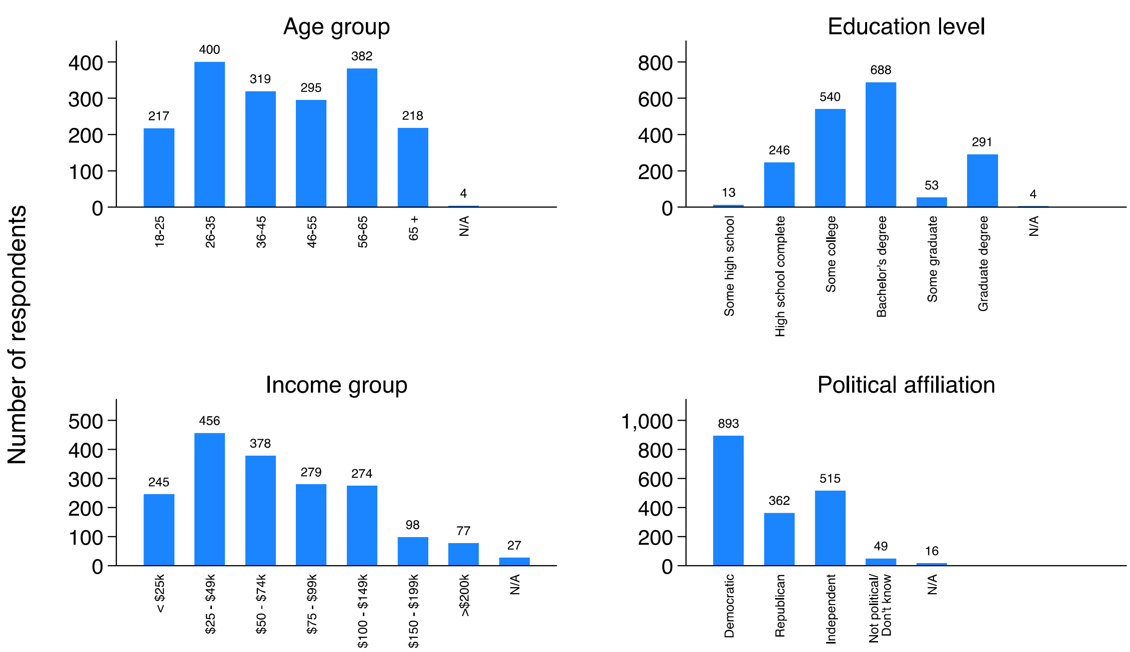

Fig. 2 Characteristics of survey respondents

and Schitter (2018) argue that survey respondents recruited by Prolific are of a higher quality than other online research platforms. The survey was built in Qualtrics and shared with Prolific database of respondents that are representative of the US population based on the US census statistics on age, sex, and ethnicity. The study gained Institutional Research Board (IRB) approval for human subject's study (University of Missouri System, IRB Project # 2094568) and the hypotheses are pre-registered with Open Science Framework (osf.io/92ea5). The research team used the think-aloud protocol to ensure the wordings and flow of the survey are easily understandable.

Data was collected between December 5–7, 2023. Out of the 1850 participants who agreed to take the survey, 1835 completed the survey. Figure 1 presents a distribution of survey respondents by state and Fig. 2 presents demography

Table 1 Variable measurement

Summary of questions	Likert scale	Variable type
Support for more CCS projects	1 = strongly oppose to 5 = strongly support	Dependent variable
1. CCS can address climate change. 2. CCS is good for the economy.	1 = strongly disagree to 5 = strongly agree	*Hypothesis 1*-Perceived benefits
1. CCS has a risk of carbon leakage. 2. CCS poses a danger to nearby communities. 3. CCS causes higher cost of living for consumers.	1 = strongly disagree to 5 = strongly agree	*Hypothesis* 2-Perceived risks (technical and socioeconomic risks)
Familiarly with CCS technology	1 = not familiar at all to 5 = extremely familiar	*Hypothesis 3*-Familiarity
1. The government is influenced by carbon-emitting industries regarding CCS. 2. The government will adequately regulate CCS.	1 = strongly disagree to 5 = strongly agree	*Hypothesis 4*-Trust for government
The US should be a world leader in CCS technology.	1 = strongly disagree to 5 = strongly agree	*Hypothesis 5*-Aspiring technological leadership
There should be more CCS in my state.	1 = strongly disagree to 5 = strongly agree	*Hypothesis 6*- NIMBY
I feel a personal obligation to do my part for (1) a renewable future, (2) reducing my carbon footprint, (3) combating climate change.	1 = strongly disagree to 5 = strongly agree	Personal norm (PN) questions
Climate change is a serious social problem.	1 = strongly disagree to 5 = strongly agree	Awareness of consequence

distribution. 48% of respondents are male, 50% female, 1.7% non-binary, and the rest preferred not to answer or self-described. The Appendix presents the power analysis and results from Cronbach's alpha test to assess the internal consistency and reliability of survey items (Taherdoost, 2017; Kupper and Hafner, 1989; White et al., 2020).

