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Public perception of CO_2 offshore storage in Germany: regional differences and determinants

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Abstract

The present study investigates and compares the public perception of CO_2 offshore storage, CO_2 onshore storage and CO_2 transport via pipeline in Germany nationwide and in two coastal regions. For this purpose, three representative surveys were carried out and analyzed with the methods of descriptive statistics and ordinal regressions. The results of our descriptive statistical analyses show clear regional differences with regard to self-reported awareness, factual knowledge, risk perceptions and general attitudes towards CO_2 offshore/onshore storage and CO_2 transport via pipeline. With regard to the public perception of the two storage options – offshore and onshore – no major differences could be identified: both are hardly accepted by the German public. In comparison to CO_2 offshore storage/CO_2 onshore storage, the attitudes towards CO_2 transport via pipeline were perceptibly more positive in all regions. Our regression analyses revealed that the perceptions of the personal and societal risks of CO_2 transport via pipeline/CO_2 offshore storage/CO_2 onshore storage as well as the perceptions of the personal and societal benefits of CCS are the most important direct determinants of general attitudes towards CO_2 transport via pipeline, CO_2 offshore storage and CO_2 onshore storage.

1. Introduction

CO_2 capture and storage (CCS) is perceived worldwide and in the European Union (EU) as a key technology for greenhouse gas (GHG) emissions mitigation [1, 2]. However, up to now only eight large-scale demonstration

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projects comprising the complete CCS process chain (capture, transport and storage) exist. None of these projects includes large fossil fuel power plants yet and none of them have been implemented within the EU [1, 3]. In Germany, the future of CCS is uncertain at present, despite the enactment of the CCS law in August 2012 [4].

One important reason why CCS has not yet been implemented in Germany is the lacking public acceptance of CO_2 storage [4]. From previous research on the public perception of CCS in Germany, it is known that in comparison to CO_2 capture and transport, the public acceptance of CO_2 storage is generally lower [5, 6]. However, previous studies on the public perception of CCS have focused on investigating public approval of or opposition to CCS as a process chain in which the CO_2 would be stored only in onshore repositories (CO_2 onshore storage), e.g. [7]. The question as to how the German public would perceive CCS if the CO_2 were to be stored under the seabed (CO_2 offshore storage) has not yet been investigated and empirical results on the public perception of CO_2 offshore storage in Germany are thus not available.

Therefore, the aim of our study was to investigate the perception of CO_2 offshore storage amongst the German public in comparison to the perception of CO_2 onshore storage and CO_2 transport via pipeline. In fact, empirical results regarding the attitudes of German citizens towards CO_2 onshore storage and CO_2 transport via pipeline already exist [5] – but these data were collected after the respondents received information about CCS using the example of the IGCC-CCS power plant in Huerth, which was planned but never realized.[1] Thus, no database existed before the start of our study to allow the investigation and systematic comparison of the general perception, i.e. the perception that is not related to a concrete project, of CO_2 offshore storage, CO_2 onshore storage and CO_2 transport via pipeline.

We carried out three representative surveys (a nationwide survey and two regional surveys) of the German public in 2013 in which the public perception of the two CO_2 storage options and CO_2 pipelines were measured with the same indicators (cf. section 2). The survey data was used to analyze and compare public perception in two dimensions: firstly between the three regions and secondly between the two storage options and CO_2 pipelines (cf. section 3). Furthermore, we identified the factors determining public attitudes towards the two CO_2 storage options and CO_2 transport via pipeline (cf. section 3). The conclusions which can be derived from our analyses with regard to the question of what limits and opportunities (still) exist for public acceptance of CCS in Germany are presented at the end of this paper (cf. section 4).

2. Methods

We conducted standardized surveys to generate a sufficient number of cases for statistical analyses. In order to draw conclusions from our statistical analyses for the population, it was necessary to perform representative surveys based on random samples (cf. section 2.2). Since we knew from previous studies that public perception of CO_2 onshore storage differs regionally [8], two regional surveys were conducted in addition to a nationwide survey. For the regional surveys, two regions located at the coast of the German North Sea were chosen: (1) district of North Frisia and (2) district of Aurich plus the islands of Borkum, Langeoog, Spiekeroog, and Wangerooge.[2]

Coastal regions were selected as study areas mainly because of their closeness to possible CO_2 offshore storage areas. From the German coastal regions, we chose two regions where activities against CO_2 storage in general already existed[3] because we were interested in whether the perception of CO_2 offshore storage differs in such regions.

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[1] Cf. http://www.rwe.com/web/cms/en/2688/rwe/innovation/projects-technologies/power-generation/fossil-fired-power-plants/igcc-ccs-power-plant/

[2] In the following, we refer to the district of North Frisia as "North Frisia" and the district of Aurich plus the islands of Borkum, Langeoog, Spiekeroog, and Wangerooge as "Aurich plus islands".

[3] Activities against CO_2 storage in these regions are documented for example on http://www.kein-co2-endlager.de/ or http://www.stadt-borkum.de/city_info/webaccessibility/index.cfm?waid=76&item_id=838788&region_id=347&design_id=0&modul_id=31&record_id=359702&fsize=1&contrast=0&search=Kohlekraftwerk (Webpages in German).

2.1. Indicators and survey method

In order to measure the public perception of CO_2 offshore storage, CO_2 onshore storage and CO_2 transport via pipeline, we used the following indicators: self-reported awareness, factual knowledge, risk perceptions and attitudes.

Awareness is an indispensable prerequisite for forming or having an attitude towards a person, object or issue. This is particularly important with regard to new objects or issues, for example new energy technologies such as CCS. Asking the general public via a representative poll whether they had heard or read about CCS is an established concept for measuring awareness of CCS, cf. e.g. [9-13]. In our surveys, the respondents reported their awareness of CO_2 storage and CCS by answering the question of whether they had heard about it by choosing between the different predefined answers "no, never heard of it", "yes, heard of it, but know nothing or just a little bit about it" or "yes, heard of it and know quite a bit or a lot about it". Accordingly, the results on public awareness in this paper are results concerning "self-reported awareness".

Knowledge of an object or issue can be measured on a subjective level or on a factual level, cf. [14]. In our surveys, we measured knowledge on a factual level by asking the respondents to decide whether a set of statements regarding CO_2, CO_2 storage and pipelines were true or false (cf. Appendix A). In analyzing the results of these questions, we could distinguish between what the respondents correctly knew and what they incorrectly believed, cf. [15]. In this paper, correct answers to such knowledge questions are defined as "factual knowledge", whereas incorrect answers are understood as "misconceptions".

