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List of publications for the publication-based thesis

Manuscript 1: Amelung, D., & Funke, J. (2013). Dealing with the uncertainties of climate engineering: Warnings from a psychological complex problem solving perspective. *Technology in Society, 35*(1), 32-40.

Manuscript 2: Amelung, D., & Funke, J. (2015). Laypeople's risky decisions in the climate change context: Climate engineering as a risk-defusing strategy? *Human and Ecological Risk Assessment, 21*(2), 533-559.

Manuscript 3: Fischer, H., Amelung, D., & Said, N. (2016). Climate change and the problem with overconfidence: The difference between perceived and actual understanding. *Manuscript submitted for publication.*

Introduction

"As we move from one rhetorical climate deadline to another, there is a real danger that a hyperventilating condition of despair and panic will lead society into making either hubristic or authoritarian responses to climate change. Before we realise it, we may see Paul Crutzen's howitzers pumping shell after shell of aerosols into the stratosphere to wage an almost literal war on climate change." (Hulme, 2014a)

What Mike Hulme warns us against in his book on different climate understandings is a rhetorically induced one-sided condition of fear, which may motivate us into drastic counteractions while at the same time blinding us to important opportunities. In order to translate Mike Hulme's proposal for a rethinking of climate change into more psychological terms, vigilantly scanning our environment for indications of danger in a motivational emphasis to prevent climate change catastrophes might constitute an inappropriate self-regulatory focus.

Such a motivational emphasis becomes apparent in current debates on climate change, which predominantly revolve around the prevention of risks, for example, when scholars encourage their readers to view climate change as a global risk management problem (Wagner & Weitzman, 2015), or when they portray the challenges of climate communication as being mainly an issue of how dangers and risks are presented or perceived (e.g., Leiserowitz, 2005).

The present work therefore makes the proposition that current debates on climate change may overemphasize the motivational focus of prevention in the sense of regulatory focus theory (Scholer & Higgins, 2011), possibly hindering necessary societal changes, or giving rise to debates around technological fixes such as climate engineering that might well prove to be a deadlock in the future (Robock, Jerch & Bunzl, 2008).

To introduce my proposition, I will first present current framings of climate change around issues of catastrophic risk, from where I will move on to explain the concept of climate engineering technology. Note that throughout this work the term "framing" is used in a broader sense than the term known from Kahneman's work on cognitive heuristics and biases (Kahneman & Tversky, 2000) and denotes "the ways in which social actors choose to organise and communicate, or 'frame', ideas such as geoengineering" (Bellamy, 2013, p.1).

I will then introduce regulatory focus theory and explain its potential to understand current dominant framings around prevention in the climate change debate. By reference to the idea of climate engineering as an exemplary outcome of a prevention orientation, I will then provide a more detailed explanation of why a sole focus on prevention may be problematic. To substantiate my claim, I will present empirical findings to show that a shift towards a promotion focus could be beneficial in our dealings with climate change and will discuss potential practical implications of how to undertake a shift from prevention to promotion in the organizational context and the general area of communication. I will conclude by discussing avenues for further research into the application of regulatory focus theory to the domain of climate change and its more general application to behavior towards risk.

Preventing climate change catastrophe and the idea of climate engineering

Decisions about the pressing environmental issues of our time such as climate change means dealing with uncertainty (Amelung & Funke, 2013; Lempert, Nakicenovic, Sarewitz, Schlesinger, 2004; Murphy et al., 2004). Confronted with a multitude of factors with global linkages and under conditions of dynamic change, we now need to plan for time scales large enough to make reliable prediction extremely difficult. We also need to consider a long and presumably incomplete list of variables, which interact in ways we do not fully understand. Therefore, the amount of anticipatory knowledge is limited, and despite of the accumulation of knowledge that can be observed in between the release dates of two successive reports of the Intergovernmental Panel on Climate Change (IPCC), scientific uncertainty is likely to remain high.