We obtained informed consent and started the survey by asking respondents to rate how familiar they are with CCS technologies on a Likert scale ranging from one (not familiar at all) to 5 (extremely familiar). Then respondents are provided a summary information along with an illustration figure to describe what a CCS is, sequentially highlighting the carbon source as a power generator, carbon capture, transportation via pipelines, and permanent storage in underground reservoirs. Respondents are also provided with the information that currently there are about 130 CCS projects in the US with more expected in the future. This information contextualizes the questions effectively and reduces ambiguities or misconceptions by providing clear and accurate information. Respondents are asked attention-check questions to ensure the quality of their responses and identify inattentiveness, if any.

Respondents are directly asked to what extent they would oppose or support the development of more CCS projects in the US where responses are recorded on a Likert scale from one (strongly oppose) to five (strongly support). Following, we have a series of questions measuring the extent of disagreement/agreement (on a 5-Likert scale ranging from one for strongly disagree to five for strongly agree) to variables measuring risk/benefit perceptions, trust in the government, and aspiring national technological leadership. Then, respondents are presented with the US map indicating the number of CCS facilities in each state and they are asked to what extent they would agree/disagree with more CCS facilities in their states. The survey ends with a list of personal norm and demography questions.

Individual traits and demographic characters are used as control variables. We ask respondents about their environmental personal norms and awareness of the consequences of climate change as individual traits that affect support for CCS projects. These questions are largely based on previous studies (Ashworth et al. 2019). Demographic variables are age, income, education level, political affiliation, gender, and state of residency. Table 1 summarizes the questions asked, their units of measurement, and how they are used to test each hypothesis to understand factors shaping support/opposition to CCS projects.

As Table 1 shows, the dependent variable ranges from one for 'strongly oppose' to five for 'strongly support' to the question, "Indicate to what extent you oppose or support the development of more CCS projects in the US". Since the dependent variable is an ordered variable, we use an ordered probit model to test hypotheses. The ordered probit model is a type of generalized linear model that is designed for ordinal dependent variables, which in this case is a 5-scale indicator of the extent of support/opposition. The model assumes unobserved latent continuous metrics underlying the observed ordinal responses. The beta coefficients show changes in the latent variable for a one-unit change in the corresponding independent variable holding other factors constant. As a robustness check, we run an ordinary least squares (OLS) regression treating the dependent as a continuous variable (see Appendix for robustness checks). In all regressions, we control for individual traits and demography variables.

Results and Discussion

The main variable of interest (that is, the dependent variable) ranges from one for 'strongly oppose' to five for 'strongly support' to the question, "Indicate to what extent you oppose or support the development of more CCS projects in the US". Figure 3 presents the distribution of responses to this question. The figure shows that there is some limited opposition towards the development of more CCS in the US where only 11.5% of respondents expressed opposition or strong opposition. Close to 49% of respondents supported or strongly supported while close to 40% were indifferent (neither support nor oppose). The high level of indifference could be explained by most of the respondents (79%) who indicated they are not familiar with the technology. A similar finding is recorded in Oltra et al. (2010), based on a focus group in Spain, where respondents would neither accept nor oppose CCS projects (or be uncertain) if they do not have sufficient information to base their decision on.

Survey results also indicate that only 6% of respondents were either familiar or extremely familiar with CCS. Despite the low level of familiarity with CCS, close to half of the respondents (49%) showed support or strong support for the development of more CCS in the US. See the Appendix for descriptive statistics of variables used in this study.

Regression results from the ordered probit model are presented in Table 2. Model (1) excludes all variables measuring individual trait, characteristics, and demography. Model (2) adds responses from personal norm (PN) and awareness of consequence of climate change questions, and Model (3) adds demography controls. Coefficients from demography variables, not presented here for brevity, do not yield statistically significant coefficients except the gender variable for female which is negative in all regressions. Variables used to measure personal norms are also not statistically significant predictors for support/opposition of more CCS projects. This result implies that public support/opposition is more driven by perceptions and concerns rather than individual traits or characteristics. The appendix includes additional robustness checks using an OLS regression, which are generally consistent with results presented in Table 2.