In order to investigate how the risks of CO_2 offshore storage, CO_2 onshore storage and CO_2 transport via pipeline are perceived by the German public, participants in the representative survey were first given brief information. The respondents were then asked to rate the personal risk and the risk for society for each of the storage options and for CO_2 pipelines on a scale of 1 (= very low) to 7 (= very high).

Attitudes can be regarded as "a general favorable, unfavorable, or neutral evaluation of a person, object or issue" [16]. In our surveys, we measured the general attitudes of the respondents towards CO_2 offshore storage, CO_2 onshore storage and CO_2 transport via pipeline by asking them how they assess in general the ideas of storing CO_2 under the seabed, storing CO_2 in onshore repositories and transporting CO_2 via pipeline, respectively. The respondents assessed the storage options and CO_2 pipelines on a seven-level Likert scale, ranging from 1 (= very negative) to 7 (= very positive).

In addition, benefit perceptions of CCS, general values and socio-demographic characteristics of the respondents were surveyed, because we assumed that they can be relevant factors influencing the attitudes towards CO_2 offshore storage, CO_2 onshore storage and CO_2 transport via pipeline (cf. section 3.5).

The questionnaire for the surveys was developed by the authors. The surveys were conducted by a professional polling firm with computer-aided telephone interviewing (CATI) from mid-March 2013 to mid-April 2013.

2.2. Sampling and participant structures of the surveys

The population for the nationwide survey was the German public above the age of 18. For the regional surveys, the public in the selected regions above the age of 18 constituted the population. The recruitment of participants using multilevel random sampling was done by a professional polling firm.

1000 interviews were realized nationwide, 503 interviews in North Frisia and 500 interviews in Aurich plus islands. The participant structures of the surveys according to region are shown in Table 1.

With regard to gender, Table 1 illustrates that in all regions 51 % of the respondents were women and 49 % were men. However, the difference in the average age of the respondents was statistically significant for the three regions: nationwide and in Aurich plus islands, the respondents were younger than the overall average, whereas in North Frisia, the respondents were considerably older.

Table 1. Participant structures of the surveys according to region

	Region			
	Nationwide (n = 1000)	**North Frisia (n = 503)**	**Aurich plus islands (n = 500)**	**Total (n = 2003)**
Gender				
Male	48.8%	48.9%	48.6%	48.8%
Female	51.2%	51.1%	51.4%	51.2%
Total	100.0%	100.0%	100.0%	100.0%
Age				
Mean	49.0 years	60.2 years	46.0 years	51.0 years
Professional qualification				
No professional qualification	7.4%	3.8%	3.2%	5.4%
Certified vocational training	67.2%	58.0%	54.3%	61.6%
Training at a post-secondary vocational school	8.5%	14.1%	20.0%	12.8%
Degree from a university	16.8%	24.0%	22.6%	20.1%
Total	100.0%	100.0%	100.0%	100.0%
Household size				
1 person	25.2%	24.1%	11.6%	21.5%
2 persons	42.4%	47.5%	37.6%	42.5%
3 persons	17.3%	11.7%	22.2%	17.1%
4 persons	12.1%	11.1%	19.0%	13.6%
More than 4 persons	3.0%	5.6%	9.6%	5.3%
Total	100.0%	100.0%	100.0%	100.0%
Home ownership				
Rented flat	58.2 %	15.7 %	21.0 %	38.2 %
Rented house	7.1 %	5.8 %	7.0 %	6.7 %
Own flat	6.7 %	8.7 %	7.6 %	7.4 %
Own house	27.2 %	69.8 %	62.8 %	46.8 %
Other	0.8 %	0.0 %	1.6 %	0.8 %
Total	100 %	100 %	100 %	100 %
Net income per household/month				
< € 1000	14.5 %	7.6 %	7.0 %	10.9 %
€ 1000-2999	52.9 %	38.8 %	34.6 %	44.8 %
€ 3000-4999	18.3 %	21.3 %	23.8 %	20.4 %
€ 5000-6999	1.9 %	2.8 %	4.0 %	2.6 %
>= € 7000	0.4 %	2.2 %	1.2 %	1.0 %
Missing	12.0 %	27.4 %	29.4 %	20.2 %
Total	100 %	100 %	100 %	100 %

The difference in regional participant structures was also statistically significant with regard to professional qualification. Nationwide, respondents with no professional qualification or with certified vocational training were overrepresented compared to the overall average, whereas respondents with training at a post-secondary school or a university degree were underrepresented. The reverse applied in the coastal regions: citizens with training at a post-secondary school or with a university degree were overrepresented and respondents with no professional qualification or with certified vocational training were underrepresented.

The differences in the professional qualification of the respondents in the three regions were reflected by the income structures which also differed statistically significantly according to region: in the coastal regions, the percentage of respondents with an income of € 3000 or more was above the overall average, whereas nationwide citizens with an income less than € 3000 were overrepresented.

However, the most striking difference between the participant structures in the three regions concerned home ownership: nationwide 58 % of the respondents were living in a rented flat, whereas in North Frisia 70 % were living in their own home and in Aurich plus islands 63 % were living in their own home. In Aurich plus islands, this

was accompanied by bigger households: compared to the overall average, households of three persons or more were overrepresented here. These differences are also statistically significant.

The representativeness of the samples of the nationwide and regional populations was proven by comparing the distributions of the criteria gender, age, professional qualification and household size with the data of official statistics. Overall, the comparisons showed that the representativeness of the samples was good despite small deviances in the populations.

2.3. Comparative approach and statistical methods

In analyzing the survey data, we followed a two-dimensional comparative approach: firstly we compared the results for the three regions; secondly we compared the perceptions of CO_2 offshore storage with the perception of CO_2 onshore storage and CO_2 transport via pipeline.

The comparisons were conducted using the indicators self-reported awareness, factual knowledge, risk perceptions and attitudes. For this purpose, we used methods of descriptive statistics (frequencies, means, standard deviations, correlations). The statistical significance of differences in the results was tested with non-parametrical tests.[4] In order to identify the factors that influence the attitudes towards CO_2 offshore storage, CO_2 onshore storage and CO_2 pipelines, we carried out ordinal regression analyses.

3. Results

In this section, we firstly explain the results of the comparative analyses of our indicators for measuring public perception of CO_2 offshore storage, CO_2 onshore storage and CO_2 transport via pipeline (section 3.1 to section 3.4.) Secondly, we describe the main results of our ordinal regression analyses (section 3.5).

