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Laypeople's Risky Decisions in the Climate Change Context: Climate Engineering as a Risk-Defusing Strategy?

Dorothee Amelung and Joachim Funke
Department of Psychology, Heidelberg University, Heidelberg, Germany

ABSTRACT

This study explores the development of laypeople's preferences for newly emerging climate engineering technology (CE). It examines whether laypeople perceive CE to be an acceptable back-up strategy (plan B) if current efforts to mitigate CO_2 emissions were to fail. This idea is a common justification for CE research in the scientific debate and may significantly influence future public debates. Ninety-eight German participants chose their preferred climate policy strategy in a quasi-realistic scenario. Participants could chose between mitigation and three CE techniques as alternative options. We employed a think-aloud interview technique, which allowed us to trace participants' informational needs and thought processes. Drawing on Huber's risk management decision theory, the study addressed whether specific CE options are more likely to be accepted if they are mentally represented as a back-up strategy. Results support this assumption, especially for cloud whitening. This result is especially relevant considering the high prevalence of the plan B framing in CE appraisal studies and its implications for public opinion-formation processes.

Key Words: climate engineering, climate politics, risk perception, moral judgment, public acceptance, values, metacognition.

INTRODUCTION

"If sizeable reductions in greenhouse gas emissions will not happen and temperatures rise rapidly, then climatic engineering, such as presented here, is the only option available to rapidly reduce temperature rises and counteract other climatic effects" (Crutzen 2006, p. 216). Climate engineering (CE; also widely known as geoengineering) denotes a set of several newly emerging technological options to

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Address correspondence to Dorothee Amelung, Department of Psychology, Heidelberg University, Hauptstraße 47–51, 69117 Heidelberg, Germany. E-mail: dorothee.amelung@psychologie.uni-heidelberg.de
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combat climate change. The options are commonly differentiated into two distinct categories: Carbon dioxide removal techniques that seek to intervene in the global carbon cycle by removing excess CO_2 from the atmosphere and solar radiation management techniques that aim at shielding incident solar radiation. The former thus addresses the main trigger for the climate's warming but would not affect global average temperature until after a time delay of several decades, while the latter only addresses the symptoms, but would show its effects at a much faster pace. An overview of suggested techniques and the current state of research can be found in the Royal Society's special report on the topic (Royal Society 2009).

Crutzen's remark quoted above has initiated a vigorous scientific debate about the possible role of CE as an emergency option or plan B if international policy efforts to meet the designated 2°Celsius limit fail. This scenario is not unlikely since the first commitment period of the Kyoto Protocol, an international agreement to significantly reduce carbon emissions (hereafter referred to as *mitigation*), has expired in 2012, while the member states of the second commitment period until 2020 are only responsible for 15% of global emissions. Furthermore, a universal climate agreement that will only become effective in 2020 cannot be expected before 2015. Moreover, the general public seems to be reluctant to adopt climate-friendly behaviors (Dutt and Gonzalez 2012; Gifford 2011; Tobler *et al*. 2012).

Since 2006, the argument that CE represents a plan B for mitigation efforts has widely been adopted by researchers as a justification for pursuing the idea and has been a prevalent contextual framing of the issue within the scientific debate (Bellamy *et al*. 2012; Ott 2011) and in the German media (Schulz 2011a,b). However, not all scientists share the notion that research and development of CE options should be encouraged to have an emergency option available (Robock 2008). Also, within an interested lay public, skepticism towards CE has already become apparent. For example, disapproving reactions to the first CE-related field trials led to their significant delay (*e.g.*, LOHAFEX, a German-Indian ocean fertilization experiment of 2009) or even to their abandonment (SPICE, a UK-based field experiment on testing the stratospheric aerosol technique that was called off in 2012) (Galaz 2012). Consistent with this reaction, the role of the public in deciding over the future of CE has been widely acknowledged: "Geoengineering research that may impact the environment, or any moves toward potential deployment, should not proceed in the absence of a wider dialogue between scientists, policymakers, the public and civil society groups" (Royal Society 2009, p. 42).

However, CE technologies are still largely unknown to the broader public in the United States and Europe (Mercer *et al*. 2011; Poumadere *et al*. 2011), and the search for factors contributing to the development of public preferences for CE technologies is still at an early stage. Because lay individuals have only marginally been exposed to information about CE, there is little understanding about the process of how they form their opinions on this topic.

The present study seeks to explore the development of laypeople's preferences with regard to CE. We applied the risky decision-making theory by Huber (2007, 2012) to explain preferences based on CE technology risk perceptions. Perceived risks are expected to play a dominant role in the future public debate on CE (Royal Society 2009). The theory promotes the idea that when people are confronted with an attractive but risky option in a decision scenario, they actively search for an

additional strategy to defuse the risks involved in this option (*e.g.*, when having oneself vaccinated against a dangerous disease before deciding to go on a trip to another country with high infection risk). This additional strategy can take the form of a back-up plan for the attractive alternative, which—within the climate change context—closely resembles the plan B narrative in the scientific debate. Research on CE might provide future generations with a back-up strategy to mitigation efforts. This idea is the central object of our study because it can be seen as one important way of framing a future public debate. Concern has already been expressed that this frame, if predominant in a political or public discourse, may prematurely enhance the acceptability of CE (Bellamy *et al*. 2012) because it leads to a positive, CE-supportive conclusion. However, this assumption has yet to be empirically tested.

We begin with a brief outline of the methodological challenge in studying public perceptions of CE because of their susceptibility to contextual framing effects. Subsequently, we introduce the plan B idea as our object of study and explain how Huber's theory in risky decision-making relates to this idea, from which we derive and test our hypotheses.

The Challenge of Studying Public Perceptions of CE

A growing body of research on public perceptions of CE has recently emerged, most of it conducted in the English-speaking world (Bellamy and Hulme 2011; Kahan *et al*. 2012; Mercer *et al*. 2011; Poumadere *et al*. 2011). In Germany, we know of one report on CE that includes an examination of likely public perceptions on CE (Rickels *et al*. 2011), yet the findings are based on expert discussions and analogous conclusions of comparable technologies rather than on empirical data. This bias of empirical data in favor of the English-speaking world implies that previous findings might not be generalizable to other countries. In line with this concern, cultural values as well as national contexts have been acknowledged as important factors of influence on the public's reactions to technological risks (Kahan 2010; Renn and Rohrmann 2010). However, we also know of one cross-cultural study on the public's support for different climate change policies, which included technological options, and which did not show large variations between economics and business students' opinions across national samples (Bostrom *et al*. 2012).

All of these studies had to deal with the methodological challenge of assessing lay opinions towards an issue that is still mostly unknown or generally not understood. This lack of knowledge implies that opinions are not well developed and therefore can easily be influenced by the question format or can depend on the way in which necessary background information is presented, that is, the way the issue or the questions themselves are framed. For example, Bellamy and colleagues (2012) argued that the context frames employed in several studies on public perceptions of CE (Mercer *et al*. 2011; Natural Environmental Research Council 2010) are likely to have influenced the acceptability of CE. Because these studies described the future in terms of a climate emergency, an implicit necessity of researching CE might have been suggested. Accordingly, Mercer and colleagues acknowledged that the "... public opinion on SRM [Solar Radiation Management] is strongly contingent on how, where and in what context SRM is discussed" (2011, p. 9). However, none of

the studies have assessed the potential role of a specific contextual framing such as the plan B idea for laypeople's preferences from a process perspective.