Overall, we find support for *Hypothesis 1* (perceived environmental and economy benefits), *Hypothesis 3* (familiarity with technology), and *Hypothesis 5* (aspiring technology leadership); we find some support for *Hypothesis 2* (perceived technical and social, but not cost of living risks) and *Hypothesis 4* (effective/adequate regulations but not regulatory capture). We do not find support for *Hypothesis* 6 (NIMBY).

Risk/Benefit Perceptions

Our results suggest that perceptions of localized technical (carbon leakage) and social risks (danger to the community) (*Hypothesis* 2) and perception of environmental and

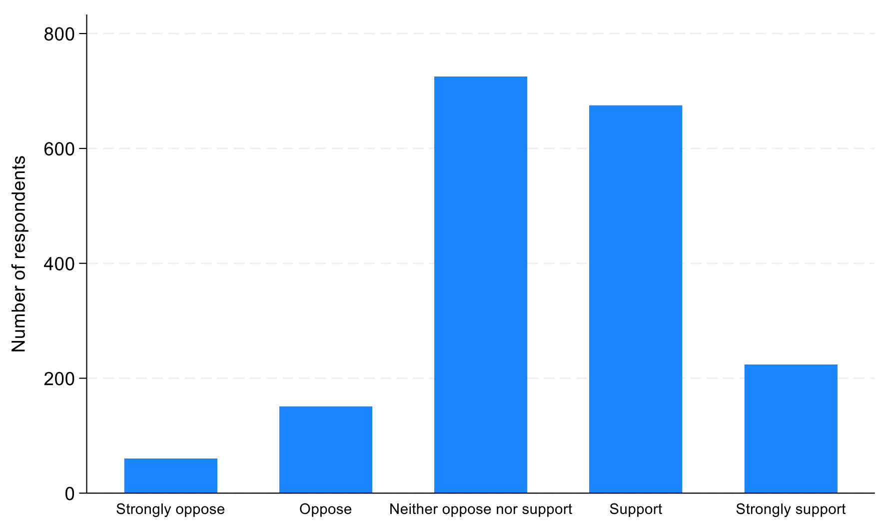

Fig. 3 Support or opposition to the development of more CCS in the US ($N = 1835$)

Table 2 Results from ordered probit models

Variables	Expected Sign (+/−)	(1) Support more CCS	(2) Support more CCS	(3) Support more CCS
Address climate change (H1)	+	0.315***	0.343***	0.344***
		(0.0451)	(0.0476)	(0.0480)
Good for economy (H1)	+	0.199***	0.203***	0.211***
		(0.0469)	(0.0469)	(0.0485)
Leakage risk (H2)	−	−0.115**	−0.105**	−0.114**
		(0.0445)	(0.0451)	(0.0457)
Danger to community (H2)	−	−0.261***	−0.252***	−0.250***
		(0.0426)	(0.0426)	(0.0434)
Higher cost of living (H2)	−	−0.0341	−0.0537	−0.0466
		(0.0343)	(0.0350)	(0.0369)
Familiarity (H3)	+	0.112***	0.117***	0.0960***
		(0.0331)	(0.0333)	(0.0349)
Industry influence of govt. (H4)	−	0.0372	0.0483	0.0404
		(0.0306)	(0.0304)	(0.0306)
Adequate govt. regulation (H4)	+	0.118***	0.123***	0.127***
		(0.0399)	(0.0402)	(0.0414)
National CCS leadership (H5)	+	0.275***	0.286***	0.286***
		(0.0396)	(0.0398)	(0.0419)
More CCS in my state (H6)	−	0.416***	0.420***	0.408***
		(0.0400)	(0.0405)	(0.0414)
Individual controls				
PN-Renewable future			−0.0480	−0.0442
			(0.0565)	(0.0584)
PN- Reduce carbon footprint			0.00622	0.0288
			(0.0574)	(0.0593)
PN-Combat climate change			0.0334	0.0260
			(0.0613)	(0.0630)
Climate change serious problem			−0.0753	−0.0812
			(0.0417)	(0.0453)
Demography controls		No	No	Yes
Observations		1835	1835	1791

PN stands for personal norm. Standard errors in parentheses

***$p < 0.01$; **$p < 0.05$

economic benefits (*Hypothesis* 1) influence the extent of support for more CCS projects in the US. However, the cost-of-living risk is not found to be correlated with support/opposition to CCS projects. This implies that while respondents may be considering local technical and social risks in evaluating CCS projects, responses are not strongly shaped by the perception of an indirect economic impact in the form of price increases. This is in contrast to previous studies which show that individuals consider the cost implications of energy technologies. For example, in discrete choice experiments, Van Rijnsoever et al. (2015) show that individuals care about the implication of a given energy technology (e.g., nuclear, solar, wind versus natural gas with CCS, etc.) on the prices they end up paying for energy (e.g., dollar per kilowatt hour). A recent study by Merk et al. (2023) examine public acceptability of carbon dioxide removal projects in Germany and show that the cost to households (e.g., cost measured in Euros paid per month) is one of the important factors that affects the acceptability of a given project.

