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Heather Bedle, Ph.D.
Hy Tran

The University of Oklahoma

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CONTACT: speer@ou.edu

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Moral Foundations and Public Perceptions of Carbon Capture and Storage with Induced Seismicity

Heather Bedle Ph.D., and Hy Tran
University of Oklahoma

Research Report

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Abstract

Moral foundations held by the public significantly influence attitudes towards energy transition policies like carbon capture and storage (CCS). This study examined the relationships between moral foundations and public perception of CCS with induced seismicity risks in a nationally representative survey of Americans, while controlling for political party and orientation. The binding moral foundation of Loyalty and the individualizing foundation of Care were associated with support for CCS, despite the risk of small earthquakes. In contrast, the individualizing foundation of Fairness and the binding foundations of Authority and Purity were correlated with opposition to CCS when considering the possibility of induced seismicity. An interaction effect was observed between the moral foundation of Loyalty and political orientation. Liberals and moderates tended to increase their support for CCS with the risk of earthquakes as their in-group loyalty increased, while conservatives' support remained unchanged with increasing in-group loyalty.

These findings suggest effective energy transition strategies should consider moral foundation dynamics in policy design and public messaging, particularly for climate mitigation aspects involving seismicity risks. Tailoring approaches to align with distinct moral concerns of different population segments could enhance public acceptance of carbon-mitigating energy solutions. Policymakers and communicators should address underlying moral foundations shaping public attitudes to develop more targeted strategies for building support, especially for methods with inherent risks.

1. Introduction

Carbon capture and storage has emerged as an important technology with potential to reduce carbon dioxide emissions and mitigate climate change (IPCC, 2021). CCS involves capturing CO2 from large stationary sources like power plants, transporting it, and injecting it into appropriate underground geologic formations for long-term storage. Interest and investment in CCS have grown globally due to its potential to reduce emissions from our reliance on fossil fuels for energy (Stephens, 2006, 2009; Kreveor et al., 2023).

However, the development and deployment of CCS faces several challenges, one of which is the risk of induced seismicity, as injecting large volumes of fluids, such as water, underground for storage can activate nearby faults and trigger seismic events (Ellsworth, 2013; Walsh and Zoback, 2015). While these induced earthquakes tend to be small, some have caused minor damage and raised concerns among the public (Ellsworth, 2013). Although CCS-induced seismicity cases have yet to occur, there is a high similarity between CCS and wastewater injection. Therefore, it is important to understand public risk perception and be prepared for a potential scenario.

This has highlighted the importance of understanding public risk perceptions related to CCS. Research has shown that perceived risks, along with perceived benefits and trust in stakeholders, are key predictors of public acceptance of CCS (L'Orange Seigo et al., 2014). The public tends to perceive leakage of CO2, induced seismicity, and the unsustainable aspects of CCS as the main risks (L'Orange Seigo et al., 2014). However, studies also reveal that providing information on CCS does not necessarily lead to higher acceptance, as many factors beyond knowledge influence opinions (Chaudhry et al., 2013).

Context, both social and geographic, also matters considerably for public acceptance of CCS projects. At the local level, prior experience with the fossil fuel industry, community empowerment, and perceived fairness in decision-making processes shape attitudes (Anderson et al., 2012; Oltra et al., 2012). People want to consider CCS within the broader energy context and portfolio of climate solutions rather than in isolation (L'Orange Seigo et al., 2014). Values like perceived "interference with nature" also appear important (L'Orange Seigo et al., 2014).

Given the critical role of public acceptance in the successful implementation of CCS projects (Chaudhry et al., 2013), it is essential to understand how the public perceives the risks of induced seismicity versus the benefits of CCS. This understanding can inform effective risk communication and public engagement efforts to support the responsible development of CCS as part of a portfolio of climate change solutions. Lack of public support has already hindered the development of several proposed CCS projects (Van Alphen et al., 2007), underscoring the importance of this research.

Despite these findings, research investigating the complex interplay between political orientation, moral foundations, and policy framing remains limited, especially in the context of CCS and its associated risks, such as induced seismicity. This study aims to address this gap by examining the independent relationships between moral foundations and attitudes toward CCS when the risk of small earthquakes is known, while accounting for the influence of political party and orientation. We hope that insights from this survey and research can help inform risk communication and public engagement efforts to support the responsible development of CCS as part of a portfolio of climate change solutions.

1.1 Energy/Climate mitigation and American demographics.

The social, political, and psychological factors shaping public perceptions of carbon capture and storage (CCS) and associated policies in the United States as the need for climate mitigation practices becomes more pressing have been studied over the last decade. Demographic variables, including age, gender, race, income, and education, have been found to predict attitudes toward climate mitigation policies, with some studies suggesting that younger, female, more educated, and higher-income Americans tend to have higher support for renewable resources and climate action (Boudet et al., 2016; Drummond & Fischhoff, 2017; Hamilton, 2011). Although there is not a solidified strong role of demographics, Krause

et al. (2014) found that those who were white, male, and liberal had more support for CCS in their local area, and Miller et al. (2007) found that women were more supportive of CCS in Australia. To this extent, the influence of demographic factors on CCS perceptions is not always consistent across studies, with some research finding limited or no significant effects (L'Orange Seigo et al., 2014; Pianta et al., 2021), suggesting complex or nuanced variables are at play.

