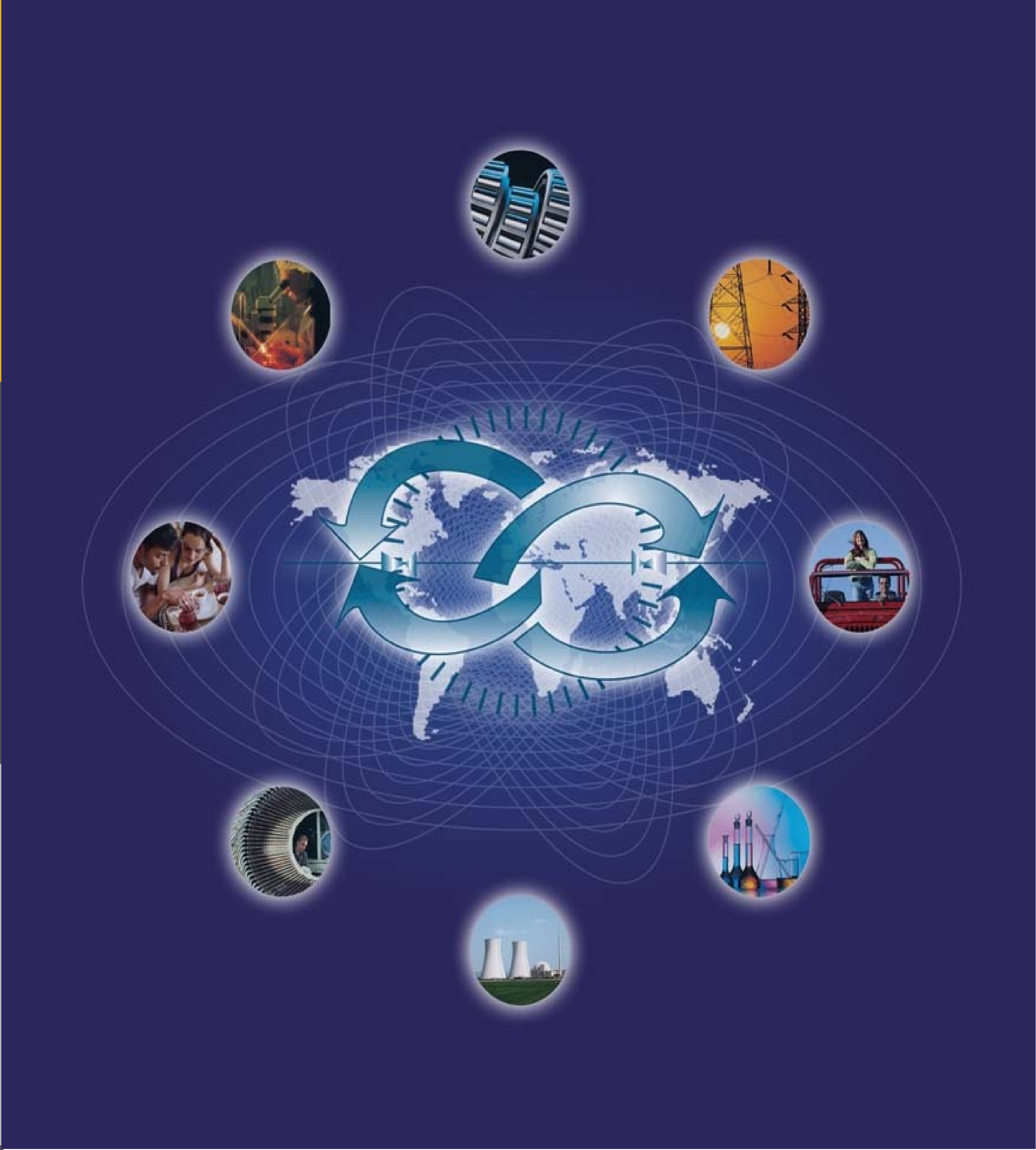

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Schumann, Diana

Public Perception of Energy Systems Transformation in Germany

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Systemforschung und Technologische Entwicklung (IEK-STE)

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Public Perception of Energy Systems Transformation in Germany

Diana Schumann

Forschungszentrum Jülich, Institute of Energy and Climate Research - Systems Analysis and Technology Evaluation (IEK-STE), D-52425 Jülich, Germany

Executive Summary

Energy systems transformation, also called energy transition, means fundamental structural changes in energy systems. The main objectives of the energy transition in Germany, the so-called “Energiewende”, are to decarbonize energy supply by switching to renewable sources and to reduce energy demand by using energy more and more efficiently. This requires, for example, changes in the energy mix, the application of new energy technologies or changes in the demand behavior of citizens. However, such transformation strategies, even if they are technically and economically feasible, may become politically unfeasible, if they are not accepted by the public. Therefore, the reliable assessment of public perception is essential for the successful management of transforming the energy system.

The aim of the paper is to explain and illustrate how a tool called technology monitoring is used in order to assess public perception of Germany’s energy system transformation. After describing the research questions examined by technology monitoring as well as the tool’s elements and methods, two examples are used to illustrate how technology monitoring can contribute to the assessment of public perception of energy systems transformation: CO_2 capture and storage (CCS) and the extraction of shale gas. For this purpose the public perception of CCS and shale gas extraction in Germany is firstly compared along the indicators self-reported awareness, factual knowledge, risk perceptions, benefit perceptions and general attitudes by applying descriptive statistical analyses. Secondly, four linear regressions were performed in order to identify the determinants of attitudes towards CO_2 pipelines, CO_2 onshore storage, CO_2 offshore storage and shale gas extraction.

The results of the study illustrate that technology monitoring contributes to the assessment of public perception of energy systems transformation by providing information which can be valuable in order to assess the societal feasibility of future energy systems and delivering information which can facilitate the management of energy transition.