Our finding is in line with Krause et al. (2014) who show that support for CCS (in the state of Indiana) is shaped by respondents' beliefs about economic impacts and safety risks. The perception of risks and benefits remains an important factor in shaping public opinion on CCS, so understanding these channels is important for policymakers in tailoring communication strategies to address specific concerns and accurately highlighting benefits and risks to build transparency. In addition, it is important to balance broader benefit categories such as addressing climate change via CCS with more local benefits (e.g., reducing local risks) such as actions taken to reduce potential danger to communities.

Familiarity with CCS

Regression results show that individuals who are more familiar with the technology are also likely to support the development of more CCS projects (*Hypothesis 3*). This finding is largely consistent with earlier studies that show a positive correlation between familiarity and CCS project support, such as the study by Sala and Oltra (2011) in Spain. This finding is also consistent with more recent findings on the role of the level of familiarity in shaping support for CCS technology (Pianta et al. 2021). Familiarity can reduce misconceptions and exaggerated perceptions of risk associated with CCS. A public familiar with CCS technology may also be more likely to recognize the safety measures in place and understand the probabilities of negative environmental impact. Individuals familiar with the technology may also recognize the role of CCS in mitigating climate change and be more inclined to support CCS as part of a broader strategy. Considering the low level of familiarity among the respondents in this study (only 6% of respondents are familiar with CCS), there is room for designing effective education and engagement efforts to build and maintain familiarity with new carbon abatement technologies. For instance, industry stakeholders can actively participate in public education by disseminating accurate information (e.g., technology showcases in communities, industry-led workshops, etc.).

Trust in Government

Individuals who believe the government would adequately regulate CCS are more supportive of CCS projects, however, the regulatory capture effect does not shape support/opposition (*Hypothesis 4*). The latter result contrasts with Boyd et al. (2017) who find that Canadians who believe the government is influenced by the carbon-emitting industry for CCS regulation would not support CCS developments. The former result is consistent with Boyd et al. (2017) who show that Canadians who believe the government would adequately regulate CCS would support CCS projects. Our findings suggest that there is a crucial role for the government in developing and enforcing a transparent regulatory framework for CCS projects to shape favorable public opinion towards CCS projects. Our results also imply that effective and transparent regulatory frameworks could create the foundation for the support of CCS development.

Aspiring Technological Leadership

Individuals who believe the US should be a global leader in CCS are more supportive of CCS projects (*Hypothesis 5*). Individuals who aspire for their nation to be a technology leader are likely to see CCS achieve environmental goals, drive economic growth, and demonstrate leadership on the global stage. The alignment of CCS with values such as innovation, economic prosperity, and environmental responsibility could make it appealing to those with aspirations for technological leadership. This finding suggests that an informational framing that highlights the global leadership in technology could help increase public acceptability of CCS. This is in line with Hurlbert and Osazuwa-Peters (2023) who show that an informational framing that emphasizes global leadership in energy was effective to reduce CCS risk perceptions in Saskatchewan, Canada.

NIMBY/YIMBY Effects

We do not find evidence for the NIMBY effect (*Hypothesis 6*) and this contrasts with previous studies that found evidence for such effect in Switzerland (Wallquist et al. 2012) and Indiana (Krause et al. 2014). Rather the regression results suggest that individuals who want more CCS in their states are more likely to support more CCS in the US. This is in support of the YIMBY effect where perceived benefits that would raise support for the development of more CCS locally would also lead to increased overall support. Individuals who support more CCS in their states may recognize the need to have more CCS projects to address climate change in a collective effort. These individuals may also believe in the importance of consistent policies nationally and locally. Individuals supporting CCS locally would also support it nationally and this reflects a recognition that addressing climate change requires a cooperative and collective effort, with support for CCS initiatives being a part of that larger endeavor. On the contrary, individuals who would not support CCS in their states are also the ones who are likely to show opposition to CCS nationwide. This is likely driven by perceived risks becoming higher than perceived benefits. See the Appendix for additional analysis on NIMBY.