CE as a Plan B

After a review of CE appraisals in the peer-reviewed and grey scientific literature, Bellamy and colleagues (2012) identified the two most prevalent ways in which CE was framed: Most frequently, the authors introduced CE against the background of (a) insufficient mitigation efforts and (b) a possible climate emergency. Taken together, these two contextual framings engender the perception that CE is an emergency back-up strategy or plan B. The line of thought is as follows: Mitigation policies might fail to meet the goal of a 2°C cap, which will lead to a rise in global average temperature above the designated level. Global warming to such high levels is unprecedented in such a short time frame and therefore potentially dangerous because it could lead to a climate emergency. CE could represent a temporary plan B while working on a more sustainable solution to climate change.

The idea of having CE available as a back-up strategy in the event that mitigation efforts fail plays an important role in the scientific debate, because it represents one major justification for more research on CE. Concurrently, the line of thought given above has already appeared in the media, for example, in German newspaper articles (Schulz 2011a,b). In these articles, the plan B narrative has already been used as a means of communicating the issue of CE to the public, which suggests that it is a possible influential framing in a future public debate on CE.

Huber's Theory of Risky Decision-Making and the Plan B Narrative

In his theory on risky choice, Huber emphasizes the processes underlying risky behavior in quasi-realistic scenario settings (Huber 2007; Huber *et al*. 2001; Huber *et al*. 1997). One important step in this process includes the active construction of a mental representation of the decision situation, which can dynamically change throughout the decision process when forming a solution (Svenson 1996). The mental representation is based on situational information the decision-maker has about the different options. When the risky decision situation is not pre-structured as it is in gambling experiments, the classical paradigm to analyze behavior under uncertainty (Kahnemann and Tversky 1979; Tversky and Kahnemann 1981), decision-makers are required to search for the information that they believe is important when forming a decision. Huber argues that in such quasi-realistic settings people usually are not interested in probabilities but instead try to actively reduce the risks involved in the situation. This means that they search for an additional action or *risk-defusing operator* to reduce the risks they identify with an otherwise attractive choice option. By incorporating such an operator into the problem space, the perceived risk of the different options is changed, which in turn influences the final decision.

To allow for a tracing of the decision process, different variations of the Active Information Search Method have been employed (Huber 2007). By use of these methods, it has been shown that most decision-makers identify a preferential option based on a screening of the option's advantages early in the process, at least if they do not act under time pressure (Huber *et al*. 2011; Huber and Kunz 2007; Svenson 1996). Then, further information search is focused on this attractive option and

the search for a risk-defusing action is initiated, if necessary. If the search for a risk-defusing operator is not initiated or if it is unsuccessful, participants have been shown to frequently adopt the MAXIMIN heuristic, according to which the alternative with the least negative outcome is chosen (Bär and Huber 2008).

So far, Huber's theory has mainly been tested in artificial scenarios, which are not based on scientific knowledge about complex relations as we can find them in the climate system. Also, the theory has been mainly applied to small-scale risks that are controllable on a personal level such as the control of infection risk by means of vaccination (Lion *et al*. 2002). However, the framework's usefulness has been proven for some real-life applications in the health and insurance sectors. For example, it has been applied to the decision-making process of genetic counselees (Shiloh *et al*. 2006), where it could successfully predict their informational needs. It was also successful in predicting customers' decisions whether to buy insurance (Ranyard and McHugh 2012; Williamson *et al*. 2000a) and has theoretically contributed to issues of applied risk management in the environmental sector such as rural development (Kostov and Lingard 2003).

In the context of the climate change problem, the theory could explain how a mental representation is developed in an opinion-formation process on CE that resembles the plan B narrative. More specifically, the theory would predict the following steps based on its process assumptions:

1. First, an attractive option is identified. In the climate change context, mitigation might represent such an initially attractive option based on an evaluation of its risks, because it is perceived to have a low potential of negative side effects on the environment, and it is more familiar compared to CE (Slovic 1987).
2. A possible negative outcome (*i.e.*, risk) of the attractive option is detected. Mitigation strategies may yield a low potential for negative side effects on the environment, however, they still bear the risk of possible failure. Note, that for the development of this mental representation, a person needs to focus on the potential risk of failure of mitigation, rather than the risks of economic and societal change, which also pertain to the mitigation strategy.
3. The decision-maker searches for an action to be taken in addition to the attractive alternative to reduce its risk. We refer to this kind of search behavior as *risk-defusing behavior*. To defuse the risk of mitigation, one could (additionally) support the development of CE technology.
4. If the search for a risk-defusing operator is successful, the attractive alternative is chosen together with this operator. In a climate change decision scenario, the decision-maker might choose mitigation together with a CE option as the risk-defusing strategy. Thus, a decision-maker who develops the idea that CE might represent a plan B to mitigation efforts is likely to include CE as part of a strategy to counteract climate change.

Huber's theory is applicable to decision situations that are obviously risky. Thus, the riskiness of the alternatives should represent a salient dimension for decision-makers. The theory's applicability to CE in the climate change context is questionable, because whether or not laypeople would focus on the dimension of risk is unclear. Numerous other criteria have been suggested as possible factors to evaluate

such a complex issue like CE. The Royal Society Report (2009) mentions several criteria, including issues of law or equity (given the global extent and regional variability of CE and climate change effects), issues of timeliness (given the large time frame which also implies questions of intergenerational justice), or cost-effectiveness considerations. However, we focus on an assessment of the risk dimension, because we assume that laypeople consider the risks to be especially important relative to other possible dimensions when they are confronted with the idea of CE technology. In line with this, the Royal Society suggests that the public's view of CE is likely to be dominated by potential negative side effects or risks of CE: "Experience with other similar issues indicates that public perceptions of geoengineering are likely to be dominated by the risk of something going wrong . . . " (Royal Society 2009, p. 42). This notion is further supported by Mercer and colleagues (2011), who found that the perceived riskiness of CE is a central aspect in the opinion-formation process. Therefore, we assume that *risk* is the attribute most people will attend to when confronted with the notion of CE. This also suggests that preferences with regard to CE are likely to be influenced by the perceived riskiness of CE.

RESEARCH QUESTIONS AND HYPOTHESES

Our primary goal in the present study was to investigate the processes underlying the formation of laypeople's preferences with regard to CE in the context of climate change. More specifically, we assessed the potential role of the plan B argument in the preference formation process with the following research question in mind: Do laypeople perceive CE to be an acceptable option as part of a risk-defusing strategy in case mitigation efforts fail? Our assumptions and hypotheses were as follows:

H1a. We assumed that perceived risk is an important factor in laypeople's preference formation process of CE. This should become evident in their informational needs.

- We hypothesized that participants would ask for the *risk* aspect more often than for any other aspect (*e.g.*, cost or effectiveness) in a quasi-realistic decision scenario.

H1b. We assumed that if perceived risk is an important factor in laypeople's preference formation process of CE, this aspect should also influence the final preferences with regard to CE.

- We hypothesized that subjective risk assessments would have an effect on the final decisions in a quasi-realistic decision scenario.

H2a. We assumed that laypeople developing the idea that CE represents a possible risk-defusing back-up plan for mitigation are more inclined to accept CE.

- We hypothesized that participants showing risk-defusing behavior for mitigation would be more inclined to accept CE as part of their decision in a quasi-realistic scenario than those who do not show this kind of behavior.

H2b. Risk-defusing behavior can only be successful if an acceptable risk-defusing strategy is found. The risks associated with the risk-defusing strategy should

therefore not exceed the perceived risks already involved in the attractive alternative because this would mean replacing one unacceptable risk with another. More specifically, the risks associated with the attractive alternative (*e.g.*, mitigation) must be traded off against the risks associated with the possible risk-defusing strategies (*e.g.*, the CE options). Therefore, we assumed that a CE option can only be chosen as a risk-defusing strategy if the associated risks are comparably low.