Keywords

Public perception, energy systems transformation, Germany, technology monitoring, CO_2 capture and storage, shale gas extraction

Contribution to

Euro-Asian Journal of sustainable energy development policy

I Introduction

Energy systems transformation, also called energy transition[1], means fundamental structural changes in energy systems, which have occurred in the past and still occur worldwide [World Energy Council, 2014]. However, energy transitions differ in terms of motivation, objectives, drivers and governance [ibid.]. The main objectives of the energy transition in Germany, the so-called “Energiewende”, are to decarbonize energy supply by switching to renewable sources and to reduce energy demand by using energy more and more efficiently [Federal Ministry of Economics and Technology (BMWi), 2015]. Thereby, Germany aims to make a significant contribution towards combating climate change.[2]

The transformation of the existing energy system in Germany into a more sustainable energy system requires long-term fundamental changes, which includes changes in the energy mix, the application of new energy technologies and possibly the exploitation of new energy sources, but also changes in the demand behavior of the citizens. However, such transformation strategies, even if they are technically and economically feasible, may become politically unfeasible, if they are not accepted by the public. Therefore, the reliable assessment of public perception is essential for the successful management of transforming the energy system.

The aim of this paper is to explain and illustrate how a tool called technology monitoring is used in order to assess the public perception of Germany’s energy system transformation. Firstly, the research questions and the aim of technology monitoring will be described as well as the tool’s elements and methods. Subsequently, by using the examples of CO_2 capture and storage (CCS) and the extraction of shale gas it will be illustrated how technology monitoring can be used for the assessment of public perception. This will include a comparison of the public perception of CCS and shale gas extraction in Germany along the indicators self-reported awareness, factual knowledge, risk perceptions, benefit perceptions and general attitudes by applying descriptive statistical analyses. Furthermore, the determinants of attitudes towards CO_2 pipelines, CO_2 onshore storage, CO_2 offshore storage and the extraction of shale gas will be identified by applying regression analyses. Against this background the contributions of technology monitoring for the assessment of public perception of energy systems transformation in general as well as possible contributions to energy scenarios in particular will be explained.

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1 The terms “energy systems transformation” and “energy transition” are used synonymously in this paper.

2 The goals and measures of the energy transition in Germany are described in detail in the German government’s Energy Concept [Federal Ministry of Economics and Technology (BMWi) & Federal Ministry for the Environment; Nature Conservation and Nuclear Safety (BMU), 2010] and the 10-Point energy agenda of the Federal Ministry for Economic Affairs and Energy [Federal Ministry of Economics and Technology (BMWi), 2014].

II Technology Monitoring

Technology monitoring is part of the integrated assessment of energy systems, which is the main focus of the interdisciplinary work of the group "Systems Analysis and Technology Evaluation" at the Institute of Energy and Climate Research at Forschungszentrum Jülich (Research Centre Jülich). The integrated assessment of the transformation of energy systems includes technical, economic, environmental and social assessment. The social assessment of energy systems transformation comprises the organization and realisation of stakeholder dialogues, the investigation of mentalities and patterns of behaviour related to energy consumption, life cycle sustainability assessment and technology monitoring. Technology monitoring is the main approach for assessing public perception of energy systems transformation and will be described in more detail in the following chapters.

II.1 Research questions and aim of technology monitoring

In order to assess the public perception of energy transition in Germany, technology monitoring investigates three general research questions: (1) What is the status quo? (2) Which dynamics does it have? and (3) What are the determinants?

Investigating the first question includes assessing how aware the general public is of energy transition and which knowledge and attitudes the public has. Examining the second question comprises measuring how the public awareness, knowledge and attitudes develop and change over time. Exploring the third question means to reveal the relevant factors which determine public perceptions and general attitudes.

Thus, the aim of technology monitoring is to contribute to the assessment of public perception of the German energy system's transformation by surveying the awareness, knowledge and attitudes among the German public regarding technologies, instruments and impacts of the energy transition.

II.2 Methods of technology monitoring

Core element of technology monitoring is a representative survey of the public in order to measure the perception of the energy system's transformation in Germany. The survey is carried out annually since 2011/12 (= IEK-STE Panel Survey). Population of the IEK-STE Panel Survey are all German citizens from the age of 18 with landline connection (cf. Table 1). Participants for the survey are recruited using multi-stage systematic random sampling. For the selection of the respondent the last birthday selection method is used, i.e. the person from the age of 18 who had the last birthday in the household will be interviewed.

Every year (= panel wave) at least 1000 interviews are realized. The reproduction accuracy of the survey sample is examined by comparing the distributions of the characteristics gender, age, professional qualification, income and household size with the data of the Microcensus, which is a representative household survey of the official statistics in Germany.

Every wave of the panel survey comprises questions which are asked every year (= core questions; e.g. questions regarding attitudes towards energy sources) as well as questions on specific up-to-date topics (e.g. questions regarding attitudes towards CCS, shale gas or expansion of the electricity grid) which vary every year or which are repeated in a larger temporal intervals (e.g. every second year).

Table 1: Parameters of the IEK-STE Panel Survey

Parameter	Specification
Population	All German citizens from the age of 18 with landline connection
Sampling procedure	Multi-stage systematic random selection from the existing landline numbers in Germany
Selection of the respondent	Last-Birthday Selection: Person from the age of 18 who had the last birthday in the household
Realised sample size	At least 1000 persons
Criteria for the representativeness of the sample	▪ Gender ▪ Age ▪ Professional qualification ▪ Income ▪ Household size
Data base for verifying the representativeness of the sample	Data of the Federal Statistical Office (Microcensus)
Survey method	Computer-assisted telephone interviews (CATI)

Source: authors' own IEK-STE 2017

Further essential elements of technology monitoring are specific representative surveys of the German public performed only once in order to investigate research questions related to research projects focussing on specific energy technologies; e.g. CO_2 storage, energy storage, vehicle to grid [Daamen et al., 2011, Duetschke et al., 2014, Duetschke et al., 2015, Pietzner et al., 2011, Pietzner et al., 2014, Schumann et al., 2014, ter Mors et al., 2013] or other aspects of the energy system's transformation, e.g. energy consumption or energy security.