Conclusion

An examination of factors that influence public support or opposition to Carbon Capture and Storage (CCS) projects is

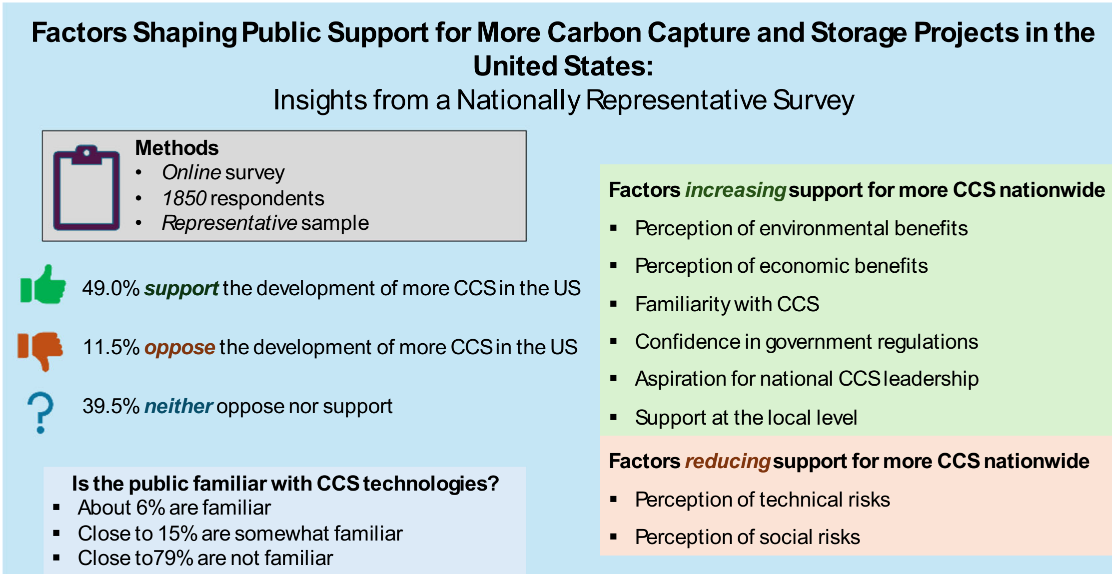

Fig. 4 Summary of study findings

important in the context of addressing climate change and transitioning to a sustainable energy future. As the imperative to reduce greenhouse gas emissions intensifies, CCS could be a promising technology capable of mitigating the impact of industrial processes and power generation on the environment. However, the successful implementation of CCS hinges not only on technological advancements and policy incentives but also on gaining public acceptance. Understanding the determinants of public support or opposition to CCS projects is crucial for policymakers, industry stakeholders, and researchers.

Public perceptions could be shaped by several factors, including environmental concerns, risk/benefit perceptions, economic considerations, governance concerns, and technology familiarity levels. Investigating these factors provides insights into the complex dynamics that influence public attitudes toward CCS, facilitating the development of targeted strategies to foster understanding, build trust, and garner widespread support for the adoption of the technology. This study provides insights from a nationally representative survey that can be used in the formulation of policies and communication strategies that align with the values and concerns of the public, ultimately paving the way for the optimal integration of CCS into national efforts to combat climate change.

The study contributes to the growing literature (Whitmarsh et al. 2019) examining factors that shape public opinion towards CCS. Previous studies have examined public perception of carbon capture and the extent of support in Canada (Boyd et al. 2017), the UK (Perdan et al. 2017), Germany (Arning et al. 2019, 2020), and Switzerland (Wenger et al. 2021), but the US context remains relatively understudied. According to a study by Tcvetkov et al. (2019), it was found that fewer than 10% of public perception surveys about CCS originate from the US. Moreover, most of the CCS public perception studies based in the US are either focused on a single state (Krause et al. 2014) or only focus on political feasibility (Pianta et al. 2021).

We design and administer a nationally representative survey on 1850 US residents. The key insights of the study are summarized in Fig. 4. Our survey shows that despite the low level of familiarity with CCS technologies (6.4%), close to half of the respondents showed some support for the development of more CCS in the US while only 11.5% indicated opposition. Our regression results suggest that support for increased CCS projects in the US is influenced by perceptions of technical and social (leakage and community danger, respectively) but not cost of living risks, perceptions of environmental and economic benefits, familiarity with the technology, confidence in government regulations, and a desire for the US to lead in CCS. We fail to find evidence for the Not-in-My-Backyard (NIMBY) effect, with individuals supporting the development of more CCS in their states also supporting it at a national level. Personal norms and demographic variables show no significant correlation with support levels.

Successful implementation of CCS projects requires public acceptance. Studying the factors that shape public support for more CCS projects is important for at least three reasons. First, understanding public attitudes helps policymakers anticipate challenges in implementing CCS initiatives. Second, it allows for the development of strategies to address concerns and make decisions related to optimal project location and timing. For example, strategies can be designed to help convey the benefits of CCS while addressing and alleviating public concerns and misconceptions. Knowledge about factors shaping support/opposition could also guide the development of policies that align with public sentiments, leading to more successful and sustainable outcomes. Finally, studying the factors that shape public support for CCS is instrumental in ensuring that these technologies are not only technically viable but also socially and publicly accepted, contributing to the overall success and effectiveness of decarbonization initiatives.