In addition to demographic variables, personal experiences and beliefs may also shape public attitudes toward CCS, for example, individuals who believe that climate change is a serious problem may be more supportive of CCS as a mitigation strategy (Chaudhry et al., 2013; L'Orange Seigo et al., 2014). Additionally, support of mitigation strategies also depends on trust of individuals in government agencies, industries, and environmental organizations (Terwel et al., 2012, Yang et al., 2016). L'Orange Seigo et al. (2014) emphasize that trust in stakeholders can have both direct effects on acceptance and indirect effects through perceived risks and benefits. They also note that researchers and Non-governmental organizations (NGOs) are often the most trusted stakeholders, while industry stakeholders are typically the least trusted.

Despite these findings, research investigating effective communication strategies and policy design for CCS remains limited and inconclusive, especially in light of policy support differing among individuals with varying partisan orientations (Pianta et al., 2021), suggesting the influence of additional factors besides socioeconomic factors on CCS-related attitudes. L'Orange Seigo et al. (2014) highlights the importance of considering the context in which CCS is deployed, including the social context of potential host communities and the broader energy context.

As CCS methods are increasingly considered and funded as a potential tool for climate change mitigation, understanding the complex social and psychological factors shaping public perceptions is crucial for informing effective communication and policy, particularly with the related risks of induced seismicity (White and Foxhall, 2016). The findings from L'Orange Seigo et al. (2014) suggest that effective communication strategies should not only focus on providing information about CCS itself but also consider the broader social and energy context in which CCS is deployed, as well as the role of trust in its various stakeholders from industries to the government. Overall previous research on the complexity of factors influencing public attitudes towards CCS, highlights the need to examine the role of influences such as political ideology and moral foundations, in shaping these perceptions.

1.2 Political Ideology

Political orientation has been consistently shown to influence attitudes toward climate change and climate action. Conservatives express less concern about climate change and less support for emissions reduction policies compared to liberals (Dunlap & McCright, 2016; Hornsey et al., 2016; McCright et al., 2016a; McCright & Dunlap, 2011). Republican party affiliation and conservative political orientation are among the strongest predictors of opposition to climate action (Clulow et al., 2021; Thomas et al., 2022). Despite these apparent ideological divides, evidence suggests that conservatives are not universally opposed to climate action (McCright et al., 2016b), and certain moral and value-based framing strategies may influence climate-related beliefs (Adger et al., 2017; Campbell & Kay, 2014). The election of Democratic governors is positively associated with the expansion of renewable energy at the state

level (Dorrell & Lee, 2020; Bonnet & Olper, 2024), highlighting the importance of political ideology in shaping climate mitigation efforts.

Taking this a step further, Pianta et al. (2021) found that support for CCS policies varies with political orientation, with Democrats being more favorable than Independents and Republicans. They argue that the ideological polarization around climate change needs to be taken into account when proposing, communicating, and implementing policies to scale up CCS in the United States. The authors suggest that future research should assess whether different framings of CCS policies have an impact on policy support among individuals with different partisan orientations, such as framing CCS deployment in terms of jobs or energy security rather than climate change. Pianta et al.'s findings agree with Campbell and Kay (2014) suggest that effective communication strategies and policy framing may help bridge the ideological divide and foster greater acceptance of CCS and other climate mitigation strategies across the political spectrum.

Pianta et al. (2021) and Campbell and Kay (2014) highlight the importance of considering ideological differences and underlying moral values when examining public support for climate mitigation policies. While political ideology is a strong predictor of attitudes toward climate change and climate mitigation efforts, moral foundations theory, as discussed by Graham et al. (2009) suggests that intuitive moral principles may also play a significant role in shaping these beliefs. Investigating the influence of moral foundations alongside political orientation can provide a more comprehensive understanding of the factors driving public perceptions of CCS and its associated risks, such as induced seismicity. This understanding can inform the development of targeted communication strategies and policy framing that appeal to a broader range of moral concerns and ideological values, potentially fostering greater acceptance of CCS and other essential components of the energy transition across the political spectrum.

1.3 Moral Foundations

Moral foundations theory (MFT) allows an understanding of principles that shape individuals' attitudes and beliefs (Graham et al., 2011; Haidt & Graham, 2007). According to MFT, people rely on a set of moral foundations, including care/harm (Care), fairness/cheating (Fairness), loyalty/betrayal (Loyalty), authority/subversion (Authority), and sanctity/degradation (Purity) (Graham et al., 2013). Graham et al. (2009) suggest that liberals and conservatives differ in their use of these moral foundations, with liberals prioritizing the individualizing moral foundations of Care and Fairness, while conservatives place greater emphasis on the binding foundations of Loyalty, Authority, and Purity.

In regard to climate change concerns, the individualizing foundations of Care and Fairness are most frequently engaged (Gromet et al., 2013; Feinberg & Willer, 2013; Koleva et al., 2012). The Care foundation, which assesses sensitivity to cruelty, suffering, and vulnerability, predicts increased concern about the anthropogenic and environmental consequences of climate change (Dickinson et al., 2016; Markowitz & Shariff, 2012). Individuals who place a higher value on the Care foundation are more likely to be sensitive to the potential harm caused by climate change to both humans and the environment.

Similarly, the Fairness foundation, which centers on justice, reciprocity, and social equity (Howell & Allen, 2019; Wolf, 2011), plays a significant role in shaping views on the equal sharing of climate mitigation costs and seeking justice against perpetrators of the climate crisis (Dawson & Tyler, 2012;

Jansson & Dorrepaal, 2015). Those who prioritize the Fairness foundation are more likely to advocate for a just distribution of the burdens associated with climate change mitigation and to hold accountable those responsible for the climate crisis.