In the IEK-STE Panel Survey, three main indicators to assess the public perception of energy systems' transformation are used: self-reported awareness, factual knowledge and attitudes of the citizens. The data is analysed with methods of descriptive statistics (frequencies, means, standard deviations, and correlations), inductive statistics (regressions, hypothesis tests) as well as with more complex multivariate methods of analysis (e.g. structural equation modelling).

In the following, the examples of CO_2 capture and storage (CCS) and the extraction of shale gas will be used in order to illustrate how technology monitoring can contribute to the assessment of public perception of energy transition.

III Assessment of public perception of CCS and shale gas in Germany

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 [European Commission, 2013, IEA, 2015]. Since CCS can be applied for reducing CO_2 emissions from fossil fuel based electricity generation it could be used as a strategy for transforming the German energy system into a more sustainable energy system. Therefore, the analysis of the perception of CCS among the German public is relevant for the assessment of public's perception of the energy systems transformation.

The extraction of shale gas is seen as a strategy for enhancing energy security [IEA, 2012] and could play an important role in transforming the German energy system into an energy system deploying less oil and being less dependent on oil imports. Thus, the evaluation of public perception of shale gas extraction in Germany is important for assessing the perception of the energy transition among the public.

In order to assess the perception of CCS and shale gas among the German public, the self-reported awareness, knowledge and attitudes of the citizens were surveyed for the first time 2011/12 in the first wave of the IEK-STE Panel Survey and for the second time 2015 in the fourth panel wave. Furthermore, the public perception of CO_2 offshore storage, CO_2 onshore storage and CO_2 pipelines was surveyed in more detail in three representative surveys (a nationwide survey and two regional surveys) of the German public which was carried out in 2013 within the framework of a project called "CCS-Chances" [Duetschke et al., 2015].[3] In this paper, the data of the two panel waves as well as the data of the national "CCS Chances survey" were used to compare the public perception of CCS and shale gas in Germany along the indicators self-reported awareness, factual knowledge, risk perceptions, benefit perceptions and general attitudes by applying descriptive statistical analyses. Additionally, linear regression analyses were performed in order to identify the factors that determine the general attitudes towards CO_2 pipelines, CO_2 onshore storage, CO_2 offshore storage and the extraction of shale gas.

III.1 Self-reported awareness of CCS, shale gas and fracking over time

Awareness is an indispensable prerequisite for forming or having an attitude towards a person, object or issue. In our surveys, the respondents reported their awareness of CCS, shale gas and fracking 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".

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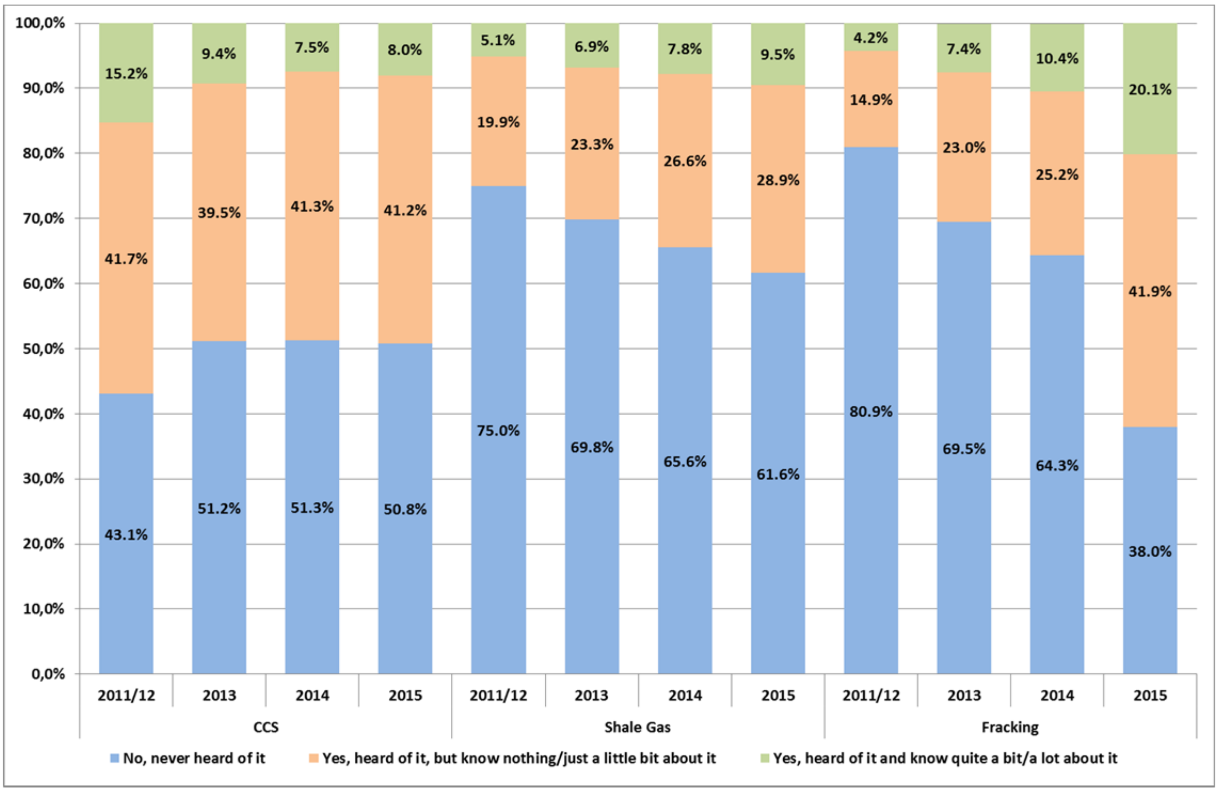
3 https://www.tib.eu/suchen/download/?tx_tibsearch_search%5Bdocid%5D=TIBKAT%3A835363600&cHash=bfea90dc8a82276cf056479593a0fb61#download-mark (webpage in German).

The results of our descriptive statistical analyses illustrate that the self-reported awareness of CCS decreased in 2013 compared to 2011/12 (cf. Figure 1). In 2011/12 43.1 % of the German public had never heard about CCS, in 2013 51.2 % answered that they had never heard of CCS. The proportion of respondents who answered that they heard quite a bit about CCS decreased from 15.2 % to 9.4 %.