At last, we wish to acknowledge some of the inherent limitations of our sampling process, design, and data collection. While respondents are nationally representative, there could be some limitations that could prevent the generalizability of results and hence results should be interpreted accordingly. For instance, there may be limitations in achieving a truly representative sample of the entire population, and using an online panel of survey respondents could create sampling bias. CCS projects often have localized impacts and a social acceptance survey with respondents who are more familiar with a current CCS project nearby may be better to capture some of these localized impacts. Finally, public understanding of CCS technology may be complex, and the survey may not fully capture the depth of public knowledge or misconceptions of the technology.

Data availability

All data will be made public on OSF (osf.io/92ea5).

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Author Contributions Mahelet G. Fikru conceptualized the research questions, obtained funding, administered the project, performed data analysis and robustness checks, and validations. Fikru also provided resources, software, and wrote the manuscript. Nhien Nguyen participated in data curation, formal data analysis, investigation, designing methodology, regression codes, validation, and visualization.

Compliance with Ethical Standards

Conflict of Interest The authors declare no competing interests.

References

Arning K, Offermann-van Heek J, Linzenich A, Kätelhön A, Sternberg A, Bardow A, Ziefle M (2019) Same or different? Insights on public perception and acceptance of carbon capture and storage or utilization in Germany. Energy Policy 125:235–249

Arning K, Offermann-van Heek J, Sternberg A, Bardow A, Ziefle M (2020) Risk-benefit perceptions and public acceptance of Carbon Capture and Utilization. Environ Innov Societal Transit 35:292–308

Ashworth P, Sun Y, Ferguson M, Witt K, She S (2019) Comparing how the public perceive CCS across Australia and China. Int J Greenh Gas Control 86:125–133

Azure JW, Frimpong S, Fikru MG (2023) Stochastic modeling of decarbonizing strategy, policy, and market-induced incentives for the US electricity sector. J Clean Prod 429:139324

Beck L (2020) Carbon capture and storage in the USA: the role of US innovation leadership in climate-technology commercialization. Clean Energy 4(1):2–11

Beck L (2020) The US Section 45Q Tax Credit for Carbon Oxide Sequestration: An Update. Global CCS Institute. Melbourne, Australia

Beck L (2020a) The US Section 45Q Tax Credit for Carbon Oxide Sequestration: An Update. Global CCS Institute, Melbourne, Australia

Bowser B, Handler BP, Littlefield A, Bazilian MD (2022) Clearing the non-technical hurdles for CCS. Payne Institute Commentary Series: Commentary. Golden, Colorado, USA

Boyd AD, Hmielowski JD, David P (2017) Public perceptions of carbon capture and storage in Canada: Results of a national survey. Int J Greenh Gas Control 67:1–9

Budinis S, Krevor S, Mac Dowell N, Brandon N, Hawkes A (2018) An assessment of CCS costs, barriers, and potential. Energy Strategy Rev 22:61

Budinis S, Fajardy M, Greenfield C (2023) Carbon Capture, Utilisation and Storage - Energy System. Int Energy Agency. https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage

Carpenter D, Moss DA (eds) (2013) Preventing regulatory capture: Special interest influence and how to limit it. Cambridge University Press. New York, NY, USA

Center for Climate and Energy Solutions (2022) U.S. state energy financial incentives for CCS. January 10, 2022. Retrieved March 12, 2023, from https://www.c2es.org/document/energy-financial-incentives-for-ccs/

de Best-Waldhober M, Paukovic M, Brunsting S, Daamen D (2011) Awareness, knowledge, beliefs, and opinions regarding CCS of the Dutch general public before and after information. Energy Proc 4:6292–6299

Dal Bó E (2006) Regulatory capture: A review. Oxf Rev Economic Policy 22(2):203–225

Danne M, Meier-Sauthoff S, Musshoff O (2021) Analyzing German consumers' willingness to pay for green electricity tariff attributes: a discrete choice experiment. Energ, Sustain Soc 11(1):15

Davies LL, Uchitel K, Ruple J (2013) Understanding barriers to commercial-scale carbon capture and sequestration in the United States: An empirical assessment. Energy Policy 59:745–761

Freund P, Ormerod WG (1997) Progress toward storage of carbon dioxide. Energy Convers Manag 38:S199–S204

Gibbins J, Chalmers H (2008) Carbon capture and storage. Energy Policy 36(12):4317–4322