3.1. Self-reported awareness

The results of our descriptive statistical analyses show that the German public are aware of CO_2 storage: half of the respondents nationwide had heard of the "storage of CO_2 in onshore repositories" and the "storage of CO_2 under the seabed", respectively (cf. Fig. 1). However, the percentage of citizens nationwide who answered that they knew "quite a bit or a lot" about CO_2 storage was low.

In the coastal regions, awareness of the terms "storage of CO_2 in onshore repositories/under the seabed" was perceptibly higher than in the rest of Germany[5] (cf. Fig. 1). In North Frisia, 67 % of the respondents had heard of the two topics; in Aurich plus islands, this figure was 60 %. The percentage of respondents who answered that they knew "quite a bit or a lot" about CO_2 storage was approximately twice as high compared to the nationwide average.[6]

In Aurich plus islands, the self-reported awareness of the term "storage of CO_2 in onshore repositories" is higher than the self-reported awareness of the term "storage of CO_2 under the seabed". Nationwide, the differences in the awareness of the two terms were only very small, whereas in North Frisia, no statistically significant differences were found.

The self-reported awareness of the term "carbon capture and storage or CCS" was lower than the awareness of "storage of CO_2 in onshore repositories/under the seabed" (cf. Fig. 1). Again, the self-reported awareness was higher in the coastal regions than in the rest of Germany and it was higher in North Frisia than in Aurich plus islands. The percentage of respondents who answered that they knew "quite a bit or a lot" about CCS was three times higher for the coastal regions than the nationwide average.

Since the results of our statistical analyses showed that the awareness of CO_2 storage and CCS differ depending on the socio-demographic characteristics of the respondents, we conducted partial correlation analyses in order to verify whether the correlation between awareness and region was still significant when the influence of the variables

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[4] Depending on the scale of the variables and the investigated question, Wilcoxon tests, Mann-Whitney U tests, Kruskal-Wallis tests and Friedman tests were used.

[5] The nationwide survey does not include respondents from the two coastal regions.

[6] Differences explained in this paper are statistically significant unless otherwise stated.

gender, age and professional qualification was controlled. The correlation coefficients in Table 2 illustrate that this is indeed the case. According to the codification of the variable "region"[7], the positive values of the correlation coefficients confirm that the self-reported awareness of "storage of CO_2 in onshore repositories", "storage of CO_2 under the seabed" and CCS was higher in the coastal regions than nationwide.
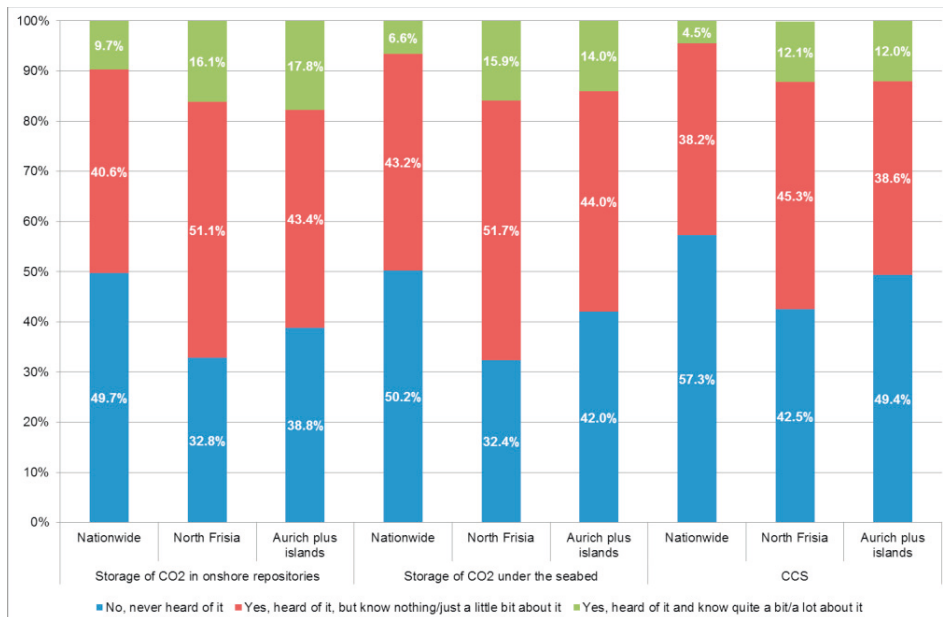

Fig. 1. Self-reported awareness of CO_2 storage and CCS according to region. Question: "Have you heard about the following topics?"

Table 2. Partial correlations between self-reported awareness of CO_2 storage, CCS and regions

Topic	Region
Storage of CO_2 in onshore repositories	.128**
Storage of CO_2 under the seabed	.145**
CCS	.126**

**. Correlation is significant at the 0.01 level (2-tailed). Control variables: gender, age, professional qualification.

3.2. Factual knowledge

In order to find out the factual knowledge of the German citizens, the respondents of our surveys were asked an open-ended question about CO_2. Furthermore, they were presented with five statements about CO_2, CO_2 storage and pipelines, respectively, and then asked whether these statements were true or false (cf. Appendix A).

The open-ended question "What does the abbreviation CO_2 mean?" was correctly answered by 63 % of the respondents nationwide. In Aurich plus islands 60 % and in North Frisia 53 % correctly knew that the abbreviation "CO_2" stands for carbon dioxide. An incorrect answer to this question was given by 31 % nationwide, by 24 % in North Frisia and by 26 % in Aurich plus islands. Accordingly, only 6 % of the respondents nationwide, 14 % in Aurich plus islands and 23 % in North Frisia said that they did not know what the abbreviation "CO_2" meant.

The results in Figure 2 illustrate that the majority of the citizens knew that CO_2 is a greenhouse gas. However, in the coastal regions the share of respondents who gave this correct answer was approximately five percentage points higher than in the rest of Germany. The correlation between the different knowledge levels regarding CO_2 and the region is still statistically significant when the influence of the socio-demographic characteristics is controlled (cf. Table 3).

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[7] In the partial correlations explained in this paper, the variable "region" is always included as a dichotomous variable which has the values "0" for "nationwide" and "1" for "coastal region".

Table 3: Partial correlations between knowledge of CO_2, CO_2 storage and pipelines according to region

Knowledge of	Region
CO_2	-.056*
CO_2 storage	.207**
Pipelines	.131**

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed). Control variables: gender, age, professional qualification.

