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by Carola Braun

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Abstract:
Carbon capture and storage (CCS) is a technology that counteracts climate change by capturing atmospheric emissions of CO2 from human activities, storing them in geological formations underground. However, CCS also involves major risks and side effects, and faces strong public opposition. Recently, the whereabouts of 408 potential CCS storage sites in Germany have been released. Using detailed survey data on the public perception of CCS, I quantify how living close to a potential storage site affects the acceptance of CCS. I also analyse the influence of other regional characteristics on the acceptance of CCS. I find that respondents who live close to a potential CCS storage place have significantly lower acceptance rates than those who do not. Living in a tourism or mining region also markedly decreases acceptance.

Keywords: Carbon capture and storage, NIMBY, climate change mitigation

JEL classification: Q54, D19, C93

Carola Braun (corresponding author)
Kiel Institute for the World Economy
24105 Kiel, Germany
E-mail: carola.kniebes@ifw-kiel.de

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1. Introduction

Carbon capture and storage (CCS) is a technology that removes atmospheric emissions of CO_2 from human activities and transport it to a storage site. The large-scale use of CCS from 2030 onwards is considered a key factor for reaching the 2°C target (IPCC 2014). In fact, all available projections suggest that the use of CCS is required to reach the 1.5 C global warming target, recently agreed on the 2015 United Nations Climate Change Conference in Paris. It is expected that CCS will become cost competitive soon (International Energy Agency 2015). However, local residents have, in the past, often fiercely opposed CCS pilot tests in Germany. These local tests gather information on the benefits and risks of CCS and are thus necessary before CCS can be applied on a large scale. It is therefore important to understand what drives local acceptance of CCS and, in particular, how the prospect of a CCS site in the neighbourhood affect local acceptance. Against this background, this paper analyses regional factors that shape the acceptance of CCS in Germany.

CCS captures CO_2 from the industrial combustion of fossil fuels before it enters the atmosphere. The captured CO_2 is first compressed and then transported to long-term storage sites. Scientists consider geological formations such as saline aquifer formations and depleted gas fields as suitable long-term storage sites. In Germany, the whereabouts of all 408 such potential saline aquifer CCS storage sites have been released in 2011 (German Federal Institute for Geosciences and Natural Resources, Greenpeace 2011). These potential storage sites are very unequally distributed across Germany. In fact, more than half of the sites are located in the northern states of Schleswig-Holstein and Lower Saxony (see Figure 1).

Putting a CCS storage site in place poses a typical public good distribution conflict: the risks of storing CCS underground are borne locally, while the benefits accrue to everyone (Rickels et al. 2011; Rosa 1988). In general, climate change and its mitigation are, by definition, public goods, as they are non-rival and non-excludable. In particular, actors who do not participate in climate mitigation efforts cannot be effectively excluded from the benefits of mitigation (IPCC 2012; Barrett 2007; Milinski et al. 2008). This also holds for CCS, as everyone benefits from the CO_2 reduction achieved by CCS. In contrast, only local actors bear the risks of CO_2 leaks from underground CCS storage sites. The tension between local risks and global benefits causes a public good distribution conflict (Rosa 1988). This distribution conflict might induce residents to develop a “not in my Backyard” (NIMBY) attitude, so that residents who live close to a CCS storage site show lower levels of acceptance.[1]

In this paper, I quantify the effect of potential CCS storage sites and other regional characteristics on the acceptance of CCS in Germany, and shed light on the potential channels through which the NIMBY effect operates. The paper is the first to analyse the NIMBY effect for CCS in Germany. Since Germans are more

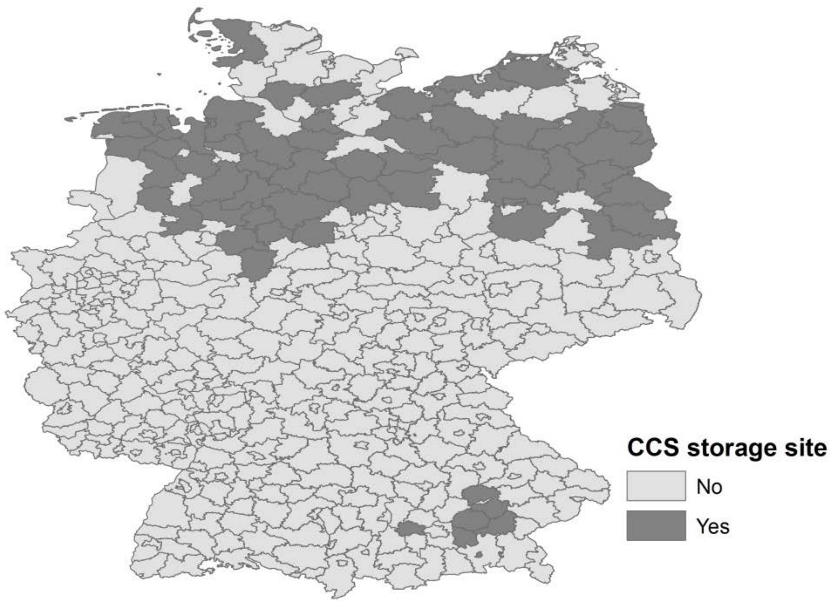
[1] The term ‘NIMBY’ (not in my backyard) is widely used in the literature to describe the phenomenon that support for a technology decreases with increasing proximity to its location (see e.g. Frey and Oberhölzer-Gee 1997; Johnson and Scicchitano 2012).

sceptical towards potentially risky technologies, such as nuclear energy or CCS, than other Europeans (European Commission 2011), Germany is an especially interesting case to consider. More generally, the paper is the first to analyse the acceptance of respondents who indeed live close to a potential CCS storage site and might thus be directly affected by CCS in the future.