Since 2013 the self-reported awareness of CCS has mainly remained stable, with around 51 % of respondents who had never heard of CCS. The proportion of respondents who answered that they heard a little bit about CCS accounted for 40 % to 42 % and the share of respondents who answered that they heard quite a bit about CCS decreased from 9 % to 8 %.

Figure 1: Self-reported awareness of CCS, shale gas and fracking over time



Question: "Have you heard about the following topics?"

Data sources: IEK-STE-Panel Survey 2011/12 (n=1000), 2013 (n=1034), 2014 (n=1006), 2015 (n=1000) IEK-STE 2017

In 2011/12 75.0 % of the German public had never heard of shale gas, in 2015 61.6 % had never heard of it. The proportion of respondents who answered that they heard quite a bit about shale gas increased from 5.1 % to 9.5 %.

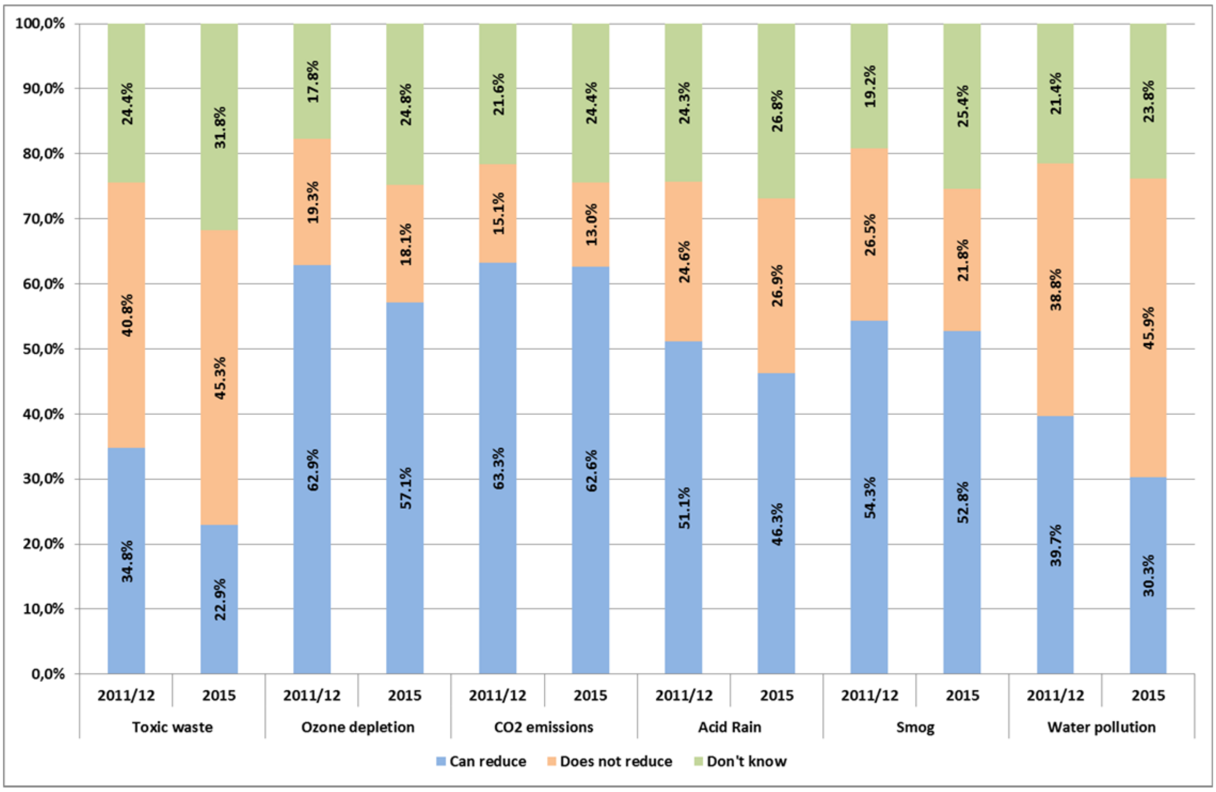
The self-reported awareness of fracking increased considerably more over time than the self-reported awareness of shale gas: in 2011/12 80.9 % of the German public had never heard of fracking, in 2015 only 38.0 % had never heard of it. The share of respondents who answered that they heard quite a bit about fracking increased from 4.2 % to 20.1 %. Figure 1 also illustrates that the self-reported awareness of fracking has particularly increased from 2014 to 2015.

The differences in the self-reported awareness of CCS, shale gas and fracking reflect the different status of public debate and media coverage regarding these topics in the last years. Whereas the development of CCS in Germany has slowed down and is suspended at present [cf. Fischer, 2014], the regulation of shale gas extraction in Germany and Europe has been intensively discussed and been accompanied by several extensive media reports.[4]

III.2 Factual knowledge about CCS and shale gas

Knowledge of an object or issue can be measured on a subjective level or on a factual level, cf. [European Commission, 2008]. The factual knowledge about CCS among the German public was measured in our panel survey by asking the question "CCS can reduce which of the following environmental concerns?" and then presenting the following environmental concerns: toxic waste, ozone depletion, CO_2 emissions, acid rain, smog and water pollution (cf. Figure 2). The question was posed only to respondents who head heard of CCS (cf. Chapter 3.1).

Figure 2: Factual knowledge about CCS



Only respondents who had heard about CCS. Question: "CCS can reduce which of the following environmental concerns?"