However, the prevalence of individualizing foundations varies across the political spectrum, with liberals endorsing Care and Fairness at higher levels than conservatives (Feinberg & Willer, 2013; Koleva et al., 2012). This disparity in moral foundations engagement contributes to the ideological divide between liberals and conservatives in their assessments of environmental risks (Gromet et al., 2013) and may help explain why liberals tend to view climate change as a more pressing concern than conservatives, which could cause differing attitudes towards climate change mitigation policies, such as CCS.

Because of the relation to climate, the differences in moral foundations are particularly relevant to the study of attitudes towards CCS and its associated risks of induced seismicity. Those who prioritize the Care foundation may be more concerned about the potential environmental and social impacts of CCS, while those who emphasize the Loyalty foundation may be more supportive of CCS if it is perceived as benefiting their in-group. Furthermore, the moral foundations endorsed by individuals may interact with their political ideology to shape their attitudes towards CCS. Conservatives who place a high value on Purity may be less supportive of CCS if they view it as a violation of the natural order, while liberals who prioritize the Fairness foundation may be more critical of CCS if they perceive it as an unfair solution that benefits or harms as in the case of induced seismicity, certain groups over others.

As climate mitigation efforts, including the deployment of CCS technologies, continue to be politically polarizing issues, considering the influence of moral foundations alongside political ideology may provide valuable insights into the psychological factors shaping public support for these policies. Therefore, this study aims to investigate the relationships between moral foundations and attitudes toward CCS when the risk of induced seismicity is known, while controlling for the influence of political party and orientation. Further research is needed to directly examine the influence of specific moral foundations on attitudes towards CCS and its associated risks, particularly in the context of induced seismicity, in order to inform the development of effective communication strategies and policy framing that can build support for climate mitigation efforts across the political spectrum.

Using original survey data collected in 2023 from a nationally representative sample of Americans, this study employs a series of logistic regression models to examine the independent relationships between moral foundations and public perceptions of CCS with induced seismicity risks, while accounting for the influence of political party and orientation. The findings contribute to the understanding of the complex interplay between moral values, political ideology, and attitudes towards CCS, informing the development of effective communication strategies and policy framing to foster greater acceptance of CCS and other essential components of the energy transition across the political spectrum. Specifically, we ask the following research questions:

- How do individual moral foundations relate to public support for or opposition to CCS when the risk of induced seismicity is known, while controlling for political party and orientation?
- Are there interaction effects between moral foundations and political ideology in shaping attitudes toward CCS with induced seismicity risks?

2. Methods

2.1 Data and Availability

This study analyzes data from a survey conducted by the authors at the University of Oklahoma. The survey was administered online by Qualtrics to a nationally representative sample of 2,188 U.S. adults from April through May 2023. Recruitment used quota-based sampling based on age, gender, income, education, race/ethnicity, and U.S. census region to ensure accurate representativeness of the United States. The University of Oklahoma Institutional Review Board approved all study procedures under protocol #15823. Data is available to share depending on the collection and sharing guidelines of the IRB. Additional details including exact question wording and descriptive statistics are available in the SPEER23 Survey Report (Bedle et al., 2024).

2.2 Dependent Variables

Support for carbon capture was measured by asking respondents' level of agreement on whether they would oppose or favor carbon capture and storage. The exact wording of the question was as follows: "How much do you oppose or favor injecting and storing carbon dioxide in the ground to reduce greenhouse gases, even if it triggers small earthquakes that occasionally cause slight damage such as knocking items off bookshelves or picture frames off walls?" The participants were given a 6-point scale ranging from 'strongly oppose' to 'strongly favor', and we treat this as a continuous variable.

2.3 Independent Variables

The independent variables in this study are the five moral foundations, as defined by Graham et al., (2011) and Haidt & Graham (2007) and discussed previously: Care, Fairness, Loyalty, Authority, and Purity.

To assess the endorsement of these moral foundations, we used the 20 question Moral Foundations Questionnaire developed and validated by Graham et al. (2011). This questionnaire consists of 10 moral relevance questions that ask respondents to rate the relevance of various moral concepts to their thinking on a 6-point scale, and 10 additional questions that ask respondents to indicate their level of agreement with statements related to each of the five moral foundations, also on a 6-point scale.

Examples of the moral relevance questions include:

- "Whether or not someone suffered emotionally" (care/harm foundation)
- "Whether or not some people were treated differently than others" (fairness/cheating foundation)

Examples of the agreement statements include:

- "Compassion for those who are suffering is the most crucial virtue." (care/harm foundation)
- "When the government makes laws, the number one principle should be ensuring that everyone is treated fairly." (fairness/cheating foundation)

Responses to the relevance questions and agreement statements were summed to create scales for each of the five moral foundations. These scales serve as the independent variables in our analysis, allowing us to examine the relationships between individuals' endorsement of specific moral foundations and their attitudes toward carbon capture and storage with earthquake risks.

2.4 Control and Moderating Variables

We control for standard demographics and other covariates that have been shown to influence environmental attitudes in previous research, as discussed previously. These control variables include political party affiliation, which has been consistently found to be a strong predictor of attitudes toward climate change and climate action (Dunlap & McCright, 2016; Hornsey et al., 2016; McCright et al., 2016a; McCright & Dunlap, 2011). Additional socioeconomic variables such as mean-centered age (along with a squared term when significant), sex, race, education, income, marital and parental status, religious service attendance, evangelical identity, biblical views, urbanicity, and US region are also included, as many of these have been shown to influence attitudes toward CCS and other environmental issues (Boudet et al., 2016; Drummond & Fischhoff, 2017; Hamilton, 2011; Krause et al., 2014; Miller et al., 2008).