In my empirical analysis, I combine novel survey data on the public perception of CCS in Germany with data on the exact locations of all potential CCS storage sites. I find that respondents who live close to a potential CCS storage site have indeed significantly lower acceptance rates than those who do not. This effect is robust to the inclusion of other potential determinants of CCS acceptance at both the individual and the regional level. Living in a tourism or coal mining region also markedly decreases acceptance. Finally, I present suggestive evidence that living close to a CCS storage site reduces acceptance by increasing the perceived risk of CCS and decreasing the perceived benefits.

The remainder of the paper is structured as follows. Section 2 surveys the previous literature and relates it to my research questions. Section 3 outlines the survey design and the data, while Section 4 presents the empirical approach. Section 5 describes the main results of the empirical analysis, and Section 6 discusses additional robustness checks. Section 7 concludes.

Figure 1: Potential CCS storage sites in Germany



Source: Own presentation with data from Knopf et al. (2010), German Federal Institute for Geosciences and Natural Resources.

2. Literature review

There exists a growing literature on public perception of CCS. However, most of these studies do not consider regional variation in acceptance rates, and thus do not analyse regional determinants of CCS.

There are large cross-country differences in public acceptance of CCS, and existing studies report both negative and positive attitudes towards CCS. Hund and Greenberg (2011), for instance, find that respondents in the US state of Illinois perceive the economic benefits of CCS as more important then their potential risks. In contrast, respondents in Europe typically raise concerns about the risks of CCS (European Commission 2011), but perceptions differ across countries. Romanians, for instance, accept CCS much more readily than Germans (Pietzner et al. 2011). Even within Germany, the few existing case studies suggest that the acceptance of CCS differs significantly across regions (Dütschke 2011; Fischedick et al. 2008). Dütschke (2011), for example, shows that local residents in the East German town of Ketzin perceive CCS rather positively, whereas residents in the East German town of Beeskow strongly oppose CCS. However, so far no study has analysed variations in local acceptance rates for Germany as a whole.

In general, previous studies show that individual-specific attitudes such as the perception of climate change or trust in institutions influence the acceptance of CCS (Kniebes et al. 2014; Terwell et al. 2009). Concerns about risks such as leakage, over-pressurization of the reservoir, and the fear of negative effects on the natural environment and public health reduces acceptance of CCS (Krause et al. 2014; Ashworth et al., 2010; Palmgren et al. 2004; Shackley et al. 2005; Wallquist et al. 2010). For countries other than Germany, safety concerns about local storage sites and falling local property prices have been shown to decrease acceptance, pointing towards a regional dimension of CCS (Krause et al. 2014; Terwel and Daamen 2012). In contrast, potential economic benefits of CCS facilities increases support for locating such facilities in the neighbourhood (Krause et al. 2014; Hund and Greenberg 2011). However, Krause et al. (2014) and Hund and Greenberg (2011) do not explicitly distinguish between the expected benefits and risks of CCS storage sites, CCS power plant and pipelines. This might lead to biased results as CCS storage sites bear most local risks, such as leakage, whereas CCS power plants also generate economic benefits by, for instance, creating new jobs.

A possible explanation for regional variation in the acceptance of CCS is the so-called “not in my Backyard” (NIMBY) effect. The NIMBY effect describes the phenomenon that residents oppose a technology, for example a windfarm, if it is too close to their homes. Often, these residents indicate that they generally support the technology, but only if it is located far away from their homes (i.e., not in their backyard). In our context, the NIMBY effect suggests that living close to a potential CCS storage site reduces the acceptance of CCS.

A few studies have provided evidence that the NIMBY effect indeed exists for CCS. A Eurobarometer poll found that the public is generally concerned about CCS storage sites within 5 km of their home (European Commission, 2011). In Switzerland, respondents are concerned about CCS storage sites near their home, but even more concerned about CCS power plants and pipelines (Wallquist et al. 2012). For the Netherlands, Huijts et al. (2007) and Terwel and Daamen (2012) provide evidence on the NIMBY effect for CCS. Huijts et al. (2007) use evidence from a case study and compare the perceptions of CCS between two Dutch municipalities. They find that CCS storage sites located in respondents' own residential area were perceived more negatively than sites located somewhere else. Terwel and Daamen (2012) show in a survey experiment that respondents who receive the (hypothetical) information of living above a potential CCS storage site show stronger concerns about the safety risks of CCS.

Krause et al. (2014) uses survey data to analyse the acceptance of CCS in general in the coal-rich US state of Indiana. Respondents reveal rather positive attitudes towards CCS: 80% of the local residents in Indiana support the use of CCS in general. However, a fifth of those who support CCS in general would oppose CCS in their local communities. Therefore, the NIMBY effect seems to reduce local support for CCS. The NIMBY effect only describes that resident often oppose locally applied technologies. It remains silent on the underlying causes, such as changes in risk perception (Devine-Wright 2005; Wolsink 2000; 2006). These underlying causes may play an important role when focussing on the perception of CCS storage sites, which bear severe local risks, but offer global benefits.

Overall, my study contributes to the existing literature in various ways. In contrast to previous studies and novel to literature, I match survey data on the public perception of CCS with geographic information about the location of CCS power plants and potential storage sites. Therefore, I do not ask respondents whether they would (hypothetically) accept a CCS storage site or CCS power plant next to their house or not (as all previous studies did). Rather, I compare perceptions of respondents who are living close to a potential storage site to those who are not. This has the advantage that some respondents in my data are not only confronted by a hypothetical scenario but face the actual risk that their region is selected as a storage site in the future. My paper is also the first to analyse the NIMBY effect for CCS in Germany, and, more generally, the first to study local determinants of CCS acceptance for Germany as a whole (previous studies for Germany have focused only on specific regions). Moreover, and novel to literature, I also distinguish between the effect of CCS storage sites and the effect of industrial power plants that use the CCS technology to capture CO_2. Finally, I analyse potential causal pathways such as a risk perception through which living close to a potential CCS storage site might affect acceptance, and thus shed light on underlying factors that might be responsible for the NIMBY effect.