- We hypothesized that, apart from risk-defusing behavior, lower subjective risk assessments of at least one CE option would be associated with CE acceptance as part of a decision in a quasi-realistic scenario.

METHOD

Participants

The majority of participants were recruited from psychology lectures and various other departments of Heidelberg University. A smaller proportion of the sample was approached at meetings of the Heidelberg formations of the "Grüne Hochschulgruppe," a students' organization of Germany's green party "Die Grünen," and "Greenpeace." We did not reject participants from nationalities other than German. However, as a prerequisite, they needed to be living in Germany so that we could expect them to have similar access to media coverage on CE and similar amounts of background knowledge on climate change and CE. Furthermore, they needed to be fluent in German, so that they would not have problems understanding the material in the study. The study was advertised as a psychological experiment on environmental issues. CE was not mentioned as a topic at this point, because we expected a low familiarity with the term and associated concepts among students and the general population. The study was conducted from May to August 2011, when media coverage was at a very low level and any form of public debate was practically non-existent (Rickels *et al*. 2011).

Three participants were excluded from all analyses due to technical problems or mistakes made by the experimenters. Of the remaining 98 participants, the majority was female ($n = 75$). 86% of the participants were of German nationality; all participants lived and worked in Heidelberg, Germany.

Participants were typically young and well educated: The vast majority of the sample participants (92.9%) were between 15 and 35 years of age. 91 participants indicated that they were currently undertaking an academic degree or had already obtained one. Their education stemmed from a broad range of disciplines (mostly in the arts or the social sciences, while about one-half ($n = 53$) were in the field of psychology). The highest level of education obtained or sought after by the remaining 7 participants was the German Abitur (the general qualification for university entrance). A minority of 20 participants were active members of an environmental group or organization (*i.e.*, the Heidelberg formations of the "Grüne Hochschulgruppe," a students' organization of Germany's green party, "Die Grünen," as well as "Greenpeace"). Please refer to the online supplemental information (SI) for a detailed overview of the nationalities, age structure, educational background and academic disciplines of the participants in our sample.

Measures

The decision scenario

A decision scenario was presented in the form of a one-to-one interview using the conversation-based Active Information Search method and participants were asked to think aloud while performing the task (Huber *et al*. 1997; Williamson *et al*. 2000b). We decided to deploy this method, because our hypotheses focused on the process of preference formation with regard to CE. The method encourages participants to ask for the information they need to make an informed decision. Therefore, it enabled us to trace important steps in the decision process such as the construction of a mental representation based on information that participants judged to be important. The method was conducted in a conversation-based manner to establish a sufficiently natural atmosphere that would keep participants engaged with the task. The interview was recorded. To standardize the approach, answers were presented on printed cards. In several pilot studies, different versions of the scenario were tested. Based on free comments as well as standardized ratings of the participants in our pretests, we reduced the amount of background information to a minimum, concentrated on simple facts, and eliminated emotionally charged adjectives such as "crisis" to make the scenario as neutral and unpersuasive as possible. We provided the participants with a role that was sufficiently realistic, a role with which they could easily identify. We also created a hypothetical situation in which they believed that their decision would have a political impact.

In the final version of the scenario, which can be found in the online supplemental information, participants were told that as citizens and taxpayers of their country, they were selected for a civil survey, asking them the method for which the "federal climate change budget" should allocate funds. Four alternative methods were presented: mitigation and three of the most controversial CE techniques including *stratospheric aerosols*, *cloud whitening*, and *ocean fertilization*. The idea behind the stratospheric aerosols technique is to inject tiny reflective particles, such as sulfate aerosols, into the stratosphere that reflect sunlight back into space, which would cause a cooling effect. The cloud whitening method has a similar rationale: it aims to enhance the reflectivity of marine clouds by injecting sea salt particles to brighten them. The ocean fertilization method is fundamentally different from the first two because it seeks to remove excess CO_2 from the atmosphere. More specifically, the method aims at enhancing natural respiratory processes in the ocean by promoting algae growth. Greater amounts of algae are then expected to take up more CO_2 from the atmosphere, hopefully storing it in the deep sea by use of the biological pump (for more detailed information on the CE options we presented as well as our rationale for choosing them, see the SI and Royal Society 2009).

The participants in the present study were provided with only a general description of the CE options in our scenario. The names of the techniques were presented together with the information that the stratospheric aerosols and the cloud whitening methods are "technological options with the aim to block incident solar radiation." Ocean fertilization was characterized as "a technological option with the aim to remove excess CO_2 from the atmosphere." We did not inform participants about the possibility to combine several options, because we wanted to avoid suggesting certain framings of the decision problem. In case participants asked for

this possibility, we had prepared a standardized answer to tell them they were allowed to combine options but that they had to prioritize them, because the federal budget would not suffice to equally support every option. Thus, while we largely followed the standard procedure to test the assumptions of Huber's theory, we also made three necessary changes as specified in the following.

a. In contrast to the common approach, we included possible risk-defusing operators (*i.e.*, the CE options) as part of the presented alternatives. This approach enabled us to test the possibility that laypeople would *spontaneously* perceive CE as a back-up strategy for mitigation efforts. At the same time, we were able to avoid suggesting the formation of any specific mental representation of the problem. We decided to include several CE options as alternatives, because previous studies found that it is unlikely for people who do not expect to find a risk-defusing strategy to actively search for one (Huber 2007; Huber and Huber 2008). If we had employed the typical approach to the theory's paradigm, we would not have expected participants to explore the situation in search for possible risk-defusing operators in the context of climate policy strategies based on their estimated background knowledge.

   Moreover, we had to develop an interview technique that introduced the choice options by use of a minimum of context information or framing that could possibly suggest an order of priority or any connections between them. Therefore, we introduced the strategies as independent decision alternatives revealing only a minimum amount of information, not suggestive of an inherent hierarchy between them. For the same reasons, we did not intervene into the decision-making process by requesting additional information in the course of the interview, by which we would have provoked specific trains of thought or would have distracted participants from their original ideas, prohibiting us from assessing the spontaneous development of certain mental representations.
b. Contrary to the standard procedure, we refrained from stating risks involved in our scenario for two reasons. First, we had observed a devastating motivational effect from emphasizing the risks and possible negative consequences of the current climate change situation and its anticipated future in several pretests with an earlier version of the scenario (common reactions were: "Well, then it's too late anyway" or "I can't listen to these worst case scenarios anymore. What difference can I make?"). Second, we were concerned that by focusing on the risk aspect, we would bias participants' mental representations of the task or even their final decisions.
c. As opposed to the scenarios that are commonly employed in Huber's experimental settings, our scenario was based on a real-life problem and on real scientific background information. Therefore, participants were expected to have (varying degrees of) background knowledge on climate change and related policies.

Background knowledge scales

To allow for the inclusion of background knowledge as a control variable we incorporated the respective measures: we asked participants to indicate the amount of previous knowledge they had of climate change, climate politics, and CE on

6-point rating scales ranging from *no background knowledge* to *very much background knowledge*.