Furthermore, this study includes political orientation as a moderating variable on the relationship between moral foundations and support for carbon capture with earthquake risks. Previous research has shown that political ideology can interact with moral foundations to shape attitudes toward various policy issues (Graham et al., 2009; Haidt & Graham, 2007). By examining the moderating effect of political orientation, this study aims to provide a more nuanced understanding of how moral foundations and ideology jointly influence public perceptions of CCS and its associated risks.

2.5 Analysis

Linear regressions were estimated to evaluate relationships between moral foundations, ideology, and the dependent carbon capture with the risk of earthquakes question. Preliminary models included just control variables, and the Subsequent model added moral foundations scales. Table 1 reports full results of the regression models with the moderating variable present.

3. Results

3.1 Socioeconomic and political factors and support for CCS

The initial regression model, which included only control variables, had an adjusted R^2 of .0930 (Table 1-Model 1a). Political orientation and party affiliation were found to be significant predictors of support for CCS with the risk of induced seismicity (Figure 1). Conservatives, Independents, and Republicans were less likely to support CCS compared to their liberal and Democratic counterparts. Religious beliefs also played a role, with biblical literalists opposing CCS, while regular church attendees showed support for the technology. Additionally, race, gender, and education were significant factors, aligning with the findings of previous studies. However, family status, urbanicity, and US region did not have a significant impact on support for CCS.

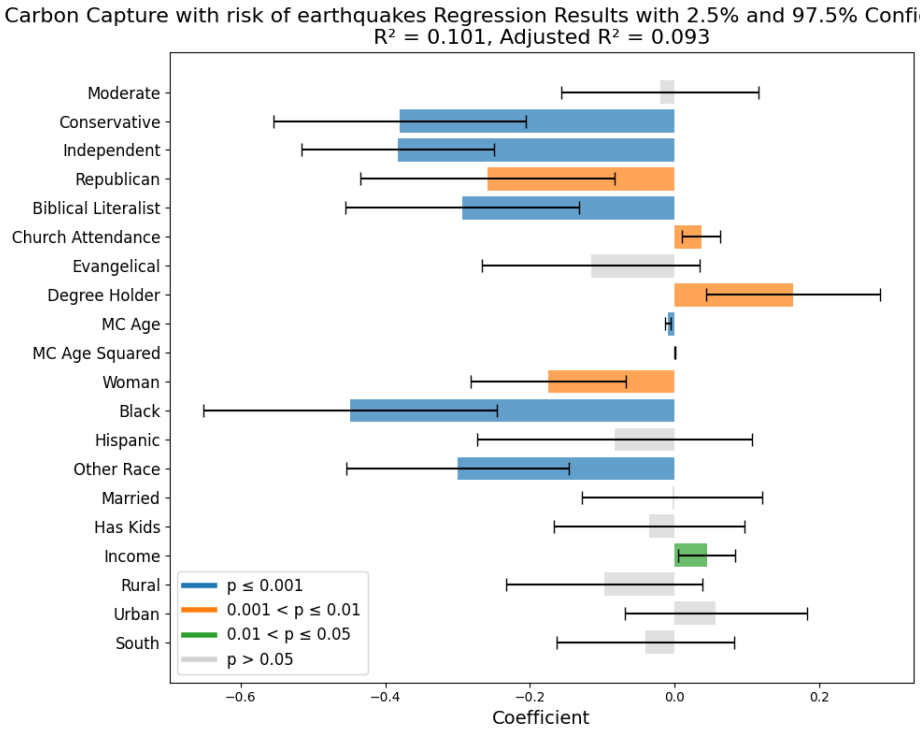
Table 1. Linear regression results for opposition and favorability towards CCS with the risk of minor earthquake occurrence.

	Model 1a β	Model 1b β	Model 1c β
Political Orientation			
Moderate	-.020	.016	.337*
Conservative	-.380***	-.310***	.165
Moral Foundations			
Care	-	.024*	.027**
Fairness	-	-.032**	-.029**
Loyalty	-	.027**	.047***
Authority	-	-.029**	-.036***
Purity	-	-.019*	-.021**
Interaction			
Loyalty x Mod.			-.031*
Loyalty x. Cons.			-.045**
Adj. R^2	.093	.106	.103

Model 1: DV = CCUSeq

* p ≤ .05 ** p ≤ .01 *** p ≤ .001

**Note: Model includes controls for party affiliation, age, sex, race, socio-economic status, family status, region, urbanicity, and religious variables*