Data sources: IEK-STE-Panel Survey 2011/12 (n=569), 2015 (n=492) IEK-STE 2017

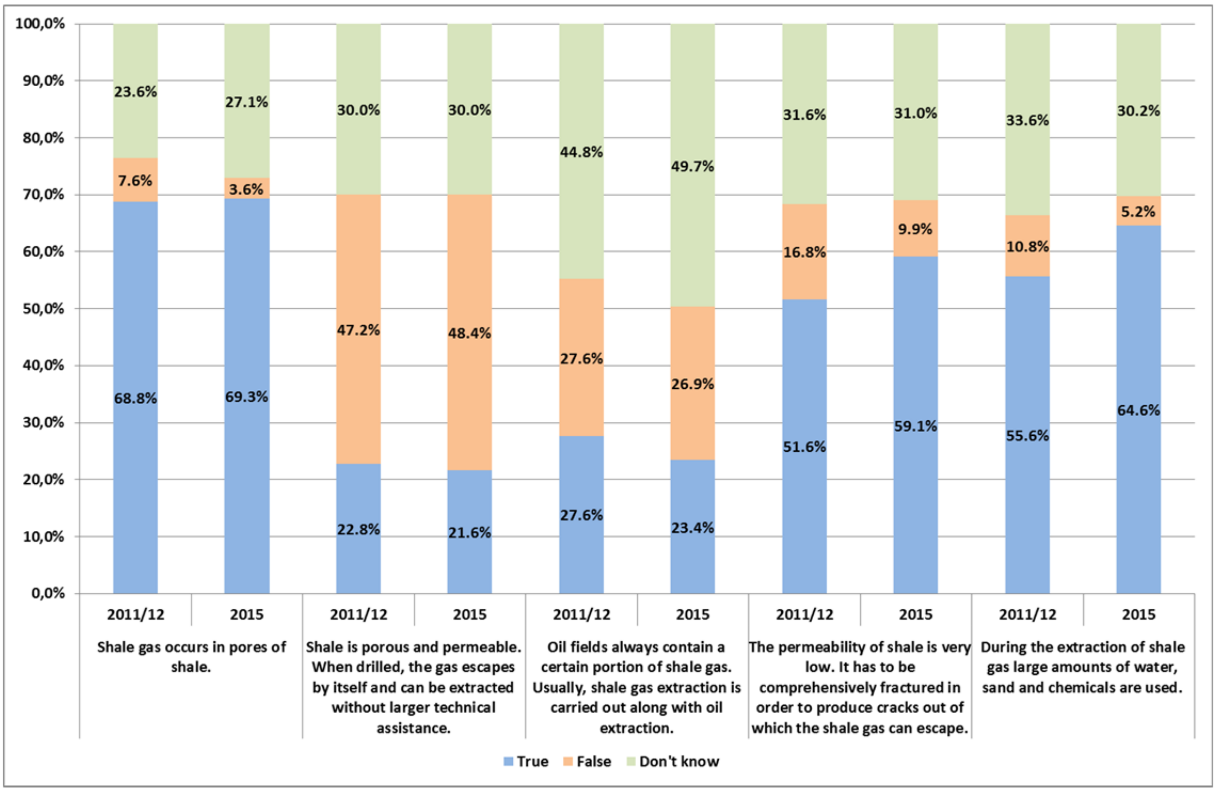
4 http://www.shale-gas-information-platform.org/areas/the-debate/shale-gas-in-germany-the-current-status.html.

The results from this question illustrate that the level of factual knowledge about CCS among the German public has increased over time with regard to some aspects, whereas is has remained stable with regard to others (cf. Figure 2). The share of respondents who knew that CCS does not reduce toxic waste increased by 4.5 percentage points and the share of respondents who knew that CCS does not reduce water pollution increased by 7 percentage points in 2015, compared to 2011/12. The share of respondents who correctly stated that CCS does not reduce acid rain increased from 24.6 % to 26.9 %. On the other hand, the proportion of respondents who knew that CCS can reduce CO_2 emissions was around 63 % in both years.

However, the results also show that misconceptions about CCS exist and persist over time. In 2011/12 62.9 % and in 2015 57.1 % of the respondents incorrectly thought that CCS can reduce ozone depletion. Furthermore, in both years more than half of the respondents incorrectly thought that CCS can reduce smog.

In order to find out the factual knowledge of the German citizens about shale gas extraction, the respondents of our surveys who had heard about shale gas were presented with the five statements shown in Figure 3 and then asked whether these statements were true or false.

Figure 3: Factual knowledge about shale gas



Only respondents who had heard about shale gas. Question: "Please tell me to the best of your knowledge whether each statement is true or false."

Data sources: IEK-STE-Panel Survey 2011/12 (n=250), 2015 (n=384) IEK-STE 2017

The results show that, similar to CCS, the level of knowledge about shale case extraction has increased over time, but only with regard to some aspects. The share of respondents who knew that during the extraction of shale gas large amounts of water, sand and chemicals are used, increased by 9 percentage points in 2015, compared to 2011/12. The proportion of respondents who knew that the permeability of shale is very low so that is has to be fractured in order to produce cracks out of which the shale gas can escape rose by 7.5 percentage points. On the other hand, the share of respondents who knew that shale gas occurs in pores of shale remained stable over time.

Furthermore, with regard to shale gas extraction also misconceptions exist which persist over time. For example, the proportion of respondents who incorrectly thought that shale is porous and permeable so that the shale gas can be extracted without larger technical assistance when the shale is drilled was 22.8 % in 2011/12 and 21.6 % in 2015.

Additionally, the proportions of respondents who did not know whether shale gas occurs in pores of shale or whether the extraction of shale gas is carried out along with oil extraction increased over time.

III.3 Risk perceptions of CO_2 pipelines, CO_2 onshore storage, CO_2 offshore storage and the extraction of shale gas

Previous studies on the acceptance of risks and technologies verified that the acceptance of technologies by the general public is greatly influenced by the intuitive perception of risks, as well as by the perception of benefits and trust [e.g. L'Orange Seigo et al., 2014, Siegrist, 2000, Siegrist et al., 2007]. In our studies, we generally differentiate between the perception of the personal risk, this means how risky the respondent think an energy technology would be to him and his family and the perception of the societal risk, this means how risky the respondent think an energy technology would be to society in general [Schumann, 2015, Schumann et al., 2014]. The risk perceptions are specified on a seven-level Likert scale, ranging from 1 (= very low) to 7 (= very high).