Given that uncertainty and risk are defining characteristics of the situation we face with climate change, a focus on risk, and especially potential catastrophic risks in discourses around climate change may be understandable, as are communication efforts to persuade a wider public of the necessity to take action. However, discussing climate change in a context which present this phenomenon as a problem that needs to be solved, a risk which has to be managed, may only be one way of contextualizing the situation, and not a particularly successful one: Despite growing international awareness, public as well as political efforts to take action are insufficient while at the same time a general consensus on *how* to act is missing.

The idea of catastrophic risk in the climate change context becomes explicit with the emergency framing of climate change (Frantz & Mayer, 2009; Schneider, 2011). Despite of the fact that it is not clear from a scientific standpoint how a "climate emergency" could be defined, the possibility of a dramatic shift into completely new and unforeseen states with potentially catastrophic consequences is increasingly deemed plausible by climate experts (Hamilton, 2013; Lenton, 2011). This notion challenges the idea that climate change is happening gradually and that politics can adapt gradually as well, which is why we may need an emergency plan other than emission cuts to offset the worst consequences. Such an emergency framing of climate change gave rise to the idea of climate engineering (CE).

CE comprises a set of heterogeneous technological ideas, which (a) aim at offsetting the temperature effects of climate change by reducing the amount of incoming solar radiation (Solar Radiation Management) or (b) aim at cancelling out rising CO_2 emissions by extracting them from the atmosphere (Carbon Dioxide Removal). The notion of massively intervening into the climate system is controversial because interventions of this scope can be expected to pose severe challenges in terms of environmental and societal risk. Even basic feasibility studies are at times viewed critically because they may lead us on a "slippery slope" to eventual deployment (the "slippery slope" argument; Jamieson, 1996).

The idea of a possible climate emergency as a justification for more research into, development of, and sometimes eventual deployment of climate engineering is one of the most widely used contextual framings in scientific and grey literature accounts of these newly emerging technologies (Bellamy, Chilvers, Vaughan & Lenton, 2012). However, this "emergency framing" of CE has also been criticized for narrowing down the problem space in a way that prematurely constrains deliberation of alternatives. (Horton, 2015; Hulme, 2014; Markusson, Ginn, Ghaleigh & Scott, 2014). Moreover, the emergency framing constitutes an example of the wide prevalence of the aspect of catastrophic risk in political and scientific discourses around climate change, which are largely confined within a risk management framework (e.g., IPCC, 2014a,b; Kunreuther, Heal, Allen, Edenhofer, Field & Yohe, 2013; Wagner & Weitzman, 2015). In this way, one of the most important arguments – and a seemingly compelling one - in favor of research and eventual deployment of CE technology has been challenged.

Additional reservations against CE as a means to tackle catastrophic climate change are put forward in our own work in which we argue that –from a psychological point of view - a false sense of controllability and security may be established via the introduction of CE into the problem field, especially if it is used in the context of a possible climate emergency (Manuscript 1). This sense of controllability may prove to be an illusion because the necessary preconditions for adequate control of a complex system – learning with the help of several feedback cycles - are not met. We therefore advocate for a learner's approach in our dealings with climate change with adequate communication between all stakeholders (e.g., political decision-makers, scientists, civil society) as one necessary precondition to facilitate this approach.

Similar to the way an emergency framing of CE has been challenged for its narrow focus, a narrow framing of climate change as a problem of multiple risks which need to be reduced, has also been challenged for its potential of missing important opportunities (Hulme, 2009). However, such a framing not only affects current political decision-making processes (IPCC, 2014a,b), it also largely influences communication with lay recipients (Smith, 2005). As part of this work, I have empirically demonstrated that the ways people understand and make sense of - or "frame" - a complex issue such as CE affect their attitude and decision behavior towards it (Manuscript 2). Therefore, a critical examination of dominant frames in scientific and public debates as well as their responsible use appears warranted.

Regulatory focus theory: Preventing risks or achieving something new?