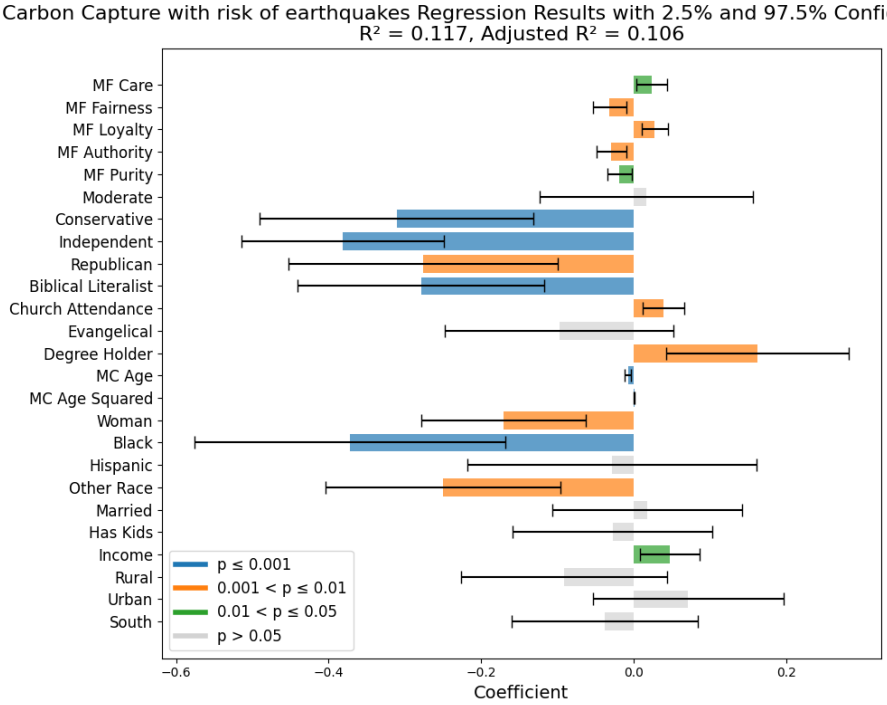


IV	coef	std err	t	P>|t|
Moderate	-0.020	0.069	-0.287	0.774
Conservative	-0.380	0.089	-4.264	0.000
Independent	-0.383	0.068	-5.624	0.000
Republican	-0.259	0.090	-2.888	0.004
Biblical Literalist	-0.294	0.082	-3.573	0.000
Church Attendance	0.037	0.014	2.719	0.007
Evangelical	-0.116	0.077	-1.508	0.132
Degree Holder	0.164	0.061	2.684	0.007
MC Age	-0.009	0.002	-4.928	0.000
MC Age Squared	0.000	0.000	3.067	0.002
Woman	-0.175	0.055	-3.194	0.001
Black	-0.449	0.103	-4.342	0.000
Hispanic	-0.083	0.097	-0.858	0.391
Other Race	-0.300	0.078	-3.830	0.000
Married	-0.003	0.063	-0.053	0.958
Has Kids	-0.035	0.067	-0.523	0.601
Income	0.045	0.020	2.230	0.026
Rural	-0.097	0.069	-1.396	0.163
Urban	0.057	0.064	0.894	0.371
South	-0.041	0.063	-0.650	0.516

Figure 1: OLS (ordinary least-squares) regression for dependent variable CCUSeq with control variables visualization and results table.

3.2 Moral foundation and support for CCS

The inclusion of the five moral foundations in the regression model (Figure 2) revealed distinct relationships with support for CCS in the context of induced seismicity risks (Table 1 – Model 1b). Individuals who scored higher on the moral foundations of Care and Loyalty were more likely to favor CCS, despite the potential risk of earthquakes. Conversely, those who placed greater emphasis on the moral foundations of Fairness, Authority, and Purity were more inclined to oppose CCS when considering the possibility of induced seismicity.



IV	coef	std err	t	P>|t|
MF Care	0.024	0.010	2.302	0.021
MF Fairness	-0.032	0.011	-2.825	0.005
MF Loyalty	0.027	0.009	3.104	0.002
MF Authority	-0.029	0.010	-2.960	0.003
MF Purity	-0.019	0.008	-2.312	0.021
Moderate	0.016	0.071	0.229	0.819
Conservative	-0.311	0.091	-3.397	0.001
Independent	-0.381	0.068	-5.635	0.000
Republican	-0.276	0.090	-3.078	0.002
Biblical Literalist	-0.279	0.082	-3.379	0.001
Church Attendance	0.039	0.014	2.823	0.005
Evangelical	-0.098	0.077	-1.279	0.201
Degree Holder	0.162	0.061	2.648	0.008
MC Age	-0.008	0.002	-4.168	0.000
MC Age Squared	0.000	0.000	3.335	0.001
Woman	-0.171	0.055	-3.116	0.002
Black	-0.372	0.104	-3.584	0.000
Hispanic	-0.029	0.097	-0.298	0.766
Other Race	-0.250	0.078	-3.196	0.001
Married	0.017	0.063	0.277	0.782
Has Kids	-0.028	0.067	-0.417	0.677
Income	0.047	0.020	2.356	0.019
Rural	-0.091	0.069	-1.328	0.184
Urban	0.071	0.064	1.117	0.264
South	-0.038	0.062	-0.609	0.542

Figure 2: OLS regression for dependent variable CCUSeq with control variables and moral foundation independent variables.

3.3 Interaction between MF Loyalty and political orientation

For Model 1c (Table 1), among the five moral foundations, only Loyalty exhibited a significant interaction with political orientation. This finding is not surprising, given that political orientation often serves as a strong group identifier, particularly for polarizing topics such as climate change and climate mitigation strategies. The analysis revealed that liberals who scored higher on Ingroup loyalty were drastically more likely to favor CCS, even with the risk of induced seismicity (Figure 3). Moderates displayed a similar, albeit more muted, effect, showing increased support for CCS as their Ingroup loyalty increased. In contrast, conservative support for CCS remained relatively unchanged, regardless of their level of ingroup Loyalty. Overall, conservatives were the least supportive group towards CCS when considering the risk of induced earthquakes. This can be seen in more detail in Figure 4, where political orientation is plotted as a two-way contour with the original survey orientation scale of 7 points. More conservative ideologies do support CCUS more if they have lower Loyalty foundations. On the other hand, for those with higher Loyalty values, the more liberal they are, the stronger they support CCS.