However, in our “CCS Chances survey” we collected data on the perceptions of the personal and societal risk of CO_2 transport via pipeline, CO_2 onshore storage and CO_2 offshore storage and not of CCS in general. This was due to the research focus of the project “CCS chances” which was the investigation of the perception of CO_2 offshore storage among the German public in comparison to the perception of CO_2 onshore storage and CO_2 transport via pipeline. Thus, in this paper we compared the risk perceptions of CO_2 pipelines, CO_2 onshore storage, CO_2 offshore storage and the extraction of shale gas (cf. Table 2).

With regard to the assessment of personal and societal risks of CO_2 transport via pipeline, CO_2 onshore storage, CO_2 offshore storage and the extraction of shale gas, a comparison of the means shows that the personal and societal risks of CO_2 onshore storage and shale gas are perceived as higher than the personal and societal risks of CO_2 pipelines and CO_2 offshore storage. However, in all cases the societal risks are deemed higher than the personal risks.

Table 2: Risk perceptions of CO_2 pipelines, CO_2 onshore storage, CO_2 offshore storage and the extraction of shale gas

	Personal risk		Societal risk	
	Mean[1]	SD[2]	Mean[1]	SD[2]
CO_2 transport via pipeline	3.7	1.8	4.1	1.6
CO_2 onshore storage	4.3	1.6	4.5	1.6
CO_2 offshore storage	3.9	1.8	4.2	1.7
Shale gas	4.2	1.7	4.7	1.6

[1] Scale from 1 (= very low) to 7 (= very high). [2] SD = Standard deviation. Question: "How risky do you think CO_2 transport via pipeline/CO_2 onshore storage/CO_2 offshore storage/the extraction of shale gas would be to you and your family/to society in general?"

Data sources: Survey "CCS Chances" 2013 (n= 1000);
IEK-STE Panel Survey 2015 (n=1000) IEK-STE 2017

III.4 Benefit perceptions of CCS and the extraction of shale gas

With regard to the assessment of benefits, we also differentiate between the perception of the personal benefit and the perception of the societal benefit [Schumann, 2015]. Benefit perceptions are also specified on a seven-level Likert scale, ranging from 1 (= very low) to 7 (= very high).

Due to the limited number of questions which we can pose in our surveys, it was not possible to include questions on the perceptions of personal and societal benefit of CO_2 pipelines, CO_2 onshore storage and CO_2 offshore storage, but only questions on the perceptions of personal and societal benefit of CCS (cf. Table 3).

Concerning the assessment of the benefits of CCS and shale gas, a comparison of means shows that the personal and societal benefits of shale gas are considered to be markedly lower than the personal and societal benefit of CCS. However, in both cases the societal benefit is perceived as higher than the personal benefit.

Table 3: Benefit perceptions of CCS and the extraction of shale gas

	Personal risk		Societal risk	
	Mean[1]	SD[2]	Mean[1]	SD[2]
CCS	3.4	1.6	3.9	1.7
Shale gas	2.8	1.4	3.4	1.5

[1] Scale from 1 (= very low) to 7 (= very high). [2] SD = Standard deviation. Question: "To what extent do you think CCS/the extraction of shale gas would benefit you and your family/society in general?"

Data sources: Survey "CCS Chances" 2013 (n= 1000);
IEK-STE Panel Survey 2015 (n=1000) IEK-STE 2017

III.5 General attitudes regarding CO_2 pipelines, CO_2 onshore storage, CO_2 offshore storage, CCS and the extraction of shale gas

The general attitude regarding CO_2 transport via pipeline, CO_2 onshore storage, CO_2 offshore storage, CCS and the extraction of shale gas was measured in our surveys by asking the question "Overall, how do you assess the idea of CO_2 transport via pipeline/CO_2 onshore storage/CO_2 offshore storage/CCS/the extraction of shale gas?" The respondents specified their general attitude on a seven-level Likert scale, ranging from 1 (= very negative) to 7 (= very positive).

A comparison of means illustrate, that the general attitude of the German public is considerably more negative towards shale gas than towards CO_2 pipelines, CO_2 onshore storage, CO_2 offshore storage and CCS (cf. Table 4). Furthermore, the general attitude is more negative towards CO_2 storage, especially CO_2 offshore storage, than towards CO_2 transport via pipeline and CCS in general.

Table 4: General attitudes regarding CO_2 pipelines, CO_2 onshore storage, CO_2 offshore storage, CCS and the extraction of shale gas

	General attitude	
	Mean[1]	SD[2]
CO_2 transport via pipeline	3.9	1.6
CO_2 onshore storage	3.3	1.7
CO_2 offshore storage	3.6	1.8
CCS	3.8	1.7
Shale gas	2.9	1.6

[1] Scale from 1 (= very negative) to 7 (= very positive). [2] SD = Standard deviation. Question: "Overall, how do you assess the idea of CO_2 transport via pipeline/CO_2 onshore storage/CO_2 offshore storage/CCS/the extraction of shale gas?"

Data sources: Survey "CCS Chances" 2013 (n= 1000);
IEK-STE Panel Survey 2015 (n=1000) IEK-STE 2017

III.6 Determinants of general attitudes towards CO_2 pipelines, CO_2 onshore storage, CO_2 offshore storage and the extraction of shale gas

In the previous sections the self-reported awareness, factual knowledge, risk perceptions, benefit perceptions and general attitudes regarding CCS, CO_2 pipelines, CO_2 onshore storage, CO_2 offshore storage and the extraction of shale gas were compared by applying descriptive statistical analyses. In addition, the question as to which factors determine the general attitudes towards CO_2 transport, CO_2 storage and the extraction of shale gas is relevant. In order to answer this question, four linear regressions were performed (cf. Appendix).