Questions for the active information search method

The Royal Society Report on CE (2009) served as an orientation in the process of collecting and roughly classifying the questions our participants would find necessary while completing the task, and in formulating the corresponding answers. We adapted the categories *probability information* (*e.g.*, "How likely is it that the 2-degrees-Celsius target will be met?"), *background information*, either general (*e.g.*, "What does climate change cost?") or specific to the alternatives (addressing the basic idea behind the technical implementation, for example, "How does option x work?"), *positive consequences* (*e.g.*, "What are the advantages or positive effects of option x?"), and *negative consequences* (*e.g.*, "What are the disadvantages or negative effects of option x?") from existing classifications (Huber *et al*. 2001; Huber *et al*. 1997; Wilke *et al*. 2008). We extended this classification scheme by the following CE evaluation criteria proposed by the Royal Society: *effectiveness* (*e.g.*, "How effective is option x on a global level?"), *timeliness* (*e.g.*, "How quickly could option x show its effects?"), *cost* ("How much would option x cost?"), *reversibility* (*e.g.*, "For how long would we need to invest in or implement option x?"). We added *fairness* as a further category possibly relevant for our participants given the context of climate change ("Are there any nations/areas that would benefit more from option x than other countries/areas?"). All of these criteria were equally applicable to the mitigation option in our decision scenario. We tested and extended our questions in several pretests. The questions we prepared can be seen as a template. Participants did not need to adhere to the exact wording of these questions to obtain the answers. As long as it was clear to the experimenter that the question concerned the information given in the answer, the respective card was presented to the participant. The formulation of the answers was also based on the Royal Society report. We adopted a factual style to avoid biased answers. The wording was held constant in between all four options to control for possible resulting effects (a full list of questions and answers is available upon request from the corresponding author).

Post-interview questionnaire

We asked participants to write down a short description of their final decision, as well as their main reasons for it, upon completion of the decision task. To measure the participants' risk perceptions to test our second hypothesis, the questionnaire included a 6-point rating scale of the perceived riskiness for each presented option. The scales ranged from *not at all risky* to *very risky*.

PROCEDURE

Prior to the experimental phase, three different experimenters were trained to adequately realize the think-aloud method. This training was done to avoid influencing participants with verbal or non-verbal cues, and to enhance comparability between the three experimenters' reactions. The participants were

randomly assigned to the three experimenters. The general procedure was as follows:

After providing demographic information they were given a more detailed introduction to the think-aloud technique. They were told not to filter their thoughts and questions but to freely voice anything that came to their minds. To encourage such a behavior and to reduce social desirability effects, we emphasized that there was no such thing as a right or wrong remark or decision. Participants were introduced to the procedure by the means of a warm-up decision scenario, unrelated to climate change. Then, the experimenter presented the climate change decision scenario to the participant and conducted and recorded the think-aloud interview. The interview was completed and recordings were stopped as soon as the participant came to a decision. There were no time restrictions. Finally, the participant was asked to complete the post-interview questionnaire, as well as the background knowledge scales. As compensation, participants could choose to receive either course credit or 5 Euro, or the equivalent value in coupons for popular shops within the city of Heidelberg.

Transcription and Coding

Each interview was transcribed by the experimenter who had originally carried it out. Because there were no time restrictions, interviews varied in length, lasting anywhere from 50 s to 37 min, 58 s. On average, participants spent nearly 10 min on the decision process. With three different experimenters, transcripts were randomly crosschecked by one of the other two transcribers.

Because three participants in our sample only spent 50 or 82 s on the task, we checked their protocols to find out if they were not motivated enough to thoroughly elaborate the problem. The protocols revealed that all three of them had a clear preference for the mitigation option and instantaneously rejected the idea behind climate engineering technology without the need for further exploration, and that they had an explicit rationale behind their decision. Therefore, we did not eliminate their cases from our analyses.

Then, the final decisions were coded by the scheme indicated in Figure 1 (codes plus subcodes and their frequencies). The decision process was coded based on the assumptions of Huber's theory and on our rationale as outlined in the introduction. This procedure resulted in three process codes corresponding to each step predicted by the theory. The frequencies of the three codes can be found in Figure 2. Based on our process codes, we identified three different ways in which the participants of our sample mentally structured the decision problem: One type of participants showed risk-defusing behavior for mitigation as predicted by theory (22.4% of the sample). A second type of participants instantaneously rejected the CE options (72.5%). The third type of participants spontaneously perceived one of the CE options as attractive (5.1%). Examples of coded statements of four participants, which illustrate these three prototypical mental representations, can be found in Table 1. We proceeded as follows:

Table 1. The decision processes of four participants exemplifying the three mental representations "risk defusing," "CE rejection," and "CE attractive."

Prototypical representation	Process code	Excerpt from protocol	Final decision
Risk defusing	Attractive alternative: mitigation	*Ok, mitigation is already a good thing . . .*	60% mitigation, 40% cloud whitening
	Mitigation risky	*However, I also need something—something— that quickly shows its effects, because the other option [mitigation] only happens insidiously . . .*	
	Risk-defusing behavior	*I need something, which works quickly—in combination with something, which works—in a sustained manner, like mitigation. . . . I am unsure at the moment—ok, I am not in favor of option 3 [ocean fertilization] because it simply takes too long and I don't have the time for this—I'm thinking about [options] one [stratospheric aerosols] and four [cloud whitening] . . .*	
Risk defusing	Attractive alternative: mitigation	*I am in favor of number 2, that is the reduction of human-induced carbon emissions*	mitigation
	Mitigation risky	*Okay, this is not super efficient, it has the risk that people do not participate, [. . .], or that not everyone participates, that is a problem, of course, . . .*	
	Risk-defusing behavior	*. . . regarding the other projects here or ideas, research will be further carried out, will it not?*	
CE rejection	Attractive alternative: mitigation	*Ok, however, I think I don't need that much information about the other three options [the CE options], because I find them to be unrealistic as yet or uncon . . . not so well predictable. That's why, I guess I would prefer mitigation, because the other things . . . well they haven't been tested yet, one does not know what will be the consequences, one does not know the risks they might have. And ocean fertilization, I find this a little awkward, therefore, I would drop the other three options [the CE options], by which one would actively intervene . . . and then . . . yes, I'd chose the alternative, which takes humans as its starting point, that is the reduction of CO_2 emissions. And therefore, I think I don't need that much information about the other options, because I already think at the outset, that they are not very promising. Or at least, I think that mitigation is the most reasonable one of the four options . . .*	mitigation

	Mitigation risky	—	
	Risk-defusing behavior	—	
CE attractive	Attractive alternative: CE	*Well, at the moment, the stratospheric aerosols seem to me to be . . . the best of the options, but . . .* *[. . .]* *Regarding cost, the stratospheric aerosols are good and regarding effectivity, they are also good . . .*	stratospheric aerosols
	Mitigation risky	—	
	Risk-defusing behavior	—	