At the same time, the respondents in the coastal regions assigned "incorrect" negative attributes to "CO_2" more often than the respondents in the nationwide survey. For example, 77 % of the respondents in North Frisia said that CO_2 is poisonous and 38 % answered that CO_2 is a water pollutant (cf. Figure 3).[8] In Aurich, 68 % responded that CO_2 is poisonous und 36 % said that CO_2 is flammable.
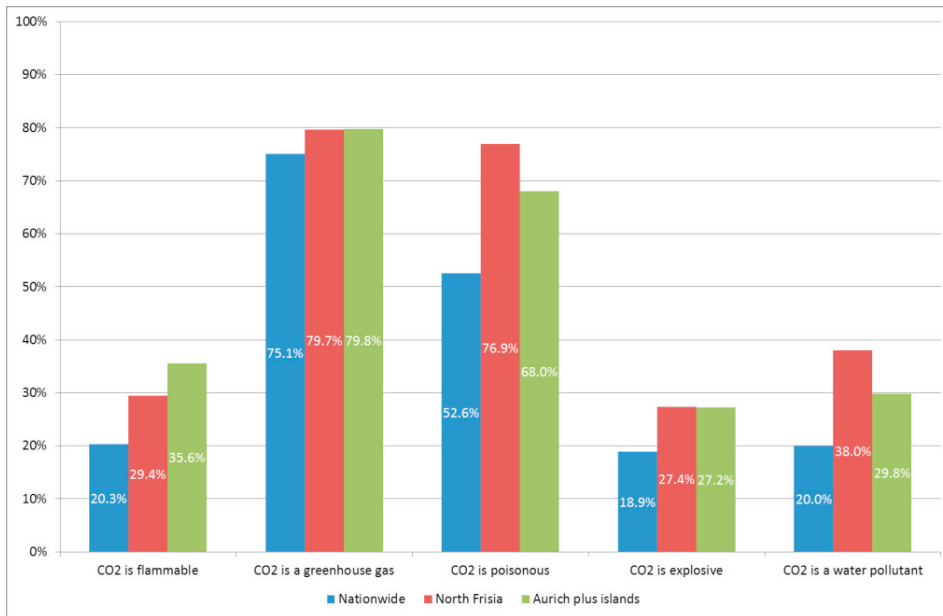

Fig. 2. Knowledge of the attributes of CO_2 according to region. Percentage of respondents who answered "true". The question is included in Appendix A.

Figure 3 shows that the average of correct answers to the five knowledge questions on CO_2 storage was considerably higher in the coastal regions than in the rest of Germany.[9] At the same time, the average of incorrect answers was also slightly higher than in the nationwide survey. The correlation between the different levels of knowledge regarding CO_2 storage and region is still statistically significant when the influence of the socio-demographic characteristics is controlled (cf. Table 3)

Figure 3 also shows that the average of correct answers to the five knowledge questions on pipelines was perceptibly higher in Aurich plus islands compared to North Frisia or the rest of Germany. The average of incorrect answers was markedly higher in North Frisia than in the other two regions. The highest average of the answer "don't know" was found in the nationwide sample. The correlation between the different knowledge level concerning

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[8] Under certain conditions, CO_2 can be lethal or lead to acidification of water. However, in principle, CO_2 is not poisonous, flammable, explosive or a water pollutant [14].

[9] The average of correct, incorrect and "don't know" answers was calculated by first summing up the percentages in each category for the five knowledge questions on CO_2 storage and pipelines, respectively. Then, the sums were divided by five and multiplied by 100. The three calculated values indicate the average percentage for answers to the five questions in the categories "correct", "incorrect" and "don't know". These three values add up for CO_2 storage and pipelines to 100%, respectively. This calculation procedure follows the procedure used in the Eurobarometer for analysing similar knowledge questions, e.g. [14].

pipelines and region is still statistically significant when the influence of the socio-demographic characteristics is controlled (cf. Table 3).
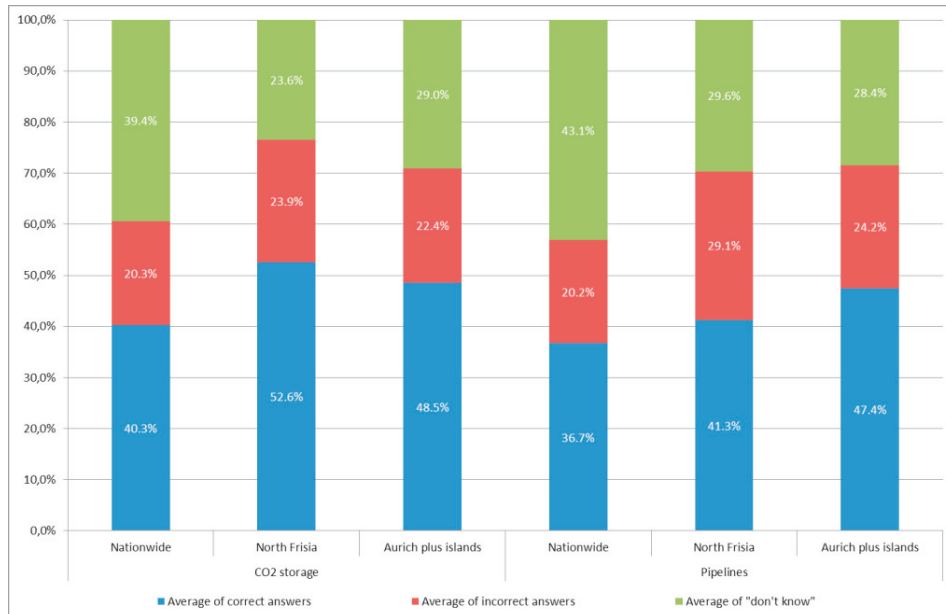

Fig. 3. Average of correct and incorrect answers to five knowledge questions on CO_2 storage and to five knowledge questions on pipelines according to region. The questions are included in Appendix A.

3.3. Risk perceptions

With regard to the assessment of risks, a comparison of the means showed that the personal and societal risks of CO_2 offshore storage, CO_2 onshore storage and CO_2 transport via pipeline were perceived markedly higher in North Frisia than in Aurich plus islands and in the rest of Germany (cf. Table 4). The personal risk of CO_2 offshore storage was assessed slightly higher in Aurich plus islands than in the nationwide average. The personal and societal risks of CO_2 transport via pipeline was perceived somewhat lower in Aurich plus islands than in the rest of Germany.