3. Data and survey design

This paper combines individual-level survey data on the public perception of CCS in Germany with data on the exact location of potential CCS storage sites and CCS power plants as well as with data on other regional characteristics. The survey data contains the county (*Kreis/kreisfreie Stadt*), in which a respondent is living. I use this regional information to identify whether a respondent lives in a county that hosts a CCS storage sites or a CCS power plant, and to link the data with other county characteristics. In the following, I briefly describe the three data sources:

Survey data

I use data from an internet representative online survey which was conducted in August 2013. Respondents aged 18 or above were recruited via an online panel. They are sampled using quotas for the characteristics of gender, age, and state of residence. In total, the working sample includes 332 observations. The average age of respondents is 49 years. Fifty-four percent of our respondents are male. Thirty percent of our respondents have a higher education entrance certificate. Table A-1 in the appendix provides summary statistics for the survey data used in my analysis.

The survey was structured as follows. At the beginning, respondents were asked about their level of awareness of the CCS. Afterwards, the survey provided respondents with information on CCS using animated graphics videos. The animations explained the information graphically and were supported by verbal explanations spoken by a professional radio presenter. The video was embedded into the survey.[2] The video first provided respondents with information on anthropogenic climate change and its likely consequences. The video then introduced mitigation, adaption and CCS as three possibilities to address climate change. Afterwards, the video explained CCS in more detail, i.e., CCS's underlying mechanisms and its impact on climate change. The video then informed participants about the current state of research and the potential benefits and risks of CCS. The information was based on peer-reviewed papers and scientific reports (taken from, e.g., IPCC 2005; IPCC 2007; IPCC 2012; UBA 2008). External experts checked the information for correctness and clarity. After watching the video, the survey asked respondents about the clarity of the video. More than 98% of the respondents indicated that they understood the video well or very well.

Afterwards, the survey elicited respondents' acceptance of CCS and asked them about their risk and benefit perception of CCS. Finally, the survey elicited respondents' socio-demographic characteristics, such as gender, age, county of residence and education.

Respondents could refrain from answering. The option 'don't know' was included in every question.

Data on CCS storage sites and power plants

The information on the exact location of all potential CCS storage sites in Germany comes from the German Federal Institute for Geosciences and Natural Resources (Knopf et al. 2010). The list contains all 408 potential CCS storage sites, where CO_2 could be stored in saline aquifers. Most CCS storage sites are located in East Freesia and below the mudflats off the coast of Schleswig-Holstein (see Figure 1, Section

[2] An English translation of the German script of the video is provided in appendix.

1). Some are also located close to the cities of Hamburg, Berlin and Munich and in certain parts of North Rhine-Westphalia and West-Mecklenburg Pomerania.

The information on potential storage sites were first released by Greenpeace in February 2011 (Greenpeace 2011). Previously, the locations of potential CCS storage sites were not known. We can thus expect that respondents in our data did not move endogenously to avoid living close to a potential storage site. The announcement of Greenpeace created a lot of media attention in Germany not only in regional newspapers, but also in nationwide newspapers and on TV.

The information on the location and status of CCS power plants comes from the operating companies themselves. At the time of our survey, there were 6 power plants in Germany, which conducted pilot tests with the CCS technology.

Data on regional characteristics of counties

The data on regional characteristics of a county comes from the Regional Database Germany (*Regionalstatistischen Datenkatalog des Bundes und der Länder*). The data is mainly collected by the German Statistical office and publicly available.

4. Methodology

My analysis consists of three steps:

In the first step, I use a regression framework to analyse the effects of living in a county with a potential CCS storage site on an individual's acceptance of CCS. I also analyse the effect of the number of storage sites located in a county and take spill over effect from neighbouring counties into account.

In particular, I estimate the following equation:

$$(I) \quad acceptance_{i,j} = \alpha + \beta X_i + \gamma Y_j + \varepsilon_{i,j}.$$

The dependent variable *acceptance* measures the level of CCS acceptance of individual *i* who lives in county *j*, measured as the level of (dis)agreement with the use of CCS. The variable *acceptance* takes ordered values from 1 ('strongly disagree') to 4 ('strongly agree'). X_i is a vector of individual socio-demographic characteristics (*gender*, *age*, *education*, *income*). *Gender* indicates whether individual *i* is female; *age* measures his or her age; education indicates whether individual *i* has a higher education entrance certificate; *income* measures his or her monthly household net income in Euro.

Y is a vector that contains three different alternative indicators for the regional presence of CCS storage sites. First, Y includes the variable *CCS storage sites,* which indicates whether county *j* has at least one potential CCS storage site. Second, it includes the variable *Number of CCS storage sites*, which measures the number of CCS storages sites in county *j*. Third, Y_j also includes the variable *CCS storage site neighbourhood,* which indicates whether county *j* borders on a county with a CCS storage site. I do not add the three indicators simultaneously but consider them one by one. I restrict the sample to those who do not live in a county with a CCS storage site when considering spill-over effects.[3] The coefficient estimate of interest is γ, which is negative if living close to a CCS storage site reduces acceptance.

In a second step, I analyse the influence of other county characteristics on acceptance. For doing so, I add sequentially county characteristics Z to equation (I), and estimate the following equation (II):

$$(II) \quad acceptance_{i,j} = \alpha + \beta X_i + \gamma Y_j + \delta Z_j + \varepsilon_{i,j}.$$

Z_j is a vector that contains county specific characteristics (east, coal mining, CCS power plant, tourism intensity, population density, and Green/Left party). The dummy variable *east* indicates whether a county is located in the eastern part of Germany. The dummy variable *coal mining* indicates whether there is coal mining in a county or not. Previous experiences with coal mining might reduce the acceptance of further interventions in the ground and might therefore decrease the acceptance of CCS.