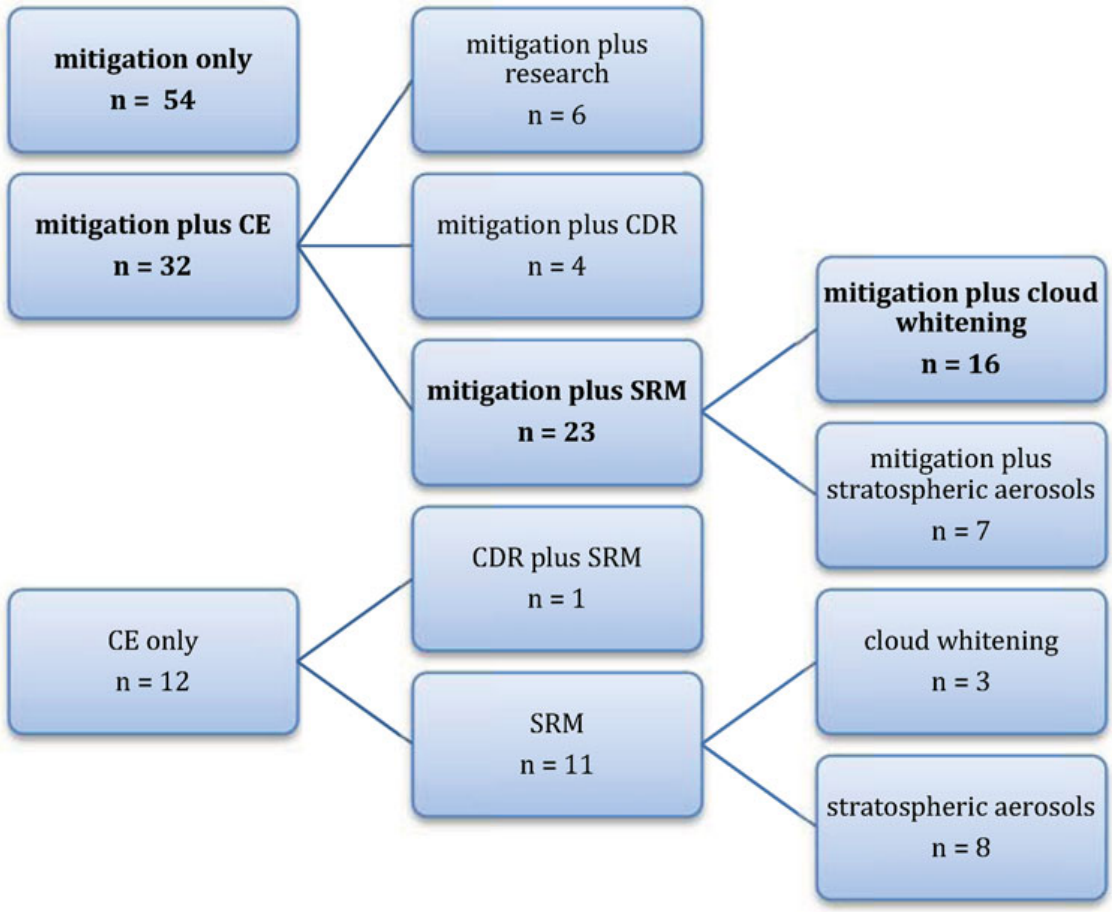

Figure 1. Overview of decision types. The most common decisions are printed in bold type. Note that the subcodes for *mitigation plus CE* do not add up to n = 32 but to n = 33. This is due to the fact that one participant decided for *mitigation plus one CDR option plus one SRM option*. *Mitigation plus CE* was coded when the participant clearly stated that mitigation was the preferred strategy while one of the CE options should be seen as additional strategy. SRM = Solar radiation management techniques like cloud whitening and stratospheric aerosols. CDR = Carbon dioxide removal techniques like ocean fertilization.

The process code *attractive alternative*

Huber's theory predicts that people identify one attractive choice early in the decision-making process and then examine it in more detail later (Huber *et al*. 2011). Based on this prediction, we coded the option that was identified by each participant as attractive in a first step. The coding was based on the following criterion: The participant had to identify one of the options as attractive after an initial screening phase, regardless of the depth or length of this screening phase.

As expected, most participants initially identified the mitigation option as an attractive alternative (79.6%). Only a small proportion of participants spontaneously perceived one of the CE options as attractive (5.1%). In the remaining 15.3% of cases, we could not identify an alternative that was perceived to be attractive after an

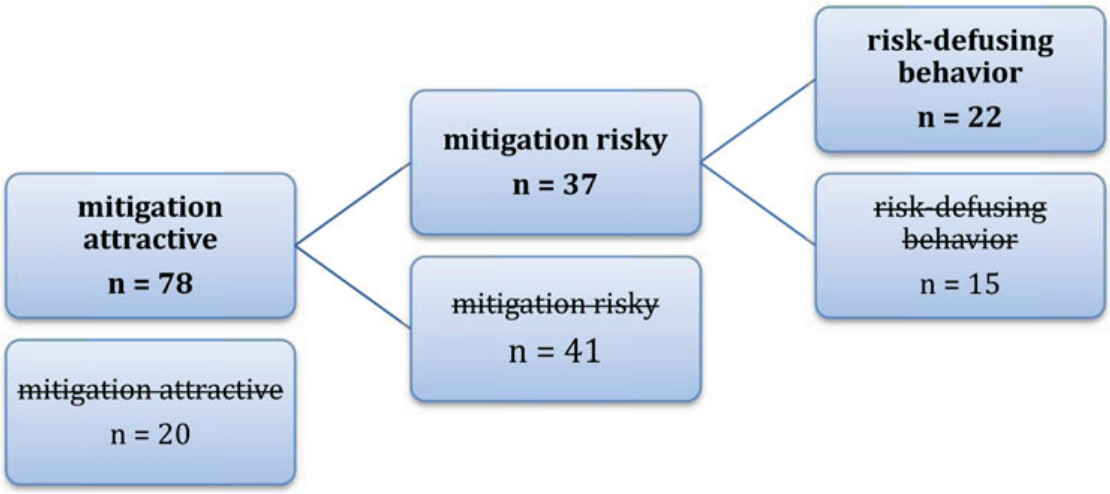

Figure 2. Frequencies of process variables "mitigation attractive," "mitigation risky," and "risk-defusing behavior." The frequencies of the crossed-out variables indicate the amount of participants who were not coded with the respective process code. Of the 20 participants who were not coded with "mitigation attractive," n = 5 initially identified one of the CE options as attractive and n = 15 did not initially identify any of the alternatives as attractive.

initial screening phase. Instead, these participants identified their preferred alternative after an exploration phase and decided for it without further examination. Often, they chose the residual alternative once they had eliminated all other options based on one or two criteria such as risk or cost. This approach resembles the MAXIMIN heuristic, according to which the option with the "least bad" outcome is chosen.

The process code *mitigation risky*

In the next step, we checked if participants who perceived mitigation to be attractive, also perceived it to be risky. We identified the (bivariate) code *mitigation risky* (0 = *no*; 1 = *yes*), if the participant mentioned possible negative outcomes or difficulties associated with the mitigation option (either retrieved from his or her own background information or asked for in the information-gathering process). Possible negative outcomes could include that political negotiations might fail or that the efforts might come too late.

Regarding the risks of mitigation, the primary focus in this study was on the risk of failure due to implementation problems or delayed reactions of the climate system. Certainly, one could conceive of other risks that might play a role in the participants' decisions like the risks associated with societal change and economic impacts as a result of cutting emissions. While the former type of risk could possibly be addressed by CE options, the latter could not. However, in analyzing the transcripts, we did not find any participants who identified the risks of societal change as a clear disadvantage to the mitigation strategy. Rather, those who acknowledged this type of risk clearly expressed their disappointment about it being a major impediment to an effective realization of the mitigation strategy.

The process code *risk-defusing behavior*

In a final step, we developed the code for *risk-defusing behavior*, again following a bivariate coding scheme (0 = *no*; 1 = *yes*). This code was assigned if mitigation had already been identified as *initially attractive alternative* and if the code *mitigation risky* had been assigned in the respective protocol. Additionally, the participant had to state clearly that he or she perceived at least one of the CE options to be potentially useful as an additional strategy for the attractive alternative (mitigation). Because the concept of risk defusing is closely related to the concept of control (Huber and Kunz 2007), it was not a sufficient criterion for this code if one of the CE options was simply perceived to be beneficial. Rather, the potential usefulness of CE options, in general, or one specific CE option, as an *additional* strategy for gaining control over any perceived shortcoming of mitigation, needed to be expressed by a participant. This means that participants who perceived CE options as beneficial, but did not consider them as a potential *complementary* strategy, were not coded with the *risk-defusing behavior* code. In this way, we wanted to make sure that this code represented a specific mental representation of the problem structure, rather than the mere positive evaluation of CE. Some participants explicitly considered one of the CE options as an emergency strategy in case of mitigation failure. In these cases the statement was clearly identified as risk-defusing behavior without the other two process codes having necessarily been assigned.