Table 4: Risk perceptions of CO_2 offshore storage, CO_2 onshore storage and CO_2 transport via pipeline according to region

| Region | Personal risk | | | | | | Societal risk | | | | | |
| | CO_2 offshore storage | | CO_2 onshore storage | | CO_2 transport via pipeline | | CO_2 offshore storage | | CO_2 onshore storage | | CO_2 transport via pipeline | |
	Mean[1]	SD[2]	Mean[1]	SD[2]	Mean[1]	SD[2]	Mean[1]	SD[2]	Mean[1]	SD[2]	Mean[1]	SD[2]
Nationwide	3.9	1.8	4.3	1.6	3.7	1.8	4.2	1.7	4.5	1.6	4.1	1.6
North Frisia	4.7	2.1	4.8	2.0	4.0	2.0	4.9	2.0	4.9	1.9	4.4	1.9
Aurich plus islands	4.2	2.1	4.3	1.9	3.5	1.9	4.3	2.0	4.5	1.9	3.9	1.8
Total	4.2	2.0	4.4	1.8	3.7	1.8	4.4	1.9	4.6	1.8	4.1	1.7

[1] Scale from 1 (= very low risk) to 7 (= very high risk). The higher the mean, the more positive the assessment of the personal/societal risk. [2] SD = standard deviation. Question: "How risky do you think CO_2 offshore storage/CO_2 onshore storage/CO_2 transport via pipeline would be to you and your family/to society in general?"

Concerning the two storage options, the results illustrate that nationwide the personal and societal risks of CO_2 onshore storage were assessed higher than the personal and societal risks of CO_2 offshore storage. In North Frisia, no statistical significant differences were found in the perceptions of the personal and societal risks of the two

storage options. In Aurich plus islands, the societal risk of onshore storage was perceived slightly higher than the societal risk of offshore storage, whereas no statistical significant differences were found with regard to the perceptions of the personal risks of the two storage options.

Compared to CO_2 transport via pipeline, the personal and societal risks of CO_2 offshore/onshore storage were perceived as visibly higher in all regions. Furthermore, the societal risks of CO_2 pipelines were assessed higher than the personal risks.

3.4. Initial preference and general attitudes

Regarding CO_2 storage, we firstly surveyed the initial preference of the citizens for CO_2 offshore storage or CO_2 onshore storage. For this purpose, the respondents were given short information about CCS and CO_2 storage and were then asked which storage option they would prefer. Afterwards, the respondents were given a second piece of information and were then asked to assess the risks of CO_2 offshore storage, CO_2 onshore storage and CO_2 transport via pipeline (cf. section 3.3) as well as to assess in general the ideas of storing CO_2 under the seabed, of storing CO_2 in onshore repositories and of transporting CO_2 via pipeline, respectively.

Concerning the question of which storage option would be preferred, Figure 4 illustrates that the majority of the German public would spontaneously prefer CO_2 to be stored nowhere at all. This result is all the more remarkable because the interviewers in the surveys only read the predefined answers to the respondents: "under the seabed of the North Sea", "in onshore repositories, nearby the emission source" and "in onshore repositories, only in sparsely populated areas." The answers "I don't care", "nowhere" and "elsewhere" were only written down by the interviewers if they were spontaneously given by the respondents.

The rejection of CO_2 storage in general which is reflected in the answer "nowhere" was visibly higher in North Frisia than in the rest of Germany or in Aurich plus islands. Nationwide, the general rejection of CO_2 storage was higher than in Aurich plus islands.

The preferences of those respondents who chose between the storage options given also differed regionally: nationwide, offshore storage would be preferred, while respondents from the coastal regions would prefer onshore storage near the emission source.
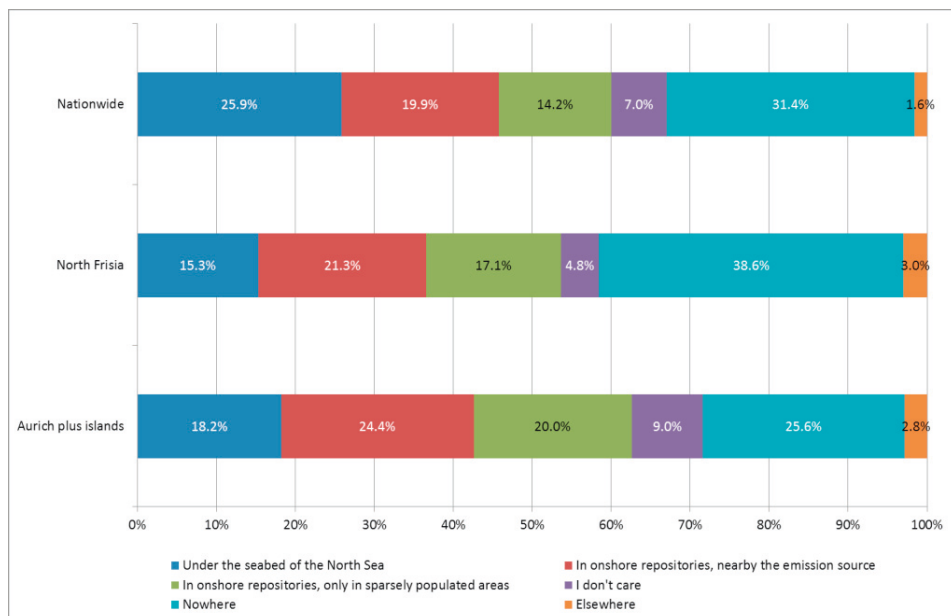

Fig. 4. Initial preferences regarding CO_2 storage according to region. Question: "Which option for CO_2 storage would you prefer?"

The general attitudes of the public regarding CO_2 offshore storage and CO_2 onshore storage were rather negative (cf. Table 5). In the coastal regions, both storage options were markedly more negatively assessed than the nationwide average. The general attitudes were also visibly more negative in North Frisia than in Aurich plus islands.

Table 5: General attitudes towards CO_2 offshore storage, CO_2 onshore storage and CO_2 transport via pipeline according to region

Region	CO_2 offshore storage		CO_2 onshore storage		CO_2 transport via pipeline	
	Mean[1]	SD[2]	Mean[1]	SD[2]	Mean[1]	SD[2]
Nationwide	3.6	1.8	3.3	1.7	3.9	1.6
North Frisia	2.4	1.8	2.3	1.7	2.9	1.9
Aurich plus islands	2.8	1.9	2.9	1.8	3.6	1.9
Total	3.1	1.9	2.9	1.7	3.6	1.8

[1] Scale from 1 (= very negative) to 7 (= very positive). The higher the mean, the more positive the assessment of CO_2 offshore/onshore storage/transport via pipeline. [2] SD = standard deviation. Question: "Overall, how do you assess the idea of CO_2 offshore storage/CO_2 onshore storage/CO_2 transport via pipeline?"

Nationwide, CO_2 transport via pipeline was generally assessed neutrally (cf. Table 5). In Aurich plus islands, the general attitude towards CO_2 pipelines was slightly more negative, while in North Frisia, it was visibly more negative than in the rest of Germany.