Global Carbon Capture and Storage Institute (2022) Legal and regulatory database. Retrieved from https://co2re.co/LegalRegulatoryDatas

Gough C, Taylor I, Shackley S (2002) Burying carbon under the sea: an initial exploration of public opinions. Energy Environ 13(6):883–900

Great Plains Institute (2022) Wyoming Carbon Capture Opportunities. Retrieved from https://carboncaptureready.betterenergy.org/wyoming/

Hurlbert M, Osazuwa-Peters M (2023) Carbon capture and storage in Saskatchewan: An analysis of communicative practices in a contested technology. Renew Sustain Energy Rev 173:113104

Hurlbert M, Osazuwa-Peters M, Rayner J, Reiner D, Baranovskiy P (2020) Diverse community energy futures in Saskatchewan. Can Clean Technol Environ Policy 22:1157–1172

International Energy Agency (2023) Section 45Q credit for carbon oxide sequestration – policies. IEA. Retrieved February 8, 2023, from https://www.iea.org/policies/4986-section-45q-credit-for-carbon-oxide-sequestration

International Energy Association (2022) Inflation Reduction Act 2022: Sec. 13104 Extension and Modification of Credit for Carbon Oxide Sequestration. IEA

Itaoka K, Saito A, Dowd AM, de Best Waldhober M, Ashworth P (2014) Influence of the large earthquake and nuclear plant accident on perception of CCS. Energy Proc 63:7133–7140

Krause RM, Carley SR, Warren DC, Rupp JA, Graham JD (2014) "Not in (or under) my backyard": geographic proximity and public acceptance of carbon capture and storage facilities. Risk Anal 34(3):529–540

Kupper LL, Hafner KB (1989) How appropriate are popular sample size formulas? Am Statistician 43(2):101–105

Lane J, Greig C, Garnett A (2021) Uncertain storage prospects create a conundrum for carbon capture and storage ambitions. Nat Clim Change 11(11):925–936

McLaughlin H, Littlefield AA, Menefee M, Kinzer A, Hull T, Sovacool BK, Bazilian MD, Kim J, Griffiths S (2023) Carbon capture utilization and storage in review: Sociotechnical implications for a Carbon Reliant World. Renew Sustain Energy Rev 177:113215. https://doi.org/10.1016/j.rser.2023.113215

Medlock KB, Miller K, Baker SG, Baker JA (2020) Carbon capture in Texas: comparative advantage in a low carbon portfolio. Rice University's Baker Institute for Public Policy. Retrieved March 6, 2023, from https://doi.org/10.25613/9ffx-6h23

Merk C, Liebe U, Meyerhoff J, Rehdanz K (2023) German citizens' preference for domestic carbon dioxide removal by afforestation is incompatible with national removal potential. Commun Earth Environ 4(1):100

Midden CJ, Huijts NM (2009) The role of trust in the affective evaluation of novel risks: The case of CO2 storage. Risk Anal Int J 29(5):743–751

Moon WK, Kahlor LA, Olson HC (2020) Understanding public support for carbon capture and storage policy: The roles of social capital, stakeholder perceptions, and perceived risk/benefit of technology. Energy Policy 139:111312

Oltra C, Sala R, Solà R, Di Masso M, Rowe G (2010) Lay perceptions of carbon capture and storage technology. Int J Greenh Gas Control 4(4):698–706

Osazuwa-Peters M, Hurlbert M (2020) Analyzing regulatory framework for carbon capture and storage (CCS) technology development: A case study approach. Cent Eur Rev Econ Manag 4(1):107–148

Osazuwa-Peters M, Hurlbert M, McNutt K, Rayner J, Gamtessa S (2020) Saskatchewan's energy future: risk and pathways analysis. Environ Innov Societal Transit 34:237–250

Palan S, Schitter C (2018) Prolific. ac—A subject pool for online experiments. J Behav Exp Financ 17:22–27

Paltsev S, Morris J, Kheshgi H, Herzog H (2021) Hard-to-Abate Sectors: The role of industrial carbon capture and storage (CCS) in emission mitigation. Appl Energy 300:117322

Peer E, Brandimarte L, Samat S, Acquisti A (2017) Beyond the Turk: Alternative platforms for crowdsourcing behavioral research. J Exp Soc Psychol 70:153–163

Perdan S, Jones CR, Azapagic A (2017) Public awareness and acceptance of carbon capture and utilisation in the UK. Sustain Prod Consum 10:74–84

Pianta S, Rinscheid A, Weber EU (2021) Carbon capture and storage in the United States: perceptions, preferences, and lessons for policy. Energy Policy 151:112149