Two coders independently coded all variables, and inter-coder reliability was computed. For all of the final decision variables, reliability was high (Cohen's $\kappa >$ .9, n = 98). Regarding the decision-process variables, reliability was only computed for *risk-defusing behavior* because the code partly depends on the other two codes, and it was the central code for our analysis. Two coders jointly developed the coding criteria for *risk-defusing behavior*, as mentioned above, and reliability with a third coder was computed. With Cohen's $\kappa = .87$, n = 98, reliability was good.

RESULTS

Relative Importance of Risk

Were questions concerning *negative consequences* relatively highly important to our participants compared to the other question types? Shown in Table 2 are the percentages of participants who asked at least one question regarding each of the available information types. *Probability* questions were excluded from the analysis, because participants had not asked for them. The question type *background information* comprised only questions that were directed at specific alternatives rather than questions that asked for general information about the climate change situation.

Cochrane's Q test was significant, $\chi^2(6) = 182.793$, $p < .001$, which suggests that the seven information types differed significantly in their distributions of participants' asking at least one corresponding question. Therefore, pairwise comparisons between questions about *negative consequences* and the other information types were computed, using the McNemar test with Bonferroni adjusted p values. Results are also shown in Table 2. Questions concerning *negative consequences* were requested by significantly more participants than all other question types except for *cost* (which

Table 2. Percentage of participants who asked for the seven available information types, respectively, and McNemar test statistics for the difference in relative importance between the information type negative consequences and each of the other information types.

Question type	%	χ^2	p	W
Background information	76.5	18.27	.000*	.43
Negative consequences	49.0	NA	NA	NA
Cost	31.6	5.95	.015	.25
Effectivity	27.6	10.26	.001*	.32
Positive consequences	12.2	34.03	.000*	.59
Reversibility	12.2	32.24	.000*	.57
Timeliness	10.2	32.60	.000*	.58

% = Percentage of participants who asked at least one question of the respective information type (with reference to the overall sample with N = 98). χ^2 = value of the McNemar test statistic for the difference between each information type and *negative consequences*. w = effect size Cohen's w for the χ^2 test statistic. NA = not applicable.
*$p < .05/6$ (Bonferroni-corrected).

was not significant but still in the expected direction) and *background information* (which was the significantly most frequent question type).

We then assessed the frequency of questions about *negative consequences* among the first two questions that the participants requested in the decision-making process as a further indicator of relative importance of this information type. Altogether, n = 36 participants asked for *negative consequences* as their first or second question (75% of those who asked for it in general), compared to n = 69 asking for *background information* (92% of all participants interested in this kind of information), n = 17 for *cost* (54.84%), n = 16 for *effectivity* (59%), n = 5 for *timeliness* (50%), and n = 2 for *positive consequences* (16.67%) and *reversibility* (16.67%) as one of their first two questions. In sum, apart from the question type *background information, negative consequences* was the most commonly required information type and, if required, was also comparably most commonly requested at the beginning of the information-gathering process.

Effects of Subjective Risk Assessments on the Final Decisions

We conducted a profile analysis on the four risk assessments of mitigation and the three CE techniques. Thus, we tested whether participants who included CE in their decisions systematically differed in their risk assessments of the options from those who did not include CE. Therefore, the grouping variable was the final decision of the participants with the two levels *CE included* and *CE not included*. One unusual case was detected as an outlier and was excluded from our analysis because the respective participant indicated all of the options to be *not at all risky*. This resulted in a sample reduction of n = 97.

The two groups *CE included* and *CE not included* differed significantly in their patterns of risk assessments on the four options, $F(3, 93) = 5.46$, $p = .002$, partial

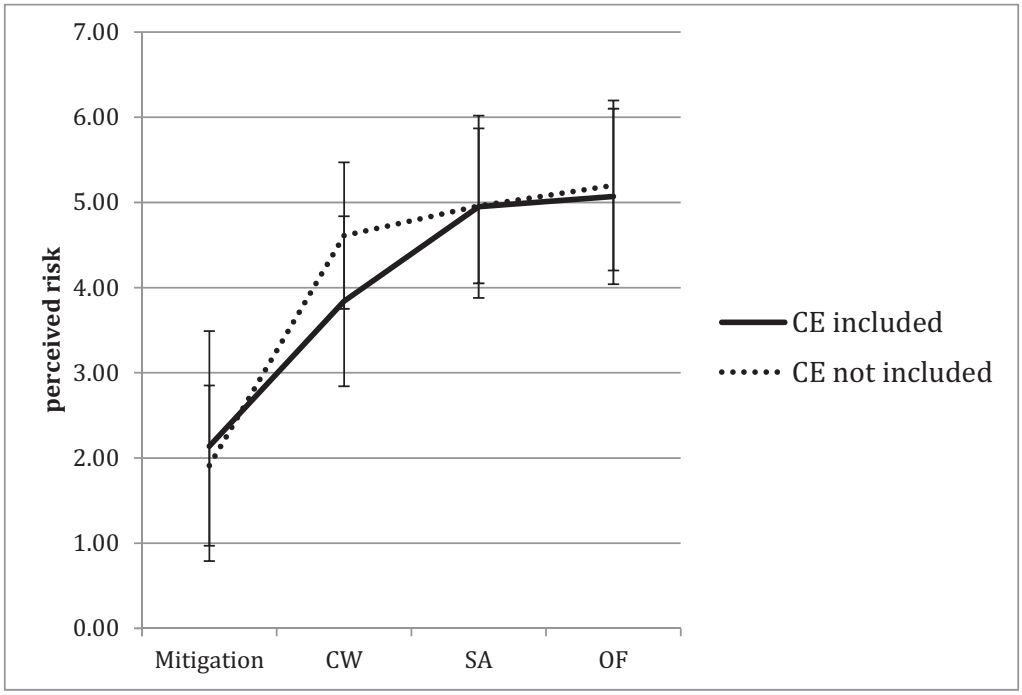

Figure 3. Mean perceived risk of the four options mitigation, cloud whitening (CW), stratospheric aerosols (SA), and ocean fertilization (OF), separately for those participants who included CE into their decision (CE included) and those who did not (CE not included). Error bars represent standard deviations.

$\eta^2 = .15$ using the Wilk's λ criterion. Thus, the subjective risk assessments had an effect on the final decision. The differences in the profiles between the two groups are shown in Figure 3.

No overall difference among the groups was found with $F(1, 95) = 1.91$, $p = .17$, partial $\eta^2 = .02$, which suggests that no group on average scored higher on all of the risk scales.

To determine the specific option's risk assessments that were responsible for the differences in the profiles between the two groups, we then performed a simple-effects analysis for the differences in the means of the four option's risk assessments between the two groups. A significant difference was found between the two groups in their risk assessments of cloud whitening, $F(1, 95) = 16.88$, $p < .001$, partial $\eta^2 = .16$. No differences were found between the two groups in the other risk assessments (mitigation: $F(1, 95) = 0.99$, $p = .32$, partial $\eta^2 = .01$; stratospheric aerosols: $F(1, 95) = 0$, $p = .96$, partial $\eta^2 = .00$; ocean fertilization: $F(1, 95) = 0.42$, $p = .52$, partial $\eta^2 = .01$).