The results of our regression analyses[5] show that the most important direct determinants of general attitudes towards CO_2 pipelines, CO_2 onshore storage, CO_2 offshore storage and the

[5] The fit indices in the appendix show a good fit for all performed regression models.

extraction of shale gas are the perceptions of personal and societal risks.[6] The perception of the societal risk has the highest estimated parameter in every regression model, followed by the perception of personal risk (cf. Appendix). Furthermore, the perceptions of societal and personal risk revealed negative correlations with the general attitude in every regression model, i.e. the higher the perceived personal or societal risk, the more negative the general attitude towards CO_2 pipelines, CO_2 onshore storage, CO_2 offshore storage or the extraction of shale gas.

The perception of societal benefit is an important positive determinant of the general attitude in all regression models: the higher the assessed societal benefit, the more positive the general attitude towards CO_2 transport via pipeline, CO_2 onshore storage, CO_2 offshore storage or the extraction of shale gas.

The perception of personal benefit is an important positive determinant of the general attitudes towards CO_2 onshore storage, CO_2 offshore storage and shale gas extraction, i.e. the higher the assessed personal benefit, the more positive the general attitude. For the general attitude regarding CO_2 pipelines, the perception of the personal benefit is not a statistically significant influence factor.

The general attitudes towards CO_2 transport via pipeline, CO_2 onshore storage and CO_2 offshore storage are also weakly positive influenced by the perception of nature as tolerant[7], whereas the perception of nature as benign is a positive determinant of the general attitudes towards CO_2 onshore storage and CO_2 offshore storage. The perception of nature as capricious determines the general attitude towards shale gas extraction weakly positive. In contrast, the general attitude of CO_2 offshore storage is weakly negative influenced by the perception of nature as ephemeral.

The perception that both the environment and the economy are important, but the economy should come first, determines the general attitudes towards CO_2 transport via pipeline, CO_2 onshore storage and CO_2 offshore storage weakly positive, whereas the influence of this factor is a bit stronger on the general attitude of CO_2 pipelines. A weak positive determinant of the general attitude towards shale gas extraction is the perception that decisions of policy and economy regarding technology are often made above citizens' heads.

IV Conclusions

Using the examples of CCS and the extraction of shale gas, this study has illustrated that technology monitoring contributes to the assessment of public perception of energy systems transformation with three different functions: (1) a descriptive, (2) a comparative, and (3) an explanatory function.

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6 This confirms results of other empirical studies on public perception of CCS [L'Orange Seigo et al., 2014].

7 For the explanation of the attitudes towards the vulnerability of nature see [Schumann et al., 2014].

The descriptive function of technology monitoring is to provide information about the awareness, the knowledge and the attitudes of the public regarding technologies, instruments and impacts of energy transition. This includes information about the status quo within the survey period as well as about the development over time.

The comparative function of technology monitoring enables for identifying similarities and differences between the perceptions of different technologies, instruments and impacts of energy transition. This makes possible to ascertain which characteristics are specific for the respective technology or instrument and which not and to derive generalizable conclusions. However, such a systematic comparison requires that the perceptions of different technologies, instruments and impacts are measured with the same indicators, such as self-reported awareness, factual knowledge and attitudes.

Furthermore, technology monitoring has an explanatory function, which was shown in this study by identifying important determinants of general attitudes regarding energy technologies.

All three functions of technology monitoring provide information which can be used for assessing public perception of different energy transition paths. This can be done for example by integrating indicators of public perception either ex-ante as input parameters or ex-post as output parameters in energy scenario construction processes [Schubert et al., 2015]. Integrating public perception indicators as input parameters would be helpful for generating holistic scenarios, whereas integrating public perception indicators as output parameters would be useful for generating normative scenarios [ibid.]. Both ways of integrating public perception indicators in energy scenarios can be valuable in order to assess the societal feasibility of future energy systems and delivering information which can facilitate the management of energy transition.

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Appendix

Table 5: Variables in the regression models

Model	Dependent variable	Independent variables
Model 1	General attitude towards CO_2 transport via pipeline	• Gender • Age • Professional qualification • Factual knowledge about 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 • Attitudes towards the relation of economy and environment
Model 2	General attitude towards CO_2 offshore storage	• Gender • Age • Professional qualification • Factual knowledge about 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 • Attitudes towards the relation of economy and environment
Model 3	General attitude towards CO_2 onshore storage	• Gender • Age • Professional qualification • Factual knowledge about 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 • Attitudes towards the relation of economy and environment
Model 4	General attitude towards the extraction of shale gas	• Gender • Age • Professional qualification • Factual knowledge about shale gas extraction • Perception of the personal risk of shale gas extraction • Perception of the societal risk of shale gas extraction • Perception of the personal benefit of shale gas extraction • Perception of the societal benefit of shale gas extraction • Attitudes towards the vulnerability of nature • Perceptions of technology

Results of the linear regression models

Model 1: General attitude towards CO_2 transport via pipeline

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,652	,426	,416	1,207

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	989,404	16	61,838	42,438	,000
	Residual	1334,727	916	1,457		
	Total	2324,131	932			

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4,712	,330		14,277	,000**
	Gender	,012	,083	,004	,145	,885
	Age	-,006	,002	-,064	-2,428	,015*
	Professional qualification	,024	,045	,013	,532	,595
	Factual knowledge about pipelines	,089	,031	,076	2,899	,004*
	Perception of the personal risk of CO_2 transport via pipeline	-,194	,042	-,214	-4,631	,000**
	Perception of the societal risk of CO_2 transport via pipeline	-,302	,044	-,309	-6,835	,000**
	Perception of the personal benefit of CCS	,076	,040	,079	1,907	,057
	Perception of the societal benefit of CCS	,157	,039	,168	4,033	,000**
	Perception of nature as benign	,013	,030	,013	,433	,665
	Perception of nature as tolerant	,080	,022	,094	3,544	,000**
	Perception of nature as ephemeral	-,049	,029	-,050	-1,731	,084
	Perception of nature as capricious	-,025	,024	-,029	-1,064	,288
	The highest priority should be given to protecting the environment, even if it hurts the economy	-,012	,030	-,012	-,402	,688
	Both the environment and the economy are important, but the environment should come first	,014	,033	,014	,429	,668
	Both the environment and the economy are important, but the economy should come first	,090	,027	,103	3,402	,001**
	The highest priority should be given to economic considerations even if it hurts the environment	-,013	,029	-,015	-,464	,643

a. Dependent Variable: General attitude towards CO_2 transport via pipeline. Method=Enter.
** p<=0.001, * p<=0.05