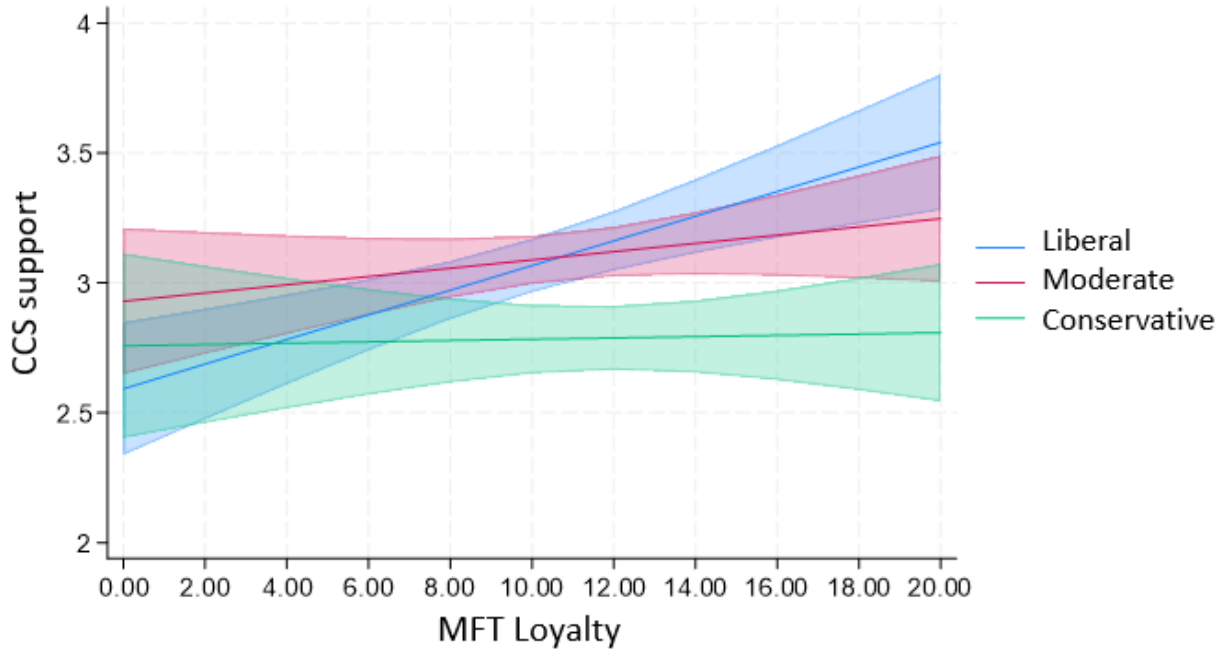


Figure 3: Interaction plot for the moral foundation of loyalty and political orientation for CCS support with the risk of small earthquakes

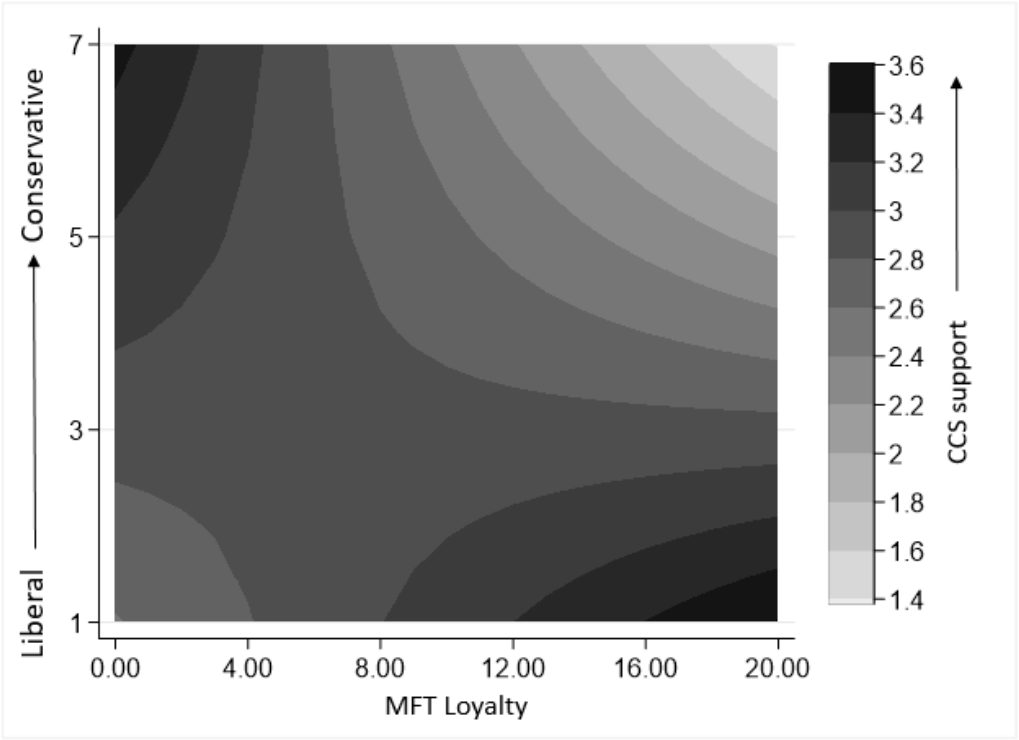


Figure 4: Two-way contour for political orientation and Loyalty for support for CCS with the risk of small earthquakes.