Prediction of CE Acceptance

A direct bivariate logistic regression analysis was performed with the final decision as dependent variable (Is a CE option part of the decision or not?) and *risk-defusing*

Table 3. Statistics of the predictors in a logistic regression analysis with CE as part of the final decision (yes/no) as DV.

							95%-CI	
Predictor	*b*	*SE*	Wald	*p*	*b**	*OR*	*LL*	*UL*
RDB	4.34	1.12	15.07	.000**	0.57	77.04	8.59	690.75
$Risk_{CW}$	−1.16	0.44	6.98	.008**	−0.35	0.31	0.13	0.74

b = unstandardized regression coefficient; *SE* = standard error of *b*; Wald = Wald statistic; *b** = standardized regression coefficient; *OR* = odds ratio; 95%-CI = 95% confidence interval; *LL* = lower level, *UL* = upper level; RDB = risk-defusing behavior; $Risk_{CW}$ = perceived risk of cloud whitening. $^{**}p < .01$

behavior together with the subjective risk assessment of cloud whitening as predictors. We included only the risk assessment of cloud whitening because we found a difference only for this option in the subjective risk values between those who included CE in their decision and those who did not.

Control variables (membership of an environmental group, sex, background knowledge) were also included in the model for a first analysis. To minimize a problem with reduced power associated with an unfavorable cases-to-variables ratio and a problem with multicollinearity, the scores of the three knowledge scales were summed to form a general knowledge scale. Cronbach's Alpha for this scale was reasonably sufficient to justify this approach, $\alpha = .82$ (n = 78).

To avoid a power problem with small cell sizes because of rare incidences, we included only the majority of participants in the analysis who had been coded with *mitigation attractive* (n = 78). There were no missing values. None of the control variables were significant. Therefore, they were excluded from the following analyses.

The full model with the two predictors against the constant-only model was statistically significant ($\chi^2 = 52.9$, $p < .001$, $df = 2$). Thus, *risk-defusing behavior* and the subjective risk of cloud whitening were able to distinguish between participants who included a CE option into their decision and those who did not. Following Nagelkerke's R^2, a moderate 66.2% of the variance in the final decision could be accounted for by the model. The model was able to correctly classify the participants with 93.3% of participants who did not include CE into their decision correctly predicted and a percentage of 81.8% of those who did include CE. This result computed to an overall success rate of 88.5%.

To test hypothesis 2b that the inclusion of the subjective risk of cloud whitening should enhance the model's classification ability above *risk-defusing behavior*, we compared our model with one that included only *risk-defusing behavior* as predictor. In this single predictor model, the explained variance (Nagelkerke's R^2) was slightly reduced to 57% and classification was reduced to 84.6%. Thus, a model with the subjective risk assessment of cloud whitening as second predictor is better than one with *risk-defusing behavior* as the only predictor.

Shown in Table 3 are the unstandardized and standardized regression coefficients for the two predictors, including the Wald statistics, standard errors, and odds ratios with 95% confidence intervals. The standardized coefficients indicate that

risk-defusing behavior was positively associated with the odds (the relative probability) of deciding for CE, whereas the subjective risk of cloud whitening was negatively associated with the odds of deciding for CE, revealing that the impact of *risk-defusing behavior* is comparably stronger.

DISCUSSION

Our primary goal was to assess if and under which circumstances laypeople embrace the idea that CE technology could represent a back-up strategy for a possible failure of mitigation efforts. As a prerequisite for laypeople to adopt the idea of such a back-up strategy, they need to put sufficient emphasis on the risk criterion. Our findings support the hypothesis that perceived risk is highly important to laypeople when confronted with the issue of CE. In line with Huber's risk theory, we also found that participants conceived the idea of a back-up strategy when they (a) realized that current political efforts to mitigate CO_2 emissions bear the risk of possible failure, and when they (b) indicated that, to them, a certain threshold of perceived risk of a CE option is undercut.

Do People Accept CE as Part of a Back-Up Strategy?

We expected those participants to show a greater tendency to accept CE, who actively explore the technology's potential service as a back-up strategy for mitigation. In our model, risk-defusing behavior was found to be the strongest positive predictor of involving CE in the final decision, which is consistent with our expectation. We also expected that participants would only accept a CE option as part of their decision, if they found at least one option with an acceptable level of risk. Because a lower perceived riskiness of cloud whitening enhanced CE acceptance above risk defusing, our hypothesis was confirmed.

In sum, participants perceived CE to be an acceptable option as part of a risk-defusing strategy for mitigation, if they found at least one CE option with an acceptable level of (subjective) risk. Therefore, acceptable risk levels seem to be an important prerequisite for actively defusing the risks of mitigation with CE. The option with the lowest perceived risk was cloud whitening. Participant protocols suggest that the low ratings were due to the perceived naturalness of this option, given that "only" sea salt particles are used (as opposed to the use of sulfur particles in the stratospheric aerosol method; see the SI for more information). If such an acceptable option was not found, active risk-defusing as predicted by Huber's framework appears to be an unsuitable strategy. In fact, if no acceptable risk-defusing operator is found or the expectation of finding one is low, the framework predicts that no risk-defusing behavior is shown (Bär and Huber 2008; Huber and Huber 2008). In these cases, the MAXIMIN heuristic has previously been identified as an alternative strategy, according to which the worst outcomes of the alternatives are compared and the option with the least bad outcome is chosen. We could also identify this kind of behavior in participants who did not spontaneously identify mitigation as an attractive option. However, at the end of their decision-making process, they were also very likely to decide for mitigation as a result of an elimination process of the other (CE) alternatives. This suggests that people are likely to accept a specific CE

option as a back-up strategy for mitigation only if the perceived risk of the option does not exceed the risk of mitigation. Thus, public perceptions of CE in the climate change context are likely to be influenced by a tradeoff between the perceived risks of specific CE options and alternative strategies for combating climate change. Therefore, it is important to assess public evaluations of CE within the broader context of alternative strategies.

Limitations

Sample bias

One of the most important aspects for participants in the present study when dealing with the climate change decision scenario was the perceived risk of the options. This focus on risks might be explained by a bias in the sample (*e.g.*, students and members of environmental organizations). Bellamy *et al.* (2012) argued that recruitment strategies can yield important framing effects, suggesting that in a more balanced sample, a larger proportion of participants might set their focus on, for example, costs or effectiveness rather than risks.

Although the bias in our sample reduces the generalizability of our results, we believe that it augments the results. Public *acceptance* of a global technology such as CE more probably means that affected people will *tolerate* it than have a positive attitude towards it (Renn 2005). A future decision for or against an eventual deployment of CE will likely be made by a political top-down approach driven by international negotiations rather than a bottom-up movement or a participatory approach, such as a national referendum. Therefore, the crucial question is whether an eventual future decision in favor of the deployment of a CE option will be tolerated by society. An eventual mobilization process, answering an unacceptable decision, is likely to be led by a minority that offers resistance to such a decision; that is, members of environmental organizations (Botetzagias and Schuur 2012) and a dedicated lay public. This tendency has already become clear with the LOHAFEX and SPICE projects. In this sense, our sample is likely to more accurately reflect the groups that might take a leading role in the question of whether or not political decisions regarding CE will be tolerated, than a more balanced sample. Still, we can state that someone who perceives risk to be an important factor in an evaluation of CE, is more likely to accept the technology if he or she perceives it as a risk-defusing strategy. Furthermore, studies involving representative samples in the United States, United Kingdom, and Canada support the idea that risk is also an influential factor for more diverse sections of the population.