Model 2: General attitude towards CO_2 offshore storage

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
2	,716	,513	,504	1,256

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
2	Regression	1519,657	16	94,979	60,191	,000
	Residual	1445,406	916	1,578		
	Total	2965,063	932			

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
2	(Constant)	3,099	,346		8,967	,000**
	Gender	,001	,088	,000	,012	,991
	Age	,000	,003	,002	,077	,938
	Professional qualification	,091	,047	,045	1,925	,055
	Factual knowledge about CO_2 storage	,060	,028	,051	2,152	,032*
	Perception of the personal risk of CO_2 offshore storage	-,185	,036	-,189	-5,188	,000**
	Perception of the societal risk of CO_2 offshore storage	-,337	,039	-,328	-8,711	,000**
	Perception of the personal benefit of CCS	,093	,041	,086	2,297	,022*
	Perception of the societal benefit of CCS	,184	,041	,174	4,541	,000**
	Perception of nature as benign	,139	,032	,122	4,393	,000**
	Perception of nature as tolerant	,073	,024	,077	3,112	,002*
	Perception of nature as ephemeral	-,059	,030	-,053	-1,945	,052*
	Perception of nature as capricious	,022	,024	,022	,893	,372
	The highest priority should be given to protecting the environment, even if it hurts the economy	,054	,031	,050	1,739	,082
	Both the environment and the economy are important, but the environment should come first	,064	,035	,056	1,838	,066
	Both the environment and the economy are important, but the economy should come first	,074	,028	,075	2,695	,007*
	The highest priority should be given to economic considerations even if it hurts the environment	-,001	,030	-,001	-,025	,980

a. Dependent Variable: General attitude towards CO_2 offshore storage. Method=Enter.
** $p<=0.001$, * $p<=0.05$

Model 3: General attitude towards CO_2 onshore storage

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
3	,642	,412	,402	1,275

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
3	Regression	1044,054	16	65,253	40,166	,000
	Residual	1488,135	916	1,625		
	Total	2532,189	932			

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
3	(Constant)	4,058	,356		11,409	,000**
	Gender	,054	,088	,016	,619	,536
	Age	-,006	,003	-,063	-2,387	,017*
	Professional qualification	-,034	,048	-,018	-,718	,473
	Factual knowledge about CO_2 storage	,027	,028	,025	,960	,337
	Perception of the personal risk of CO_2 onshore storage	-,162	,041	-,162	-3,930	,000**
	Perception of the societal risk of CO_2 onshore storage	-,356	,042	-,355	-8,521	,000**
	Perception of the personal benefit of CCS	,114	,041	,113	2,788	,005*
	Perception of the societal benefit of CCS	,137	,041	,140	3,369	,001**
	Perception of nature as benign	,080	,032	,076	2,478	,013*
	Perception of nature as tolerant	,060	,024	,068	2,507	,012*
	Perception of nature as ephemeral	,009	,030	,009	,295	,768
	Perception of nature as capricious	-,025	,025	-,027	-1,005	,315
	The highest priority should be given to protecting the environment, even if it hurts the economy	,021	,031	,021	,673	,501
	Both the environment and the economy are important, but the environment should come first	,032	,035	,031	,915	,360
	Both the environment and the economy are important, but the economy should come first	,060	,028	,065	2,129	,034*
	The highest priority should be given to economic considerations even if it hurts the environment	-,006	,031	-,006	-,189	,850

a. Dependent Variable: General attitude towards CO_2 onshore storage. Method=Enter.
** p<=0.001, * p<=0.05

Model 4: General attitude towards shale gas extraction

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
4	,789	,622	,615	1,007

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
4	Regression	1638,800	17	96,400	94,998	,000
	Residual	996,496	982	1,015		
	Total	2635,296	999			

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
4	(Constant)	3,050	,315		9,677	,000**
	Gender	,111	,068	,034	1,625	,104
	Age	,002	,002	,023	1,069	,285
	Professional qualification	-,003	,035	-,002	-,096	,923
	Factual knowledge about shale gas extraction	-,021	,021	-,022	-1,014	,311
	Perception of the personal risk of shale gas extraction	-,119	,029	-,125	-4,107	,000**
	Perception of the societal risk of shale gas extraction	-,360	,032	-,350	-11,145	,000**
	Perception of the personal benefit of shale gas extraction	,201	,034	,179	5,945	,000**
	Perception of the societal benefit of shale gas extraction	,350	,034	,318	10,314	,000**
	Perception of nature as benign	,023	,021	,024	1,070	,285
	Perception of nature as tolerant	,007	,020	,007	,331	,741
	Perception of nature as ephemeral	-,017	,023	-,017	-,754	,451
	Perception of nature as capricious	,037	,018	,042	2,037	,042*
	Technology guaranties the competitiveness of our country and is important in order that Germany can keep up with the globalisation	-,004	,025	-,003	-,158	,875
	Technology makes our life too fast moving and intransparent and leads to that we cannot concentrate on the important things of life any more	-,015	,022	-,017	-,710	,478
	Technology is one crucial cause for negative impacts on the environment, climate and health	-,018	,023	-,018	-,764	,445
	Decisions of policy and economy regarding technology are often made above citizens' heads	,058	,028	,050	2,112	,035*
	New ways should be found in order to involve citizens more in decisions regarding the use of technology	-,041	,026	-,036	-1,556	,120

a. Dependent Variable: General attitude towards shale gas extraction. Method=Enter.
** p<=0.001, * p<=0.05

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Leitung/Head: Prof. Jürgen-Friedrich Hake

Forschungszentrum Jülich

Institute of Energy and Climate Research

IEK-STE: Systems Analysis and Technology Evaluation

52428 Jülich

Germany

Tel.: +49-2461-61-6363

Fax: +49-2461-61-2540,

Email: preprint-ste@fz-juelich.de

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