The dummy variable *CCS power plant* indicates whether there is a power plant in a county that uses CCS technology to capture CO_2. CCS power plants are not necessarily located next to CCS storage sites. The variable *tourism intensity* equals the overnights stays in hotels in a county divided by the population in the same county. Respondents who live in a county with high tourism intensity might report lower levels of CCS acceptance as they might perceive CCS as a threat to the tourism sector of the region.

The variable *population density* equals the population over the area of a county. Respondents who live in highly populated urban areas might perceive CCS differently than respondents who live in the countryside.

The variable *Green/Left party* measures the local vote share of the Green and Left party in the 2013 election for the German parliament. I expect this variable to negatively correlate with local acceptance of CCS, since the two parties strongly oppose CCS.

In a third step, I analyse potential causal pathways through which CCS storage sites might affect acceptance. In particular, I hypothesize that living in a county with a potential CCS storage site affects acceptance by changing the awareness of CCS or the perception of risk and benefits. I test these hypotheses by adding measures of awareness and perception to equation (I), and estimate the following equation (III):

[3] I restrict the sample in this way as almost every individual in my sample who lives in a county with a CCS storage site also lives next to a county with a CSS storage site. Due to multi-collinearity, I am therefore not able to distinguish direct from spill-over effects for individuals who live in a county with a CCS storage site.

$$(III) \quad acceptance_{i,j} = \alpha + \beta X_i + \gamma Y_j + \mu W_i + \varepsilon_{i,j}.$$

W_i is a vector that contains measures of an individual's awareness and perception of CCS (level of awareness, risk perception, benefit perception). The variable *awareness* captures self-reported awareness of CCS. It takes ordered values from 1 if a respondent had never heard about CCS before to 3 if the respondent had heard a lot about CCS before. The variables r*isk perception* and *benefit perception* measure how an individual assesses the risk and benefits of CCS. Both variables take ordered values from 1 ('very small) to 4 ('very large'). If indeed the presence of a potential CCS storage site affects acceptance through any of the variables in W, the coefficient estimate of β should be pushed towards zero by including W. At the same time, awareness and/or perception should have a significant effect on acceptance.

I estimate all equations by OLS.[4] Standard errors are clustered at the level of administrative districts (*Regierungsbezirke*) to allow for a correlated error terms.

5. Results

In the following, I first present the results on the effect of CCS storage sites on the acceptance of CCS from estimating equation (I). I then present the results from estimating equation (II), which also accounts for other county characteristics. Finally, I shed light on possible causal pathways through which CCS storage sites affect acceptance by presenting the results from estimating equation (III).

Effects of potential CCS storage sites

Table 1 reports the results from estimating equation (I). In the baseline Regression in column (1), I use a dummy variable that indicates the existence of at least one CCS storage sites in a county. The result suggests that the acceptance of CCS declines by 0.24 points if an individual lives in a county that has at least one potential CCS storage site. This corresponds to a 10% percent increase relative to the sample mean of 2.54 points. The effect is statistically significant with a p-value of 0.081. Furthermore, I find that the acceptance of CCS is 0.31 points higher for females than for males. All other socio-demographic characteristics do not have a statistically significant effect on acceptance.[5]

In column (2), I replace the dummy variable for CCS storages sites by a continuous variable that counts the number of CCS storage sites in a county. I find that the acceptance of CCS declines by 0.11 points for every additional CCS storage in a county. The effect is statistically significant with a p-value of less than

[4] As a robustness check, I also performed ordered logit regressions. The results, which can be obtained from the author upon request, are very similar to the OLS results.

[5] In unreported regressions, I also include interaction terms between socio-demographic characteristics and CCS storage site. The regressions suggest the negative effect of living close to a CCS storage site is stronger for males and for high educated individuals. However, the differences are not statistically significant.

0.001. Overall, therefore, I find clear evidence that living in a county with at least one potential CCS storage site reduces an individual's acceptance of CCS.

Next, I test for the existence of spill-over effects, restricting the sample to those who do not live in a county with a CCS storage site. In particular, I add a dummy to the regression equation that indicates whether an individual lives in a county that borders on a county with a CCS storage site. The results in column (3) suggest that spill-over effects indeed exist. Living next to a county with at least one CCS storage site reduces the level of acceptance by 0.21 points. Therefore, the presence of CCS storages sites appears to reduce the level of acceptance in a relatively large geographic area.

Table 1: OLS regression equation (I), clustered standard errors

Acceptance	(1)	(2)	(3)
CCS storage site	-0.2375*		
	(0.1322)		
Number of CCS storage sites		-0.1082***	
		(0.0264)	
CCS storage site neighbourhood			-0.2140*
			(0.1155)
Female	0.3067**	0.3166**	0.2822**
	(0.1161)	(0.1137)	(0.1130)
Age	0.0011	0.0011	0.0026
	(0.0036)	(0.0037)	(0.0038)
Education	-0.0955	-0.1118	-0.0337
	(0.0995)	(0.1040)	(0.1054)
Income	0.0003	0.0004	0.0001
	(0.0004)	(0.0004)	(0.0004)
Constant	2.3536***	2.3433***	2.3504***
	(0.2295)	(0.2290)	(0.2314)
Observations	332	332	282
R^2	0.0340	0.0422	0.0324

Standard errors clustered at the level of administrative districts in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Acceptance is measured on a scale of 1 (strongly disagree) to 4 (strongly agree).

Influence of regional characteristics

I next add, one by one, additional county characteristics as explanatory variables, taking model (1) of Table 1 as the baseline regression. The results presented in Table 2 show that the significantly negative effect of living in a county with a potential CCS storage site remains robust to the inclusion of additional county characteristics. If anything, the negative effect of CCS storage sites becomes stronger with the inclusion of additional controls. This is a first indication that the negative effect of CCS storages sites is not driven by unobserved county characteristics.