Pietzner K, Schumann D, Tvedt SD, Torvatn HY, Næss R, Reiner DM, Ziogou F (2011) Public awareness and perceptions of carbon dioxide capture and storage (CCS): Insights from surveys administered to representative samples in six European countries. Energy Proc 4:6300–6306

Psarras PC, Comello S, Bains P, Charoensawadpong P, Reichelstein S, Wilcox J (2017) Carbon capture and utilization in the industrial sector. Environ Sci Technol 51(19):11440–11449

Sala R, Oltra C (2011) Experts' attitudes towards CCS technologies in Spain. Int J Greenh Gas Control 5(5):1339–1345

Seigo SLO, Arvai J, Dohle S, Siegrist M (2014) Predictors of risk and benefit perception of carbon capture and storage (CCS) in regions with different stages of deployment. Int J Greenh Gas Control 25:23–32

Shu DY, Deutz S, Winter BA, Baumgärtner N, Leenders L, Bardow A (2023) The role of carbon capture and storage to achieve net-zero energy systems: Trade-offs between economics and the environment. Renew Sustain Energy Rev 178:113246

Stephens JC (2009) Technology leader, policy laggard: CCS development for climate mitigation in the US political context. Caching the carbon: the politics and policy of carbon capture and storage, 22–49. Cheltenham, UK: Edward Elgar Publishing

Taherdoost H (2017) Determining sample size; how to calculate survey sample size. Int J EconManag Syst 2:237–239

Tcvetkov P, Cherepovitsyn A, Fedoseev S (2019) Public perception of carbon capture and storage: A state-of-the-art overview. Heliyon 5(12):e02845

Terwel BW, Harinck F, Ellemers N, Daamen DD (2009) Competence-based and integrity-based trust as predictors of acceptance of carbon dioxide capture and storage (CCS). Risk Anal Int J 29(8):1129–1140

Terwel BW, Harinck F, Ellemers N, Daamen DD (2011) Going beyond the properties of CO2 capture and storage (CCS) technology: How trust in stakeholders affects public acceptance of CCS. Int J Greenh Gas Control 5(2):181–188

Terwel BW, Harinck F, Ellemers N, Daamen DD, De Best-Waldhober M (2009) Trust as predictor of public acceptance of CCS. Energy Procedia 1(1):4613–4616

Tokushige K, Akimoto K, Tomoda T (2007) Public acceptance and risk-benefit perception of CO_2 geological storage for global warming mitigation in Japan. Mitig Adapt Strateg Glob Change 12:1237–1251

Van Rijnsoever FJ, Van Mossel A, Broecks KP (2015) Public acceptance of energy technologies: The effects of labeling, time, and heterogeneity in a discrete choice experiment. Renew Sustain Energy Rev 45:817–829

Wallquist L, Seigo SLO, Visschers VH, Siegrist M (2012) Public acceptance of CCS system elements: a conjoint measurement. Int J Greenh Gas Control 6:77–83

Wallquist L, Visschers VH, Siegrist M (2010) Impact of knowledge and misconceptions on benefit and risk perception of CCS. Environ Sci Technol 44:6557–6562

Wallquist L, Visschers VH, Siegrist M (2011) Antecedents of risk and benefit perception of CCS. Energy Procedia 4:6288–6291

Wenger A, Stauffacher M, Dallo I (2021) Public perception and acceptance of negative emission technologies–framing effects in Switzerland. Clim Change 167(3):1–20

Wennersten R, Sun Q, Li H (2015) The future potential for Carbon Capture and Storage in climate change mitigation–an overview from perspectives of technology, economy and risk. J Clean Prod 103:724–736

White IR, Marley-Zagar E, Morris T, Parmar MK, Royston P, Babiker AG (2020) Sample size calculation for an ordered categorical outcome. In London Stata Conference 2020 (No. 08). Stata Users Group. London, UK

Whitmarsh L, Xenias D, Jones CR (2019) Framing effects on public support for carbon capture and storage. Palgrave Commun, 5(1):19

Whitmarsh L, Xenias D, Jones CR (2019) Framing effects on public support for carbon capture and storage. Palgrave Commun 5(1):1–10
Wong-Parodi G, Dowlatabadi H, McDaniels T, Ray I (2011) Influencing attitudes toward carbon capture and sequestration: A social marketing approach. Environ Sci Technol 45(16):6743–6751
Yang L, Zhang X, McAlinden KJ (2016) The effect of trust on people's acceptance of CCS (carbon capture and storage) technologies: Evidence from a survey in the People's Republic of China. Energy 96:69–79
Zapantis A, Townsend A, Rassool D (2019) Policy priorities to incentivize large-scale deployment of CCS. Thought Leadership Report. Global CCS Institute. Melbourne, Australia