4. Discussion

4.1 The role of moral foundations in shaping attitudes towards CCS

The present study aimed to examine the relationships between moral foundations and public perception of carbon capture and storage with induced seismicity risks, while controlling for political party and orientation. Our results demonstrate that the binding moral foundation of Loyalty and the individualizing foundation of Care were associated with support for CCS, despite the risk of small earthquakes. This finding aligns with research by Koleva et al. (2012), who found that the moral foundations of care, fairness, and purity were significantly related to support for tougher measures on global warming. Similarly, Jansson and Dorrepaal (2015) observed that the moral foundations of harm and fairness were positively associated with personal climate change norms, suggesting that concerns for the well-being of others and the environment can drive acceptance of climate mitigation strategies like CCS.

Interestingly, the individualizing foundation of Fairness and the binding foundations of Authority and Purity were correlated with opposition to CCS when considering the possibility of induced seismicity. These results suggest that individuals who prioritize these moral foundations may perceive CCS with induced seismicity risks as a violation of their moral concerns. For example, those who emphasize the Fairness foundation may view the distribution of risks and benefits associated with CCS as unjust, consistent with the findings of Dawson and Tyler (2012) and Jansson and Dorrepaal (2015), who noted that fairness concerns shape views on the equal sharing of climate mitigation costs and seeking justice against perpetrators of the climate crisis. Similarly, individuals who place a high value on the Purity foundation may consider the injection of CO2 into the subsurface as a form of contamination or desecration of the natural environment, echoing the values of perceived "interference with nature" identified by L'Orange Seigo et al. (2014) as important in shaping public attitudes towards CCS.

These findings contribute to a more nuanced understanding of the moral and psychological factors shaping public attitudes towards CCS and its associated risks. By revealing the specific moral foundations that are associated with support for or opposition to CCS in the context of induced seismicity, our study highlights the importance of considering the diverse moral concerns of different population segments when designing and communicating CCS policies and projects. This is consistent with the solution aversion model proposed by Campbell and Kay (2014), which suggests that skepticism towards issues like climate change may be caused by the implications that climate change solutions hold for certain individuals' ideological values. It is important to be aware that individuals who prioritize different moral foundations may have different reasons for supporting or opposing CCS, and these reasons may not always align with the information used to promote CCS as a climate mitigation strategy.

Our results suggest that effective public engagement and risk communication strategies for CCS should go beyond simply providing information about the technical aspects of CCS and its potential risks and benefits. Instead, these strategies should also aim to address the underlying moral concerns and values that shape individuals' attitudes towards CCS. This is in line with the recommendations of Terwel et al. (2012) and Yang et al. (2016), who emphasized the importance of trust in stakeholders and perceived fairness in decision-making processes for public acceptance of CCS projects. By acknowledging and engaging with the diverse moral foundations that influence public perceptions of CCS, policymakers and

communicators may be able to create more targeted and persuasive approaches to building trust and support for CCS projects, as suggested by the findings of Feinberg and Willer (2013) and Koleva et al. (2012).

In regards to MFT, our survey shows insights that can be used to help shape public attitudes towards CCS with induced seismicity risks. The findings highlight the importance of considering the diverse moral concerns that underlie public support for or opposition to CCS, as emphasized by researchers such as Campbell and Kay (2014), Feinberg and Willer (2013), and Jansson and Dorrepaal (2015). By understanding and addressing these moral foundations, policymakers and project developers can work towards more effective and socially acceptable deployment of CCS as a critical component of the global response to climate change.

4.2 The interaction between moral foundations and political orientation

The interaction observed between the moral foundation of Loyalty and political orientation provides further insights into the nuanced nature of public attitudes towards CCS. Liberals and moderates tended to increase their support for CCS with the risk of earthquakes as their group loyalty increased, while conservatives' support remained unchanged. This finding suggests that liberals with stronger loyalty ties may be more willing to accept the risk of small earthquakes in favor of climate mitigation solutions, as their commitment to their group's values and goals, which often prioritize environmental protection, outweighs the perceived risks associated with CCS.

The two-way contour plot (Figure 4) reveals an intriguing pattern in the relationship between political orientation, Loyalty, and support for CCS with induced seismicity risks. Among the most conservative individuals, support for CCS decreases as their Loyalty increases. However, strong conservatives with low Loyalty tend to support CCS, possibly due to a reduced emphasis on group values and a greater focus on individual concerns. In contrast, among those with higher Loyalty values, support for CCS increases as individuals become more liberal. This suggests that the interaction between Loyalty and political orientation is not a simple linear relationship.

This is somewhat consistent with the solution aversion model proposed by Campbell and Kay (2014), which argues that skepticism towards issues like climate change may be driven by the perceived implications of climate change solutions for an individual's ideological values. In this case, conservatives with strong Loyalty ties may view CCS as a threat to their group's values and goals, such as the preservation of traditional energy systems and the rejection of government intervention in the economy. As a result, they may be more likely to oppose CCS, even in the face of potential benefits for climate mitigation.

The significance of political factors in shaping attitudes towards CCS is further supported by the findings of Pianta et al. (2021), who highlighted the role of policy design features and political ideology in influencing public support for CCS policies. They note the need to consider the ideological polarization around climate change when proposing and implementing CCS policies, which aligns with our findings.