Column (1) adds a dummy for living in the eastern part of Germany to the regression. The result suggests that respondents from the eastern part of Germany have a significantly higher level of acceptance than respondents from the western part of Germany. However, the significantly negative effect of living in a county with a potential CCS storage site remains robust to this inclusion and becomes even stronger compared to the baseline scenario.[6] I also find that respondents who live in a county with a high vote share for the Green and Left party show significant lower levels of acceptance (column 2). Both parties strongly oppose CCS.

I also find that respondents who live in a county with coal mining report a significantly lower acceptance of CCS (column 3). Previous experiences with coal mining might reduce the acceptance of further interventions in the ground or might increase fears of further industrialization of the region.

Moreover, I find that respondents who live in a county with high tourism intensity report a significantly lower acceptance of CCS (column 5). Respondents who live in such counties might perceive CCS as a threat to the tourism sector of the region.

In contrast, I do not find a statistical significant effect of CCS power plants (column 4) on the acceptance of CCS. This result seems plausible, as the major risk of CO_2 leakage does not occur when capturing CO_2 but when storing the captured CO_2 in underground formations. I do also not find a statistically significant effect of population density (column 6) on the acceptance of CCS.

Finally, column (7) shows that the CCS storage sites effect remains robust if I control for all regional characteristics at once. The results are very similar if I use the number of CCS storage site rather than the CCS dummy as explanatory variable (see Table A-2, column (2), in the Appendix).

Table 2: OLS regression results equation (II), clustered standard errors

[6] In an unreported additional regression, I also control for living in the city states of Hamburg or Bremen. Again, I continue to find a negative and statistically significant effect of CCS storage sites on acceptance. In addition, I also add a dummy for living in the southern parts of Germany. The negative effect of CCS storage sites on the acceptance of CCS again remains robust

Acceptance	(1)	(2)	(3)	(4)	(5)	(6)	(7)
CCS storage site	-0.2655**	-0.3030**	-0.2608**	-0.2438*	-0.2703**	-0.3200**	-0.2920**
	(0.1289)	(0.1064)	(0.1224)	(0.1347)	(0.1284)	(0.1259)	(0.1386)
Female	0.3040**	0.3136**	0.3004**	0.3106**	0.3268**	0.3205**	0.2949**
	(0.1161)	(0.1282)	(0.1305)	(0.1186)	(0.1261)	(0.1311)	(0.1306)
Age	0.0017	-0.0002	-0.0003	0.0013	0.0001	-0.0001	-0.0008
	(0.0036)	(0.0043)	(0.0041)	(0.0036)	(0.0043)	(0.0043)	(0.0041)
Education	-0.1022	-0.1393	-0.1241	-0.0962	-0.1091	-0.1111	-0.1382
	(0.1010)	(0.1135)	(0.1125)	(0.1005)	(0.1122)	(0.1129)	(0.1131)
Income	0.0004	0.0002	0.0002	0.0003	0.0001	0.0001	0.0002
	(0.0005)	(0.0005)	(0.0005)	(0.0004)	(0.0005)	(0.0005)	(0.0005)
East	0.1553*						0.0603
	(0.0978)						(0.1568)
Green/Left Party		-0.2413**					-0.1751
		(0.0867)					(0.1124)
Coal Mining			-0.8143***				-0.7683**
			(0.2192)				(0.2983)
CCS power plant				-0.1303			-0.1805
				(0.2362)			(0.2370)
Tourism					-0.0914**		-0.0686
					(0.0412)		(0.0419)
Population density						-0.0001	-0.0001
						(0.0001)	(0.0001)
Constant	2.2857***	2.7646***	3.2390***	2.3508***	2.5932***	2.4786***	3.5991***
	(0.2436)	(0.3306)	(0.2944)	(0.2293)	(0.3175)	(0.2864)	(0.3934)
Observations	332	292	292	332	292	292	292
R^2	0.0385	0.0614	0.0597	0.0347	0.0562	0.0437	0.0871

Standard errors clustered at the level of administrative districts in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Acceptance is measured on a scale of 1 (strongly disagree) to 4 (strongly agree).

Causal pathways

Why does living close to a potential CCS storage site reduces acceptance? One potential answer is that living close to a CCS storage site increases awareness of CCS, and awareness, in turn, decreases the acceptance of CCS (Kniebes et al. 2014 indeed find that higher level of awareness coincide with lower levels of acceptance). A second potential answer is that it reduces the perceived benefits of CCS and/or increases the perceived risks. After all, the risks of storing CCS underground are generally borne by the local population, as the major risk of CCS is CO_2 leakage. In contrast, the overall benefits of mitigating climate change are enjoyed not only by the local but by the general population.

The results in Table 3 provide suggestive evidence for the second but not for the first potential explanation. I first add self-reported awareness as a control variable to the baseline regression (column

1).[7] Overall, 84% of the respondents stated to have heard at least somewhat about CCS before the time of the survey. I find that the level of awareness indeed decreases the acceptance of CCS, i.e., respondents with a higher level of knowledge on CCS have a significant lower level of acceptance. However, the effect of living close to a CCS storage site remains largely unaffected. This suggests that the effect does not operate through awareness, as living close to a CCS storage site does not affect awareness. In fact, a regression of awareness on CCS storage site and control variables shows that living close to a CCS storage site has no statistically significant effect on awareness (coefficient of 0.058, p-value of 0.464).