The "preventing risk" framework in which the climate change problem is discussed might overemphasize a focus on prevention instead of promotion in the sense of psychological regulatory focus theory (Scholer & Higgins, 2011). According to this theory, a prevention focus is a motivational tendency characterized by a need for security and a preservation of the status quo rather than the attainment of new gains.

Regulatory focus theory posits that a prevention focus is not the only motivational focus we can adopt to regulate our behavior: People self-regulate their behavior driven by varying combinations of two uncorrelated motivational tendencies: a focus on prevention or on promotion. People with a prevention focus are more easily motivated by security and safety needs and the avoidance of undesired goal states. In other words, these people are more in alignment with goals that advocate going from -1 (some loss) to 0 (the status quo or a neutral end-state) rather than trying to achieve +1 (a gain). On the other hand, people with an active promotion focus feel a better 'regulatory fit' with goals, which are in alignment with their growth and advancement needs and the attainment of gains. These people would not consider the status quo (a '0') a desired end-state, but would seek to achieve a gain (+1) (Scholer & Higgins, 2011).

Because the two motivational foci are uncorrelated, people can be motivated by both tendencies in varying degrees, also depending on the task they are confronted with. However, most people appear to have a general preference for one of the two tendencies.

Climate engineering: A focus on prevention

In Manuscript 1 of this work, we have argued that CE may be seen as a tool to reduce the psychological experience of uncertainty (Amelung & Funke, 2013). If CE is a tool to reduce experienced uncertainty, a prevention focus can be the motivational tendency behind the adoption of such a tool. In other words, the idea of climate engineering may be an exemplary outcome of a preferential focus on prevention.

In a similar way, authors from other disciplines have advocated for the necessity of a new societal perspective on risk in the context of climate change and CE. One philosophy author argues, for example: „Now geoengineering promises possibilities for providing the conditions that allow the perpetuation of fossil fuel powered neoliberalism further into the future. Or rather it might, if security continues to be formulated in terms of the perpetuation of the existing political order, precisely the order that has generated such dramatic ecological disruption in the first place.“ (Dalby, 2015, p. 3).

In this example, the author argues that CE is used as a means to establish or return to a status quo that needs to be preserved rather than put into question. In other words, CE is the means to satisfy the need for security and non-losses.

CE is an option intended to regulate the risks of climate change in reference to a goal state that is characterized by the presence or absence of negative outcomes. It is not a means designed towards a goal state characterized by the presence or absence of positive achievements. In other words, it is not intended to provide us with an idea of how a "better" or more sustainable world could look like, but it aims at largely preserving the status quo while trying to prevent the worst from happening.

Regulatory focus theory does not imply that prevention- and promotion-focused individuals necessarily differ in the overall aim they want to achieve (e.g., sustainability). However, they should differ in the strategies they prefer to reach their goal: "…when individuals have fallen below the status quo, as in a stock investment paradigm, prevention-focus strength, but not promotion-focus strength, predicts a willingness to take risks that may possibly return participants to the status quo" (Scholer & Higgins, 2011, p. 150).

In the context of climate change, an anticipated fall below the status quo (anticipated losses due to climate change) might trigger a motivation to do whatever necessary, even if very risky in itself (such as CE), to return to the status quo. From a promotion focus, the idea of CE must sound a little less intriguing because nothing more positive is attained by it than what we have today. Thus, a strengthened focus on prevention more than a promotion focus would heighten the willingness to consider a risky strategy such as CE to ensure the status quo.

In a similar vein, many participants in our study (Manuscript 2) used CE as a potential means to insure against the risks of mitigation failure, possibly as a result of an implicit focus on the prevention of losses as opposed to the achievement of gains: climate change as well as the decision alternatives provided to the participants were clearly conceptualized in terms of potential losses and non-losses rather than in terms of gains and non-gains, as revealed by the information they inquired about (e.g., questions concerning negative consequences were four times more common than questions on positive consequences), and the thought processes they expressed. This focus on risks and losses by our participants is especially noteworthy because in the introduction to the scenario task, the potentiality of a loss resulting either from climate change or any of the options was not explicitly mentioned.