CO_2 onshore storage was evaluated more negatively than CO_2 offshore storage in the nationwide survey. In the regional surveys, no statistical differences could be found in the general attitudes towards the two storage options. In comparison to CO_2 transport via pipeline, the attitudes towards CO_2 offshore storage/CO_2 onshore storage were perceptibly more negative in all regions.

3.5. Determinants of general attitudes towards CO_2 storage and CO_2 transport via pipeline

The previous sections showed that the self-reported awareness, factual knowledge, risk perceptions and general attitudes regarding CO_2 storage and CO_2 transport via pipeline differ according to region. In addition, the question as to which factors determine the attitudes towards CO_2 storage and CO_2 pipelines is relevant. In order to answer this question, three ordinal regressions were performed.

The dependent variable in model 1 was the general attitude towards CO_2 transport via pipeline. In model 2, the dependent variable was the general attitude towards CO_2 offshore storage and in model 3, it was the general attitude towards CO_2 onshore storage (cf. Table 6). The independent variables included in all models were gender, age, professional qualification, perceptions of the personal/societal benefit of CCS, attitudes towards the vulnerability of nature (the so-called "myths of nature") and attitudes towards the relation of economy and environment (cf. Table 6).[10]

Furthermore, factual knowledge and risk perceptions were taken into account, but their specifications differed in the three models. In model 1, knowledge of pipelines and the perceptions of personal/societal risks of CO_2 transport via pipeline were included. In model 2 and model 3, knowledge of CO_2 storage was included as well as perceptions of the personal and societal risks of CO_2 offshore storage and CO_2 onshore storage, respectively (cf. Table 6). The regression analyses were performed separately for the three regions nationwide, North Frisia and Aurich plus islands.

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[10] How we measured the "attitudes towards the vulnerability of nature" and "attitudes towards the relations of economy and environment" is explained in Appendix B.

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Table 6: Variables in the regression models

Model	Dependent variable	Independent variables
Model 1	General attitude towards CO_2 transport via pipeline	• Gender • Age • Professional qualification • Knowledge of pipelines • Perception of the personal risk of CO_2 transport via pipeline • Perception of the societal risk of CO_2 transport via pipeline • Perception of the personal benefit of CCS • Perception of the societal benefit of CCS • Attitudes towards the vulnerability of nature ("myths of nature") • Attitudes towards the relation of economy and environment
Model 2	General attitude towards CO_2 offshore storage	• Gender • Age • Professional qualification • Knowledge of CO_2 storage • Perception of the personal risk of CO_2 offshore storage • Perception of the societal risk of CO_2 offshore storage • Perception of the personal benefit of CCS • Perception of the societal benefit of CCS • Attitudes towards the vulnerability of nature ("myths of nature") • Attitudes towards the relation of economy and environment
Model 3	General attitude towards CO_2 onshore storage	• Gender • Age • Professional qualification • Knowledge of CO_2 storage • Perception of the personal risk of CO_2 onshore storage • Perception of the societal risk of CO_2 onshore storage • Perception of the personal benefit of CCS • Perception of the societal benefit of CCS • Attitudes towards the vulnerability of nature ("myths of nature") • Attitudes towards the relation of economy and environment

Based on the results of our regression analyses[11], Table 7 summarizes the most important determinants of general attitudes towards CO_2 transport via pipeline, CO_2 offshore storage and CO_2 onshore storage. The determinants in the table are listed in descending order of their strength of influence, i.e. the factors with the highest influence are mentioned first, followed by those with the second-highest influence, etc.

Table 7 shows that the perceptions of the personal and societal risks of CO_2 transport via pipeline/CO_2 offshore storage/CO_2 onshore storage as well as the perceptions of the personal and societal benefits of CCS are the most important determinants of general attitudes towards CO_2 transport via pipeline, CO_2 offshore storage and CO_2 onshore storage. The lower the perceived personal or societal risk, the more positive the general attitudes towards CO_2 pipelines or CO_2 offshore storage/CO_2 onshore storage. The lower the assessment of the personal or societal benefit of CCS, the more negative the general attitudes towards CO_2 transport via pipeline or CO_2 offshore/onshore storage.

Other important factors were the attitudes towards the relation between economy and environment and the attitudes towards the vulnerability of nature, which are rooted in so-called "myths of nature" (cf. Appendix B). However, the results of our regression analyses were ambiguous with regard to the correlation between attitudes towards the relation between economy and environment and attitudes towards the vulnerability of nature, respectively, and general attitudes towards CO_2 transport via pipeline or CO_2 offshore/onshore storage. For example, respondents in the rest of Germany who agreed with the statement that the marine environment is very adaptable and will recover from any harm caused by people (perception of nature as "benign") had positive attitudes towards CO_2 transport via pipeline. In Aurich plus islands, those respondents who rejected the perception of nature as "benign" had positive attitudes towards a CO_2 pipeline.

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[11] The fit indices for our models are included in Appendix C. They show a good fit for all performed regression models. The results regarding parameter estimates within the models are too comprehensive to present in an appendix to this paper. Readers who are interested in the detailed results will be provided with them if they send an email to the corresponding author.

Table 7: Most important determinants of general attitudes towards CO_2 transport via pipeline, CO_2 offshore storage and CO_2 onshore storage

General attitude towards…	Nationwide		North Frisia		Aurich plus islands	
CO_2 transport via pipeline (Model 1)	▪	Perception of the societal risk of CO_2 transport via pipeline	▪	Perception of the societal risk of CO_2 transport via pipeline	❖	Perception of the personal risk of CO_2 transport via pipeline
	❖	Perception of the personal risk of CO_2 transport via pipeline	❖	Perception of the personal risk of CO_2 transport via pipeline	▪	Perception of the societal risk of CO_2 transport via pipeline
	○	Approval of the perception of nature as "benign"	□	Perception of the personal benefit of CCS	○	Rejection of the perception of nature as "benign"
	➢	Perception of the societal benefit of CCS	◉	Rejection of the statement that the economy should come first	□	Perception of the personal benefit of CCS
	□	Perception of the personal benefit of CCS			➢	Perception of the societal benefit of CCS
CO_2 offshore storage (Model 2)	▪	Perception of the societal risk of CO_2 offshore storage	▪	Perception of the societal risk of CO_2 offshore storage	▲	Rejection of the statement that the highest priority should be given to economic considerations even if it hurts the environment
	❖	Perception of the personal risk of CO_2 offshore storage	❖	Perception of the personal risk of CO_2 offshore storage	□	Perception of the personal benefit of CCS
	➢	Perception of the societal benefit of CCS	□	Perception of the personal benefit of CCS	▪	Perception of the societal risk of CO_2 offshore storage
	✘	Rejection of the perception of nature as "tolerant"	➢	Perception of the societal benefit of CCS	❖	Perception of the personal risk of CO_2 offshore storage
					➢	Perception of the societal benefit of CCS
CO_2 onshore storage (Model 3)	▪	Perception of the societal risk of CO_2 onshore storage	□	Perception of the personal benefit of CCS	➢	Perception of the societal benefit of CCS
	❖	Perception of the personal risk of CO_2 onshore storage	❖	Perception of the personal risk of CO_2 onshore storage	▪	Perception of the societal risk of CO_2 onshore storage
	➢	Perception of the societal benefit of CCS	▪	Perception of the societal risk of CO_2 onshore storage	❖	Perception of the personal risk of CO_2 onshore storage
	✘	Rejection of the perception of nature as "tolerant"	▪	Approval of the perception of nature as "capricious"	▲	Rejection of the statement that the highest priority should be given to economic considerations even if it hurts the environment
	○	Approval of the perception of nature as "benign"	◉	Approval of the statement that the environment should come first		