As we consider the implications of our results for effective energy transition strategies, policymakers and communicators should take into account the dynamics of moral foundations when designing public messaging campaigns and policy initiatives related to CCS, especially when addressing the potential risks associated with induced seismicity. This is in line with the findings of Adger et al. (2017) and Campbell

and Kay (2014), who emphasized the importance of considering moral reasoning and ideological values in the context of climate change adaptation and motivated disbelief.

To develop effective communication strategies and policy frameworks that foster public acceptance of CCS and other essential components of the energy transition, it is crucial to understand the complex interplay between moral values, political ideology, and risk perceptions, as highlighted by Steg et al. (2015) and Trutnevyte (2018). Our findings suggest that a nuanced approach, tailored to the distinct moral concerns and political orientations of different population segments, may be most effective in building support for CCS, for instance, emphasizing the loyalty aspect of supporting CCS as a climate mitigation strategy might be particularly effective for engaging liberals, as our results indicate that liberals with stronger loyalty ties are more likely to accept the risks associated with CCS in favor of climate mitigation goals. In contrast, highlighting the potential economic benefits and job creation associated with CCS might resonate more strongly with conservatives, who may be more receptive to arguments that align with their ideological values and priorities.

4.3 The role of risk perception and personal experience

The role of risk perception in shaping attitudes towards CCS is further supported by the findings of Shah et al. (2022), which highlight the importance of perceived risks and benefits in determining public support for CCS. The "risk-risk tradeoff" concept discussed in their paper is particularly relevant to our results, as it suggests that individuals weigh the risks of climate change against the risks of induced seismicity when forming their opinions on CCS. This tradeoff may be influenced by moral foundations and political orientation, with liberals prioritizing climate mitigation and conservatives focusing more on the potential risks associated with CCS.

Additionally, Hornsey et al. (2016) found in their meta-analysis that climate change beliefs have only a small to moderate effect on people's willingness to act in climate-friendly ways. This suggests that while beliefs in climate change can motivate people to support environmental policies in principle, this support may waver for policies that imply personal costs. These personal costs could reasonably related to earthquake risks, or moral costs and is something to consider when tackling the communication of risks associated with the energy transition.

The findings of Zoback and Gorelick (2012), White and Foxall (2016) and Bedle et al. (2022) underscore the importance of considering induced seismicity risks in the context of public attitudes towards CCS, especially as Zoback and Gorelick (2012) and White and Foxall (2016) argue that there is a high probability that earthquakes will be triggered by the injection of large volumes of CO2 into brittle rocks commonly found in continental interiors. They emphasize that even small- to moderate-sized earthquakes can threaten the seal integrity of CO2 repositories, perhaps creating additional subsurface risks. With this in mind and thinking about how people’s perceptions may change as they experience earthquakes, Bedle et al. (2022) found that personal experience with earthquakes significantly shapes perceptions of past and future seismicity in a case study in Oklahoma. As people experienced more seismicity, their awareness and concern about future seismic events increased, as did their concern about global climate risk. These results align with construal level theory (Trope and Liberman, 2003), which suggests that events become more concrete and concerning when directly experienced. As people become more concerned about induced seismicity, it follows that the perceived risks of CCS may become too high to continue support for this type of carbon mitigation, which then may have broader

implications for the acceptance of other energy transition technologies that may involve similar risks, such as geothermal injection and hydrogen storage. As these technologies become increasingly important in the effort to mitigate climate change and introduce new energy sources to society.

4.4 Limitations and future research directions

It is important to acknowledge the limitations of our study and suggest future research directions. While our study focused on CCS, future research could examine the role of moral foundations in shaping attitudes towards other energy transition technologies. Additionally, future studies could investigate the effectiveness of different communication strategies tailored to specific moral foundations and political orientations in increasing public acceptance of CCS and other energy transition technologies.

In summary, our findings, combined with the insights regarding induced seismicity from Bedle et al. (2022) and Zoback and Gorelick (2012) and others, highlight the complexity of public perceptions and the need for careful consideration of both the technical and social aspects of seismic risks in the development and communication of CCS projects. The strong influence of perceived social norms on information seeking intentions in the study by Kahlor et al. (2019) could be related to the Loyalty foundation, as it involves aligning one's actions with the expectations of close others. This finding provides additional support for the relevance of the Loyalty foundation in shaping attitudes and behaviors related to CCS and induced seismicity risks, as observed in our study.

5. Conclusion

The demographically representative social survey of Americans in 2023, reveals a complex interplay between moral foundations, political factors, and risk perceptions in the public attitudes toward carbon capture and storage with induced seismicity risks. The binding moral foundations of Loyalty and the individualizing foundation of Care were associated with support for CCS, while the individualizing foundation of Fairness and the binding foundations of Authority and Purity were correlated with opposition when considering induced seismicity. The interaction between Loyalty and political orientation further highlights the nuanced nature of the acceptance of CCS by the public.

The insights from this study, combined with the findings of Shah et al. (2022), Bedle et al. (2022),and Zoback and Gorelick (2012), emphasize the importance of considering both technical and social aspects of induced seismicity risks in the development and communication of CCS projects. Policymakers and communicators should consider the dynamics of moral foundations in conjunction with political factors when crafting public messaging campaigns and policy initiatives related to CCS and other energy transition technologies that have an inherent risk associated with them. As the world continues to grapple with the challenges of climate change and the need for a sustainable energy transition, understanding the complex factors that influence public perceptions and acceptance of new technologies will be essential for developing effective policies and strategies to mitigate greenhouse gas emissions and address associated risks.

Data and Code Availability

As much as is allowed by the IRB and survey collection agreements, data and code can be made available by contacting speer@ou.edu.

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