I then add an individual's perception of the risk of CCS (column 2), her perception of the benefits of CCS (column 3), and her perception of both risk and benefits (column 4) as control variables. As expected, an individual's level of acceptance decreases in the perceived risk of CCS and increases in the perceived benefits. Importantly, adding perceived risk and benefits halves the coefficient estimate on the CCS storage site dummy and renders the dummy statistically insignificant. This suggests that living close to a CCS storage site reduces acceptance by increasing the perceived risk of CCS and decreasing the perceived benefits. In additional regressions, I regress risk perception and benefit perception on CCS storage site and control variables. Somewhat surprisingly, I find that living close to a CCS storage markedly reduces benefit perception (by 0.173 points, p- value of 0.068), but increases risk perception only moderately (by 0.079 points, p- value of 0.268). This finding is surprising, as especially the risks and not so much the benefits of CCS occur local.

[7] I come to broadly similar conclusions if I take equation (II) which includes all regional characteristics, as a baseline regression (see Table A-3 in the appendix). The results also hold if I take number of CCS storage sites as the dependent variable (see Table A-2, column 3 and 4 in the appendix).

Table 3: OLS regression results equation (III), clustered standard errors

Acceptance	(1)	(2)	(3)	(4)
CCS storage site	-0.2470*	-0.1800	-0.0952	-0.0992
	(0.1397)	(0.1437)	(0.1146)	(0.1197)
Female	0.2511*	0.3055**	0.1176	0.1489
	(0.1296)	(0.0982)	(0.0867)	(0.0889)
Age	0.0024	-0.0012	0.0005	-0.0001
	(0.0037)	(0.0032)	(0.0027)	(0.0025)
Education	-0.0509	-0.0282	-0.1212	-0.0780
	(0.1040)	(0.0823)	(0.0827)	(0.0816)
Income class	0.0003	0.0001	0.0004	0.0004
	(0.0004)	(0.0004)	(0.0004)	(0.0004)
Awareness	-0.1635**			-0.0094
	(0.0800)			(0.0549)
Risk perception		-0.6054***		-0.3298***
		(0.0642)		(0.0669)
Benefit perception			0.7768***	0.6465***
			(0.0590)	(0.0685)
Constant	2.5829***	4.1875***	0.4358**	1.7395***
	(0.2811)	(0.3155)	(0.1844)	(0.3705)
Observations	332	315	320	311
R^2	0.0486	0.2992	0.4986	0.5679

Standard errors clustered at the level of administrative districts in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01. Acceptance is measured on a scale of 1 (strongly disagree) to 4 (strongly agree).

6. Robustness check

The location of CCS storage sites is not random. In fact, potential storage sites cluster in the northwest and the northeast of Germany (see Figure 1, Section 3). One might, therefore, be concerned that the dummy for CCS storage sites capture the effect of other unobserved regional characteristics. To deal with this concern, I have already shown that the effect of CCS storage sites is robust to the inclusion of other county characteristics (see Table 3, Section 5). In this section, I further test whether living close to a CCS storage site also affects the acceptance of Solar Radiation Management (SRM) and afforestation. If so, the observed effect might be caused by a general opposition against climate engineering (CE) technologies in the affected regions.

SRM is a CE technology that counteracts climate change by the injection of sulphate dioxide into the stratosphere. Afforestation of large areas such as the Sahara and the Australian Outback is another CE measure, which is meant to slow down climate change by absorbing CO_2 from the atmosphere. Therefore, all three measures, CCS, SRM and afforestation, are large scale interventions into the earth' climate system to counteract climate change. However, whereas the risks of CCS are confined locally, the risks of SRM and afforestation affect all regions in Germany to the same degree. I would therefore not expect the locations of potential CCS storage sites to affect the acceptance of SRM or afforestation.

If they did, this would point towards unobserved factors correlated with both the locations of CCS storage sites and a general opposition against CE technologies.

Table 4 reports the results of re-estimating equation (I) with acceptance of SRM as the dependent variable. The acceptance of SRM and afforestation was elicited in two separate surveys, which were identically structured to the CCS survey. All three surveys were conducted in the same week and respondents were randomly assigned to one of the surveys. Overall, the SRM working data set contains N = 393 observations and the afforestation working data set contains N = 336 observations.

The results in Table 4 show that living in a county with a potential CCS storage site has no statistically significant effect on the acceptance of SRM (see columns 1 and 2). In fact, the coefficient estimate of *CCS storage site* is even positive (but not statistically significant). I also do not find any evidence for spill-over effects from living in a county bordering on a county with a CCS storage site on the acceptance of SRM (column 3). In line with these results, I also do neither find a statistically significant effect of *CCS storage site,* nor of *Number of CCS storage sites, nor* of *CCS storage site neighbourhood* on the acceptance of afforestation (Table A-4, appendix). These results support my previous interpretation that the negative effect of CCS storages sites is not driven by unobserved county characteristics.

Table 4: OLS regression equation (I) for SRM, clustered standard errors

Acceptance	(1)	(2)	(3)
CCS storage site	0.1107 (0.1194)		
Number of CCS storage sites		0.0553 (0.0426)	
CCS storage site neighbourhood			0.0923 (0.1018)
Female	-0.0200 (0.0807)	-0.0185 (0.0814)	-0.0098 (0.0833)
Age	-0.0054 (0.0033)	-0.0054 (0.0033)	-0.0045 (0.0036)
Education	-0.1167 (0.1130)	-0.1096 (0.1126)	-0.0864 (0.1200)
Income	0.0001 (0.0004)	0.0001 (0.0004)	0.0002 (0.0004)
Constant	2.4050*** (0.2440)	2.3994*** (0.2439)	2.2830*** (0.2546)
Observations	393	393	346
R^2	0.0088	0.0121	0.0068

Standard errors clustered at the level of administrative districts in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01. Acceptance is measured on a scale of 1 (strongly disagree) to 4 (strongly agree).

7. Discussion and conclusion

This paper has analysed the influence of regional determinants on the acceptance of carbon capture and storage (CCS) in Germany. The CCS technology is able to deliver significant emissions reductions and its deployment both in industrial and power applications is required for reaching the two degree target (International Energy Agency 2015). However, CCS goes along with several risks. The main risk of CCS, i.e. leakage of CO_2, occurs at the deposits, and affects therefore only regions that have CCS storage sites.