Additional support for the claim that an endorsement of CE may be the result of a prevention focus more than a promotion focus can be drawn from the empirical finding that a promotion focus is associated with a higher sense of control and with a lower tendency to predict trend reversals or sudden shifts (such as a climate emergency due to a tipping-induced qualitative climate regime shift) in a generally stable trend (such as gradual warming) (Guo & Spina, 2015). A prevention focused individual's sense of control would therefore be lower, while such an individual would also deem a possible climate emergency to be more plausible. Both would lead to a greater endorsement of CE technology to re-establish one's sense of control.

From a broader sociological viewpoint, the consequences of a collective emphasis on prevention were already described within Ulrich Beck's seminal work about the "world risk society". In this sense, the entire debate among researchers whether CE technology might be a good idea to deal with climate change, might stem from a general perspective on risk and uncertainty in terms of what Ulrich Beck calls the "risk contract":

"That a risk contract is a possible or necessary response to the adventure involved in opening up and conquering new markets and in developing and implementing new technologies is a social invention … that was extended to almost all social problem areas and gradually perfected with the emergence of national capitalism. Consequences that at first affect individuals become 'risks', that is, systemic, statistically describable, and hence, 'calculable' event types that can be subsumed under supra-individual compensation and avoidance rules." (Beck, 2009, p. 7).

Beck challenges these traditional dealings with risk because the premise on which the "state-sanctioned risk contract" was enacted, is no longer prevailing. Therefore, he challenges the assumption "…that it is possible to control and compensate for industrially generated insecurities and dangers, an assumption which is central to the risk contract." (p. 7)

A generalized and unbalanced motivational focus on prevention may be seen as an expression of the "risk society" in Ulrich Beck's sense. Furthermore, this unbalanced focus poses several problems such as an overemphasis on the status quo or the prevention of necessary changes. A framework of self-regulation with its regulatory focus theory might offer a new perspective to these problems in that it provides us with an idea how an alternative approach could look like: How could a stronger focus on promotion be beneficial in our dealings with climate change?

A focus on promotion: Finding creative solutions for climate change

A focus on promotion has been found to be advantageous in organizational and team contexts, in which it fosters creativity, and innovation (Shin et al., 2016; Shin, 2014; Wallace et al., 2016; Zhou et al., 2012). Because innovation and the finding of creative solutions will be a crucial factor if we want to effectively respond to climate change (e.g., Holdren, 2006), what implications may these findings have for the climate change domain?

As part of this work, we have identified various characteristics of the climate change problem, which affect a decision-maker's ability to adequately control its dynamics, such as a network of interacting variables, or scientific uncertainty with regard to influencing factors, their interactions, and resulting future trends (Manuscript 1). These characteristics necessitate that problem solvers perform specific cognitive tasks to effectively deal with them including building an adequate mental representation of the problem, or predicting future trends.

In the following sections, I will outline the results of several studies, which demonstrate positive effects of a promotion focus on the performance of several of these tasks relevant to problem-solvers in the context of climate change including (a) the achievement of an adequate problem representation, (b) an endorsement of dynamic change, (c) a flexible up-dating of mental models as well as (d) the development of sufficient motivational persistence to facilitate learning. Given that, with climate change, political decisions taken at this point in time will affect all of humanity for the coming decades and even centuries, other stakeholders including the public should be included as much as possible in respective decision-making processes. Therefore, the results I am going to present do not only pertain to political decision-makers, but civil society as a whole because political decisions need to be supported by the people, or because solutions may even be more effective when found and implemented in bottom-up processes than in a political top-down process (Ostrom, 1990). This means that each member of society may be regarded as a problem solver and not merely as a passive recipient of climate policy decisions.