Wording of answer material

Similar to other public perception studies on CE, it was important for our study that the information material we presented our participants with, did not implicitly suggest any valuation or judgment. Although we tried to keep the wording as neutral as possible and to adopt a factual style, the specific selection of information units in the prepared answers might have influenced the risk perception of the different CE options in our decision scenario. The nature of the particles used in the cloud whitening technique ("sea salt") as opposed to the particles in the stratospheric aerosol technique ("sulfur") might have been the main driver of the difference in

perceived risk between the two; many participants mentioned that the description of the cloud whitening method sounded more natural to them, sometimes with explicit reference to the sea salt particles. This is important to consider, because the nature of the particles is subject to an ongoing scientific debate. Especially for the stratospheric aerosol technique, other materials than sulfur have already been proposed that might sound less deterrent, such as specifically engineered nanoparticles (Keith 2010). This also suggests that public opinions will dynamically change in parallel to the scientific progress that is made with the development of CE technology. Therefore, these opinions cannot be regarded as static.

OUTLOOK

Considering the Issue of Framing in CE Appraisal Studies

Bellamy and colleagues encourage greater consideration of implicit framings in CE appraisal studies to avoid premature closure around specific ways of thinking about the problem or around specific CE options. As we took an effort to avoid suggesting any specific ways of representing the climate change issue or related strategies, we believe we could minimize this effect. This is especially important given that studies such as ours contribute to a spreading of information on CE; most of our participants heard about the issue for their first time. Presumably, our participants will also discuss the issue within their peer-groups and hereby conduce to the diffusion of the topic to wider parts of society and to the shaping of public opinions. Upstream engagement is increasingly acknowledged as an important means to include the public in risk management processes (Corner and Pidgeon 2010; Renn 2008). Therefore, the issue around climate change and CE needs to be presented in a responsible and balanced way in public perception studies. Although, for our study, we believe that we were successful in doing so, we see possibilities of improvement for future decision scenario studies in terms of the following two aspects:

We decided to restrict the set of possible options in our scenario to four, so that our participants were not overburdened or demotivated. However, this could have imposed the impression on them that these four options represent a preselection based on their viability, their political importance, or any other criteria. As a result, our participants could have been less creative and open to other possibilities. In effect, only one of our participants mentioned adaptation as a possible strategy alongside with mitigation and thus introduced a new option.

To address this issue in future studies using the scenario technique, one could mention that the presented CE options are only prototypical examples for a wider range of options and that they do not have precedence over others. It could also be useful to prepare a sheet of information on other proposed CE options and other climate policy strategies together with a balanced selection of sources for further information to correct any bias that could have been provoked by the study. Indeed, many of our participants expressed their interest in obtaining further information upon completion of the study, not only about CE but also about emission scenarios and mitigation policies. This is further evidence for the claim that studies such as ours are important with regard to upstream engagement processes: some participants evidently felt an enhanced motivation to keep informed about climate change,

related policies, and, most interestingly, their own possibilities of contributing to the reduction of emissions as a result of our study. Also, our observations are in line with the study of Kahan and colleagues (2012), which showed that participants who were exposed to information about CE were more concerned with climate change than a control group. If our participants' enhanced motivation to contribute to emission targets as a result of our study will convert into action, is questionable. However, because these considerations indicate that studies such as ours potentially affect upstream engagement processes, they highlight the responsibility of the authors of these studies to adequately present the issue to their subjects.

On a similar note and as Bellamy and colleagues (2012) have elaborated on, the framings in CE appraisal studies have the power to structure and influence scientific, political, and public debates around the issue. As our findings support the assumption that the plan B framing has the potential to enhance at least conditional support for CE also in laypeople, it gives cause for concern that this framing is highly prevalent in the research community. Our findings thus highlight the importance for researchers to carefully present the issue of CE in appraisal studies, also to their fellow researchers.

Other Factors Influencing Public Perceptions of CE

Risk not only is part of traditional expert evaluations of newly emerging technology such as CE, it has also been highlighted in previous studies as an influential factor in the development of public opinions on CE. Our study supports the assumption that risk framings will play an important role in public evaluations because most of our participants concentrated on the negative consequences of CE for the environment, which they evaluated as especially reprehensible. Such a focus on environmental risk, however, is expectable of members of environmental organizations or people, who are interested in environmental issues, both of which were characteristics of many of our participants. In addition to the environmental risks of CE, some of our participants mentioned other aspects to consider in evaluating the options, such as an equitable distribution of risks between the developed and the developing world or trust in scientific and political institutions. Other aspects such as these may also play a role in a public opinion-formation process and may even be more influential in different groups of society than they were in our sample. It therefore is important to keep in mind that environmental risk is only one dimension on which CE in its broader context can and needs to be evaluated (Amelung and Funke 2013). In line with this, Bellamy and colleagues (2012) caution against the temptation to focus too much on traditional technical evaluation criteria of performance and risk in the context of CE. In Germany, among other countries, there have already been attempts by governmental agencies to broaden the scope of traditional technical risk evaluation criteria such as the amount of damage and probability of occurrence to criteria such as *inequity and injustice* to achieve a more effective risk management of increasingly complex and global risks (German Advisory Council on Global Change [WBGU] 2000). Also, strategies for an increased participation of public stakeholder groups have been advocated as a means to broaden the perspectives on complex issues such as CE (Corner and Pidgeon 2010). Therefore, an exclusive focus on the risk dimension does not account for the complexity of the

issue of CE and all possible perspectives on it. For example, a CE technique that might be perceived to have an acceptable amount of negative consequences on the environment such as cloud whitening is not likely to be accepted by wider parts of society if the administering institution appears to have vested financial interests and therefore is not trusted. Also, our participants' focus on the negative consequences of CE for the environment, which influenced their decisions, can possibly be attributed to the homogeneity of the sample, as most of the participants are likely to have pro-environmental attitudes by tendency.

Hence, to avoid premature closure around too narrow framings of the issue and to account for the complexity of the issue, it would be interesting for future studies to directly test the relative importance of different evaluation criteria or ways of framing the issue for different groups of the public. It could also be informative to compare the relative importance of different ways of framing the issue between stakeholder groups in the developed and developing countries. Given that negative impacts of CE are likely to be regionally diverse, and risks might be enhanced for developing countries (Royal Society 2009), framings around fairness considerations could have a higher impact on public perceptions in developing countries.

CONCLUSION

Our study suggests that laypeople who perceive CE as a back-up strategy for mitigation with an acceptable level of risk have a comparably more favorable attitude toward the notion of CE, even though our participants' choice for CE as a back-up plan, as demonstrated in our study, can merely be interpreted as a conditional tolerance for CE and should not be mistaken for a generally positive evaluation of it. The plan B idea is a common contextual framing to justify research on CE in the scientific debate and has also been adopted by the media. Thus, it may significantly influence opinion-formation processes in scientific, public and political debates. Therefore, concern is warranted that the high prevalence of the plan B framing might prematurely enhance the acceptability of CE technology (Bellamy *et al*. 2012). Our results also substantiate the concern that the introduction of an easy technological resort could undermine current mitigation efforts (the so-called "moral hazard," cf. Davies 2010). Because a failure of mitigation is perceived to be less severe with the introduction of a back-up strategy, the motivation to support inconvenient mitigation strategies may be reduced as well.

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SUPPLEMENTAL MATERIAL

Supplemental data for this article can be accessed on the publisher's website.

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