I therefore hypothesize that living close to one of the 408 potential CCS storage sites in Germany reduces the acceptance of CCS, and test this hypothesis using novel survey data. I also shed light on the potential channels through which this “not in my backyard” (NIMBY) effect might operate, and test for the effect of other regional characteristics on the acceptance of CCS in Germany.

My results are as follows: First, I find that living in or next to a county with at least one CCS storage site reduces an individual’s acceptance of CCS significantly. Therefore, the presence of CCS storage sites appears to reduce the level of acceptance in a relatively large geographic area. These results are in line with previous findings of Krause et al. (2014) who also documents a NIMBY effect for CCS in the US state of Indiana.

Second, I find that the NIMBY effect is robust to the inclusion of other potential determinants of CCS acceptance at both the individual and the regional level. In contrast to Wallquist et al. (2012) but in line with Fischerdick et al. (2008), I find that CCS storage sites but not CCS power plant affect the acceptance of CCS. Moreover, I also find that living in a tourism or coal mining region markedly decreases acceptance. This contrasts with previous findings of Krause et al. (2014) who do not find an effect of coal mining on the acceptance of CCS in the US. However, Krause et al. (2014) do not distinguish between the acceptance of CCS storage sites and CCS power plants. This might be essential though, as the CCS technology is proposed for power plants such as of coal fire plants. Therefore, respondents who live in coal mining regions might gain from the economic benefits of CCS power plants but they might still oppose CCS storage sites in their region. Therefore the risk of CCS storage sites and the benefit of CCS power plants might outweigh in coal mining regions, leaving no potential for CCS storage sites in such regions.

Third, I present evidence that living close to a CCS storage site reduces acceptance by markedly decreasing the perceived benefits of CCS and also by slightly increasing the perceived risks. This is in line with previous results (Krause et al. 2014; Singelton et al. 2009; Terwel and Daamen 2012). I also show that the effect of CCS storage sites on acceptance does not operate through higher levels of awareness. In contrast to Krause et al. (2014), I find that awareness decreases rather than increases acceptance.

However, respondents in my survey report much higher average levels of awareness than those in Krause et al. (2014), so that the two samples might not be directly comparable.

Summing up, my results paint a dark picture of the potential future of CCS storage in Germany. In particular, placing a CCS storage site is likely to meet fierce local resistance. As potential storage sites decrease acceptance not only in their host but also in neighbouring counties, CCS storage sites might stir resistance in a relatively large geographic area. Since the effect operates mainly through the risk and benefit perceptions of local residents, a possible strategy to increase the support of CCS could be to compensate residents for the risks of CCS storage. In particular, residents who live close to a CCS storage site could be compensated for the additional risk they incur by those who are not directly affected. However, paying compensation may also fire back if individuals perceive such payments as proof for the dangers of CCS (Frey and Oberholzer-Gee 1997).

Raising awareness is no promising strategy to win support of residents. Quite to the contrary: awareness seems to decrease rather than increase acceptance (see also Kniebes et al. 2014).

My study lends itself to various extensions. In particular, my study does not focus on the specific risks and benefits of CCS. It would thus be interesting for future research to distinguish between the specific risks and benefits and to analyse the effect of compensating local residents. Moreover, future research could also explicitly focus on Bio-energy with carbon capture and storage (BECCS), as it has been shown for climate engineering that describing technologies with natural proses increases acceptance (Corner and Pidgeon 2014).

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9. Appendix

Table A-1: Summary statistics

		CCS		SRM		Afforestation	
Variables	Domain	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Acceptance	1 - 4	2.5421	0.9105	2.1119	0.9355	3.130	0.7044
Female	0 - 1	0.4638	0.4994	0.4936	0.5005	0.4791	0.5003
Age	18 - 91	49	14.0685	51	14.6314	48	14.3705
Higher education	0 - 1	0.3042	0.4607	0.3180	0.4663	0.3095	0.4629
Income	125 - 7500	1676.20	115.246	2497.13	147.51	1571.42	107.97
Awareness	1 - 3	1.7530	0.7203	1.2620	0.4948	1.7023	0.6872
Risk perception	1 - 4	2.8730	0.7917	3.2826	0.7739	2.4357	0.7532
Benefit perception	1 - 4	2.5562	0.8209	2.4582	0.7817	2.9656	0.7398
N		332		393		336	

Summary statistics are based on the observations that are used in the baseline regression (equation I)

Table A-2: OLS regression results equation (III) with equation (II) as a baseline scenario, clustered standard errors

Acceptance	(1)	(2)	(3)	(4)
Number of CCS storage sites	-0.1082***	-0.1029***	-0.0548**	-0.0594**
	(0.0264)	(0.0273)	(0.0241)	(0.0269)
Female	0.3166**	0.2997**	0.1564*	0.1376
	(0.1137)	(0.1282)	(0.0883)	(0.0929)
Age	0.0011	-0.0010	-0.0001	-0.0002
	(0.0037)	(0.0042)	(0.0025)	(0.0028)
Education	-0.1118	-0.1524	-0.0847	-0.0577
	(0.1040)	(0.1161)	(0.0832)	(0.0842)
Income	0.0004	0.0003	0.0004	0.0004
	(0.0004)	(0.0005)	(0.0004)	(0.0005)
East		0.0401		0.1250
		(0.1443)		(0.1532)
Green/Left Party		-0.1547		0.0282
		(0.1129)		(0.0909)
Coal Mining		-0.7783**		-0.7693**
		(0.3011)		(0.3750)
CCS power plant		-0.1719		-0.1273
		(0.2347)		(0.1748)
Tourism		-0.06750		-0.0664*
		(0.0450)		(0.0359)
Population density		-0.0001		-0.0001
		(0.0001)		(0.0001)
Awareness			-0.0108	-0.0258
			(0.0559)	(0.0628)
Risk Perception			-0.3300***	-0.3024***
			(0.0673)	(0.0699)
Benefit Perception			0.6423***	0.6693***
			(0.0679)	(0.0715)
Constant	2.3433***	3.5718***	1.7476***	2.4846***
	(0.2290)	(0.3866)	(0.3728)	(0.6352)
Observations	332	292	311	275
R^2	0.0422	0.0909	0.5703	0.6046