(a) *Achievement of an accurate problem representation.* An accurate representation of the problem is a crucial prerequisite for the finding of better and more accurate solutions (Amelung & Funke, 2013; Reiter-Palmon, Mumford, O'Connor, Boes & Runco, 1997). In the complex domain of climate change, this necessitates a certain degree of engagement in the problem identification process not only on the side of political decision makers but also by members of the public. If there is high engagement in the process of understanding the problem, it will be more likely that different views and additional alternatives are being considered, and that hereby a more accurate representation of the problem is achieved.

Our own work demonstrates that people differ considerably in the time and effort they put into this first step of a problem solving process: the establishment of an accurate problem representation (Manuscript 2). Interestingly, a higher engagement in the problem identification process and a higher likelihood of the consideration of additional alternatives is associated with a promotion focus because it makes it more likely that the "correct" alternative (a "hit") is included, and because promotion focused individuals are less sensitive to "false alarms" (Henker, Sonnentag & Unger, 2015; Liberman et al., 2001). Prevention oriented individuals, on the other hand, are less inclined to simultaneously endorse alternative hypotheses but prefer to make a quick decision for one explanation to ensure against "false alarms", an error of commission rather than an error of omission.

To achieve a more accurate problem representation of the complexities of climate change, we also need to be able to identify connections and overarching themes between individual pieces of data, which may also include the identification of distal and non-obvious relationships between factors (cf. Amelung & Funke, 2013). Such processes are facilitated by a relational elaboration style rather than an item-specific elaboration style, which examines the details of individual factors independent of others. A relational elaboration style has been found to be adopted primarily by promotion focused individuals (Zhu & Meyers-Levy, 2007).

Similar to a relational elaboration style, the ability to identify connections between seemingly unrelated events or trends, to "connect the dots" and hereby recognize underlying patterns in a complex environment has also been found to be crucial for the recognition of opportunity in the business sector (Baron & Ensley, 2006). Opportunity recognition may therefore be one of the beneficial outcomes of a relational elaboration style. This could be the mechanism behind findings, which indicate that promotion focused individuals also show an increased tendency to recognize opportunities and that they identify opportunities characterized by higher degrees of innovation (Tumasjan & Braun, 2012).

Scholars have argued that to effectively deal with climate change, important opportunities should not be missed because connections between seemingly disparate items are not perceived. The argument is that by broadening our focus and making these connections, we could increase the odds to achieve our climate policy goals. For example, looking at alternative sustainable development paths, or global investment opportunities could be more efficient in our dealings with climate change than climate policies which narrowly focus on the difficult balance between minimizing or adapting to climate change impacts and restricting domestic cost (Robinson et al., 2006). Thus, opportunity recognition based on a relational elaboration style, both of which are associated with a promotion focus, can be regarded as important prerequisites for our ability to cope with and avert future negative impacts of climate change.

(b) *Endorsement of dynamic change.* We have also established in Manuscript 1 that an important characteristic of the complex problem of climate change is the lack of stability of the environment we seek to control. In other words, we have to deal with the dynamics of the different overlapping (social and natural) systems, which compound other uncertainties (Amelung & Funke, 2013). In these kinds of highly dynamic and unstable environments, which are characterized by high amounts of uncertainty, managers' and CEOs' promotion focus has been found to be more beneficial for venture performance than a focus on prevention only. The authors of one of these studies have found this relationship to be mediated by managers' endorsement of changes in the business concept rather than a clinging to original concepts (Hmieleski & Baron, 2008; Wallace et al., 2010). Therefore, a focus on promotion may be more suited to adequately respond to the uncertainties of climate change than a focus on prevention because the former induces a higher willingness to endorse necessary changes.

(c) *Flexible up-dating and learning.* In Manuscript 1, we have advocated for a learner's approach to cope with the changing demands of a complex and highly uncertain environment. Such an approach requires the ability to flexibly adapt one's mental model and to reframe the problem based on the integration of new information or based on changing demands of the environment such as shifting goals etc. (Amelung & Funke, 2013).