Concerning the attitudes towards the relation between economy and environment, the results showed for example that respondents in Aurich plus islands who rejected the statement that "both the environment and the economy are important, but the economy should come first" had rather positive attitudes towards CO_2 offshore storage and rather negative attitudes towards CO_2 onshore storage.

4. Conclusions

The aim of our study was to investigate the perception of CO_2 offshore storage amongst the German public in comparison to the perception of CO_2 onshore storage and CO_2 transport via pipeline. For this purpose, three representative surveys of the German public were performed and the results were analyzed using descriptive statistics and ordinal regressions.

The results of the analyses reveal that CO_2 storage is hardly accepted by the German public. To the question of which option of CO_2 storage they would prefer, the majority of the respondents answered spontaneously (i.e. without being provided with this predefined answer) that they would prefer CO_2 to be stored nowhere at all.

In refusing CO_2 storage, no major differences could be identified between the two storage options – offshore and onshore. The citizens of the coastal regions refused both storage options in equal measure. In the rest of Germany, CO_2 onshore storage was assessed slightly more negatively than CO_2 offshore storage.

In principle, the rejection of CO_2 storage was higher in the two coastal regions than in the rest of Germany and highest in North Frisia. This was illustrated by higher risk perceptions and more negative attitudes towards both storage options.

Nationwide, CO_2 transport via pipeline was generally assessed neutrally. In Aurich plus islands, the general attitude towards CO_2 pipelines was slightly more negative and in North Frisia visibly more negative than in the rest of Germany. In comparison to CO_2 offshore storage/CO_2 onshore storage, the attitudes towards CO_2 transport via pipeline were perceptibly more positive in all regions.

The most important direct determinants of general attitudes towards CO_2 transport via pipeline, CO_2 offshore storage and CO_2 onshore storage, according to our regression results, are the perceptions of the personal and societal risks of CO_2 transport via pipeline/CO_2 offshore storage/CO_2 onshore storage as well as the perceptions of the personal and societal benefits of CCS. Even though the ranking order of importance of these factors varied at times depending on the region and model (cf. Table 7), they were the only influencing factors that revealed systematic correlations with the attitudes towards CO_2 transport via pipeline, CO_2 offshore/CO_2 onshore storage with the same trend in every region and regression model: the lower the perceived personal or societal risk, the more positive the general attitudes towards CO_2 pipelines or CO_2 offshore storage/CO_2 onshore storage. The lower the assessed personal or societal benefit of CCS, the more negative the general attitudes towards CO_2 transport via pipeline or CO_2 offshore/CO_2 onshore storage.

These results confirm the results of other multivariate analyses of CCS acceptance [6], in which risk and benefit perceptions were also found to be the most important determinants of attitudes towards CCS and to influence the attitudes in the same manner as in the present study.

The fact that risk perceptions were identified in different analyses as relevant factors determining attitudes towards CCS, CO_2 transport and CO_2 storage suggests that the perception of CCS as a risk technology is increasingly consolidating. Examples like the disapproval of nuclear energy or gene technology in Germany lead to the assumption that the rejection of a technology is difficult to influence positively when their perception as a risk technology is consolidated amongst the public. The results of our study for North Frisia indicate that in this region the perception of CCS is already consolidated. This is illustrated by the principally higher risk perceptions and principally more negative general attitudes towards CO_2 pipelines and CO_2 offshore/onshore storage.

However, the analyses also showed that the higher the assessed benefit and particularly the societal benefit of CCS, the more positive the attitudes towards CCS, CO_2 transport and CO_2 storage. Against the background of a consolidating or already consolidated perception of CCS as a risk technology, this study cannot answer the question as to what extent this result provides a starting point for information or communication strategies that could help to reduce the disapproval of CO_2 storage amongst the German public and thereby provide opportunities for CCS in Germany.

Acknowledgements

Appendix A. Knowledge questions regarding CO_2, CO_2 storage and pipelines

Knowledge questions regarding CO_2

I will now read to you different statements about carbon dioxide (CO_2). Please tell me to the best of your knowledge whether each statement is true or false.

CO_2 is..	True	False	Don't know
flammable.		X	
a greenhouse gas.	X		
poisonous.		X	
explosive.		X	
a water pollutant.		X	

Correct answers are marked with an "X".

Knowledge questions regarding CO_2 storage

I will now read to you different statements about the storage of carbon dioxide (CO_2). Please tell me to the best of your knowledge whether each statement is true or false.

Statement	True	False	Don't know
Empty oil or gas reservoirs are not suitable for the storage of CO_2.		X	
It is possible to store CO_2 under the seabed of the German North Sea.	X		
Offshore storage of CO_2 means that CO_2 is stored in the sea.		X	
Offshore storage of CO_2 means that CO_2 is stored under the seabed.	X		
Onshore storage of CO_2 means that CO_2 is stored under the mainland.	X		

Correct answers are marked with an "X".

Knowledge questions regarding pipelines

I will now read to you different statements about pipelines. Please tell me to the best of your knowledge whether each statement is true or false.

Statement	True	False	Don't know
The overall length of already existing pipelines for natural gas and mineral oil in Germany is more than 25,000 kilometres.	X		
Pipelines onshore normally exist at a depth of not less than one metre below ground.	X		
In Germany, approximately 80 percent of the crude oil for the production of petrol, diesel, kerosene and heating oil are transported via pipeline.	X		
The transport of large quantities of carbon dioxide via pipeline would be much more expensive than transport by train or lorry.		X	
Up to now, no pipeline has existed worldwide for the transport of carbon dioxide.		X	

Correct answers are marked with an "X".