Standard errors clustered at the level of administrative districts in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01. Acceptance is measured on a scale of 1 (strongly disagree) to 4 (strongly agree

Table A-3: OLS regression results equation (III) with equation (II) as a baseline scenario, clustered standard errors

Acceptance	(1)	(2)
CCS storage sites	-0.2920**	-0.1794
	(0.1386)	(0.1309)
Female	0.2949**	0.1347
	(0.1306)	(0.0933)
Age	-0.0008	-0.0001
	(0.0041)	(0.0028)
Education	-0.1382	-0.0507
	(0.1131)	(0.0831)
Income	0.0002	0.0004
	(0.0005)	(0.0005)
East	0.0603	0.1446
	(0.1568)	(0.1494)
Green/Left Party	-0.1771	0.0202
	(0.1124)	(0.0871)
Coal Mining	-0.7683**	-0.7627**
	(0.2983)	(0.3749)
CCS power plant	-0.1805	-0.1347
	(0.2370)	(0.1804)
Tourism	-0.0686	-0.0669**
	(0.0419)	(0.0335)
Population density	-0.0001	-0.0001
	(0.0001)	(0.0001)
Awareness		-0.0266
		(0.0613)
Risk Perception		-0.3016***
		(0.0696)
Benefit Perception		0.6720***
		0.0722)
Constant	3.5991***	2.4876***
	(0.3934)	(0.6357)
Observations	292	275
R^2	0.0871	0.6041

Standard errors clustered at the level of administrative districts in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01. Acceptance is measured on a scale of 1 (strongly disagree) to 4 (strongly agree

Table A-4: OLS regression equation (1) for afforestation, clustered standard errors

Acceptance	(1)	(2)	(3)
CCS storage site	-0.0688		
	(0.1724)		
Number of CCS storage sites		-0.0076	
		(0.0479)	
CCS storage site neighbourhood			0.0256
			(0.0920)
Female	-0.0916	-0.0907	-0.0681
	(0.0720)	(0.0727)	(0.0739)
Age	0.0058**	0.0057**	0.0063**
	(0.0026)	(0.0026)	(0.0027)
Education	-0.0419	-0.0438	-0.0918
	(0.0817)	(0.0813)	(0.0816)
Income	0.0004	0.0003	0.0004
	(0.0003)	(0.0003)	(0.0003)
Constant	2.8480***	2.8493***	2.8186***
	(0.1723)	(0.1716)	(0.1717)
Observations	336	336	301
R^2	0.0297	0.0289	0.0358

Standard errors clustered at the level of administrative districts in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01. Acceptance is measured on a scale of 1 (strongly disagree) to 4 (strongly agree).

Information provided in the CCS video

Sunlight warms the Earth and its atmosphere. Greenhouse gases in the atmosphere such as CO_2 ensure that some warmth remains close to the Earth's surface. This makes the Earth warm enough for humans, animals, and plants to live on.

Since the start of industrialisation around 1850, people have emitted a great amount of greenhouse gases by burning coal, oil, and gas. These gases trap more heat in the atmosphere and cause a gradual increase in the average global temperature.

Since 1900, the global temperature has risen by approximately 0.8°C. Almost all countries agree that the increase in the average global temperature should not exceed 2°C compared to pre-industrial levels. This is called the 2°C target.

By 2100, a further increase in temperature between 0.9 and 5.4°C is expected. The development depends strongly on the amount of greenhouse gases emitted in the future. To reach the 2°C target, the current level of emissions would have to be cut by more than half until 2050. By 2100, greenhouse gas emissions would have to be reduced to almost zero.

It is virtually certain that climate change will cause a rise in sea levels. The frequency of heat waves is very likely to increase as well as the number of heavy precipitation events in many regions. It is likely that in the future, more areas will be affected by longer droughts and that the frequency and intensity of tropical cyclones will increase. In addition, part of the emitted CO_2 is absorbed by the ocean, causing ocean acidification.

There are different ways to deal with climate change:

We can reduce greenhouse gas emissions or adapt to the new climate by building dikes. Another option is carbon capture and storage sub-seabed (CCS).

The CCS technology captures CO_2 from the industrial combustion of fossil fuels. The CO_2 is compressed and stored in suitable geological formations under the seabed. It is not released into the atmosphere. This process additionally uses approximately 25% of the generated energy, which increases the overall demand for fossil fuels.

On a small scale, CO_2 has already been stored in the ground for approximately 30 years. CO_2 is injected for the recovery of oil and gas to make this process easier. The experiences indicate a high level of storage safety.

Former oil and gas fields as well as sub-seabed saline aquifers are considered to be safe and permanently suitable deposits.

Pipelines and ships carry the compressed CO_2 to the deposits.

There, it is pumped into tiny hollows of the sub-seabed deposit, where it has to be stored for several thousands of years. During this time it merges with the rock and it is rendered permanently harmless.

Scientists think further applied research on CCS would be useful. The processes, benefits and risks are already well understood.

Some expected benefits and risks of CCS are now introduced to you.

Benefits of CCS are that global warming as well as acidification of the oceans would be slowed down. Furthermore, deploying CCS would be less expensive than an energy transition from fossil fuels to renewable energies.

The risks of CCS include the possible leakage of CO_2 from the well or from the deposits caused by increased pressure. This could lead to a local acidification, which would endanger the biodiversity of that area.