The climate change problem can be framed within multiple potential categories, which in turn will activate specific pertinent approaches and goals. For example, framed as an economic problem, climate change will in most cases be assessed within a cost-benefit framework with cost reduction and welfare maximization as associated goals. Climate change may also be categorized as an issue of equity between nations or generations, warranting the establishment of compensation rules, as a security issue, determining negotiations over legal frameworks and international treaties, or as a global catastrophe calling for a risk management approach.

The ability to simultaneously hold these categories within conscious access as well as to adaptively shift between them based on changes in the environment is crucial to facilitate a learner's approach. Such an ability can be termed cognitive flexibility. Cognitive flexibility or the ability to access and retrieve ideas from different semantic categories as well as the capacity to switch between categories and goals is associated with a promotion focus (Baas, De Dreu & Nijstad, 2008).

(d) *Development of sufficient motivational persistence to enable learning.* Promotion focused individuals have been found to perform better at difficult tasks, and to be less likely to quit a difficult task after failure (i.e., to be more persistent), because they are less vigilant towards losses (Crowe & Higgins, 1997). Thus, a promotion focus may provide us with the necessary persistence in our motivation to tackle climate change. This could be especially important given the amount of findings, which demonstrate psychological "numbing" to the issue of climate change due to negative representations of "failure" and "doom" in the media (Moser, 2007).

In sum, a promotion focus appears to enhance a person's problem solving skills in ways, which are especially adaptive in highly complex, uncertain and unstable environments. Therefore, a more balanced focus towards promotion may indeed be more beneficial to effectively deal with the complexities and ambiguities of climate change than a sole focus on prevention, especially in the face of difficulty and drawbacks.

If this is the case, how can a shift towards a more pronounced focus on promotion be achieved in the climate change context?

Even if regulatory focus is conceptualized as a chronic personal tendency, it has been shown in numerous studies that a specific regulatory focus can also be induced by simple environmental cues, including task instructions with an emphasis on the attainment of gains (promotion) or the avoidance of losses (prevention), for example (e.g., Keller & Bless, 2006).

In addition, shifts in regulatory focus have also been observed as a result of specific leadership styles in the organizational context or as a consequence of certain framings in communication. In its applications to the organizational, leadership, and communication contexts, these results may be useful to improve the design of efficient climate policies or climate communication processes between stakeholders. I will therefore discuss the potential of these two applications of regulatory focus theory to (a) the organizational context and (b) to the communication context as potential starting points to achieve a shift in our collective focus from prevention to promotion, and will discuss avenues of future research.

Practical implications: promoting change in the organizational context

Insights on how to capitalize on the advantages of a promotion focus in the domain of climate policy-making may be drawn from studies in leadership and organizational contexts, which treated specific regulatory states such as the promotion focus as the outcome variable. For example, a focus on promotion has been found to be induced by transformational leadership behaviors.

Originally observed by political scientist James Burns (1978, 2003) in political leaders such as Franklin D. Roosevelt, the concept was later applied to the organizational context (Bass, 1990). Transformational leadership behaviors include challenging dominant perspectives (the status quo), articulating a vision (making the positive outcomes more salient), hereby shifting the focus away from security concerns to the necessary task, and fostering cooperation in pursuit of a common goal (Bass, 1990). Via the *induction* of a focus on promotion, a transformational leadership style has been shown to foster creative problem-solving (Henker, Sonnentag & Unger, 2015). Because conflicting goals or security concerns are among the major barriers to climate action as identified by The 'American Psychological Association's Task Force on the Interface Between Psychology and Global Climate Change' (Swim et al., 2009), a transformational leadership style may be especially well suited to address these issues within an organizational context (such as the business sector).

Furthermore, policies as well as leadership behaviors, which address these issues may be effective in promoting necessary transformational processes on different levels in the climate policy domain. Existing literature on leadership in the climate policy domain addresses the who, the why, and the how of leadership (Karlsson et al., 2011). Regulatory focus theory could provide a framework to understand 'why' specific ways of leadership may be important to achieve specific climate policy goals, and may also provide tentative answers to the 'how', given that inappropriate leadership behaviors have been discussed as one of the critical barriers to necessary changes in climate policies, such as adaptation (Moser & Ekstrom, 2010).