Appendix B. Approaches for measuring the attitudes towards the vulnerability of nature and attitudes towards the relation of economy and environment

The theoretical foundation for surveying the attitudes towards the vulnerability of nature was the so-called "myths of nature" [17], which are rooted in anthropological cultural theory. According to [17], there are four different "myths of nature": (1) the myth of nature as "benign", which means that the environment is very adaptable and will recover from any harm caused by people, (2) the myth of nature as "tolerant", i.e. that with expert management, environmental disasters can be prevented, (3) the myth of nature as "ephemeral", which means that the environment is very fragile and the slightest human interference will cause a major disaster and (4) the myth of nature as "capricious", i.e. that it does not matter what we do, the environment will change in unpredictable ways both for the better and the worse.

In order to measure the extent to which the "myths of nature" are reflected by the attitudes of citizens towards the vulnerability of the marine environment, the respondents were asked to assess on a scale from 1 (= strongly

disagree) to 7 (= strongly agree) the extent to which they agreed with the following four statements: (a) the marine environment is very adaptable and will recover from harm caused by people (myth of nature as "benign"), (b) with good management, we can prevent environmental disasters in the marine environment (myth of nature as "tolerant"), (c) the marine environment is very fragile and the slightest human interference can cause a major disaster (myth of nature as "ephemeral") and (d) no matter what we do, the marine environment will change in unpredictable ways both for the better and the worse (myth of nature as "capricious").

The basis for surveying the attitudes towards the relevance of environmental protection was a concept from existing studies on public acceptance of CCS which investigated the significance attributed to environmental protection in relation to the economic situation [9, 18, 19]. Building on these studies, the respondents of our survey were asked to assess on a scale from 1 (= strongly disagree) to 7 (= strongly agree) the extent to which they agree with the following four statements: (a) the highest priority should be given to protecting the environment, even if it hurts the economy, (b) both the environment and the economy are important, but the environment should come first, (c) both the environment and the economy are important, but the economy should come first and (d) the highest priority should be given to economic considerations even if it hurts the environment.

Appendix C. Model fits

Model 1											
		Model Fitting Information					**Goodness-of-Fit**			**Pseudo R-Square**	
Nationwide	Model	-2 Log Likelihood	Chi-Square	df	Sig.		Chi-Square	df	Sig.	Cox and Snell	.483
Link function: Logit	Intercept only	3334.762				Pearson	14979.409	5487	.000	Nagelkerke	.497
	Final	2719.694	615.068	81	.000	Deviance	2715.299	5487	1.000	McFadden	.184
		Model Fitting Information					**Goodness-of-Fit**			**Pseudo R-Square**	
North Frisia	Model	-2 Log Likelihood	Chi-Square	df	Sig.		Chi-Square	df	Sig.	Cox and Snell	.477
Link function: Negative log-log	Intercept only	1643.513				Pearson	3930.410	2775	.000	Nagelkerke	.493
	Final	1333.973	309.541	81	.000	Deviance	1333.973	2775	1.000	McFadden	.188
		Model Fitting Information					**Goodness-of-Fit**			**Pseudo R-Square**	
Aurich plus islands	Model	-2 Log Likelihood	Chi-Square	df	Sig.		Chi-Square	df	Sig.	Cox and Snell	.501
Link function: Negative log-log	Intercept only	1792.815				Pearson	2929.499	2811	.058	Nagelkerke	.514
	Final	1456.600	336.215	81	.000	Deviance	1456.600	2811	1.000	McFadden	.188

		Model 2									
		Model Fitting Information					**Goodness-of-Fit**			**Pseudo R-Square**	
Nationwide	Model	-2 Log Likelihood	Chi-Square	df	Sig.		Chi-Square	df	Sig.	Cox and Snell	.600
Link function: Logit	Intercept Only	3506.242				Pearson	9629.117	5499	.000	Nagelkerke	.614
	Final	2651.588	854.654	81	.000	Deviance	2651.588	5499	1.000	McFadden	.244
		Model Fitting Information					**Goodness-of-Fit**			**Pseudo R-Square**	
North Frisia	Model	-2 Log Likelihood	Chi-Square	df	Sig.		Chi-Square	df	Sig.	Cox and Snell	.532
Link function: Negative Log-log	Intercept Only	1406.507				Pearson	5424.960	2757	.000	Nagelkerke	.562
	Final	1043.828	362.679	81	.000	Deviance	1043.828	2757	1.000	McFadden	.258
		Model Fitting Information					**Goodness-of-Fit**			**Pseudo R-Square**	
Aurich plus islands	Model	-2 Log Likelihood	Chi-Square	df	Sig.		Chi-Square	df	Sig.	Cox and Snell	.517
Link function: Negative Log-log	Intercept Only	1676.331				Pearson	3499.197	2811	.000	Nagelkerke	.534
	Final	1324.572	351.759	81	.000	Deviance	1324.572	2811	1.000	McFadden	.210
		Model 3									
		Model Fitting Information					**Goodness-of-Fit**			**Pseudo R-Square**	
Nationwide	Model	-2 Log Likelihood	Chi-Square	df	Sig.		Chi-Square	df	Sig.	Cox and Snell	.521
Link function: Negative Log-log	Intercept Only	3379.089				Pearson	7651.489	5499	.000	Nagelkerke	.535
	Final	2693.157	685.933	81	.000	Deviance	2693.157	5499	1.000	McFadden	.203
		Model Fitting Information					**Goodness-of-Fit**			**Pseudo R-Square**	
North Frisia	Model	-2 Log Likelihood	Chi-Square	df	Sig.		Chi-Square	df	Sig.	Cox and Snell	.560
Link function: Negative Log-log	Intercept Only	1398.122				Pearson	3901.161	2757	.000	Nagelkerke	.591
	Final	1006.854	391.268	81	.000	Deviance	1006.854	2757	1.000	McFadden	.280
		Model Fitting Information					**Goodness-of-Fit**			**Pseudo R-Square**	
Aurich plus islands	Model	-2 Log Likelihood	Chi-Square	df	Sig.		Chi-Square	df	Sig.	Cox and Snell	.490
Link function: Negative Log-log	Intercept Only	1687.848				Pearson	4585.456	2811	.000	Nagelkerke	.505
	Final	1362.682	325.166	81	.000	Deviance	1362.682	2811	1.000	McFadden	.193

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