However, an awareness of the different levels on which leadership may play a role (local, national, international) is warranted in the climate policy domain because it is more complex than the domain of single organizations. This means that entire nations or economic-political unions of member states can act as leaders, and on each level, there may be more than one leader (e.g., the EU or China) (Karlsson et al., 2011). Still, research on leadership styles such as the transformative style may serve as an inspiration to derive guidelines for an effective implementation of necessary transformative processes via climate policies on regional and local levels, for example.

Practical implications: promoting change in communication

Present conceptualizations of climate change in scientific and public debates largely revolve around the prevention of losses. For example, communication with the public is currently focused for the most part on persuading wider masses of the severity of anticipated climate change impacts, at the same time stressing the urgency to take action (Moser, 2009; Pearce, Brown, Nerlich & Koteyko, 2015). It can be assumed that a sole focus on the avoidance of harm, in terms of losses and non-losses, may self-perpetuate a societal debate of climate change under the one-sided focus of prevention. This may be true for the public, which is exposed to respective media framings, as well as political decision makers who are exposed to expert debate around the prevention of risks (e.g., Wagner & Weitzman, 2015).

Because, as I have established, the prevention focus may not be a suitable approach under conditions of uncertain change, this has wide implications for the area of risk communication and how climate change and climate engineering are put into context in scientific and political debates.

For example, framing the climate change problem in terms of the avoidance of risk may produce less “regulatory fit” with certain audiences and may therefore elicit psychological reactance. Empirical evidence for this idea comes from a recent study which showed that framing climate change in terms of the achievement of gains, such as a more caring society or technological progress, was able to motivate more pro-environmental action intentions in climate deniers than framing it in terms of the avoidance of risk (Bain et al., 2012). In a similar study, support of CO_2 mitigation policies was enhanced by framing them in terms of slightly reduced gains than in terms of losses (Hurlstone et al., 2014). In another study with a large community sample, framing climate change solutions around personal sacrifices was less effective in promoting mitigative behavior intentions than a framing around positive values and visions (Gifford & Comeau, 2011).

The idea that a focus on risks may not mobilize wider parts of society into action against climate change is not new: Experts in Communication have already argued that the promotion of fear induces feelings of disempowerment rather than behavior change (Moser, 2007). The abovementioned examples demonstrate that a shift from a prevention focus to a promotion focus may yield more encouraging results, at least with certain subgroups of society (e.g., climate skeptics).

One important assumption of regulatory focus theory is that a message will be most effective and acceptable if it produces regulatory fit with a person's dominant focus (Scholer & Higgins, 2011). This implies that not one single focus will be necessarily acceptable and effective for all parts of society and in all situations. Therefore, a balanced communication of potential gains *in addition to* potential losses may be the most effective way to address all parts of society regardless of their pre-existing beliefs or value orientations.

Also, because climate science clearly reveals that climate change poses severe threats to humanity, and the public needs to be informed about these findings, simply replacing a focus on losses with a sole focus on gains and opportunities may yield equally imbalanced and ineffective discourses. Rather, a more balanced inclusion of both foci in climate messages may lead to more inclusive debates based on a more comprehensive picture of the situation, and may re-establish trust, which may have been lost due to climate campaigns with evidently coercive political agendas (cf. Bowman et al., 2010; Brulle, Carmichael & Jenkins, 2012; Fischhoff, 2007).

Our work (Manuscript 3) demonstrates the potential usefulness of non-coercive ways of communicating climate science, and provides some evidence for the importance of regulatory focus mechanisms for climate communication: participants from Germany, India and the US showed a lower willingness to donate money to mitigation projects not only if their objectively measured text understanding of excerpts from the IPCC reports' Summary for Policy-makers was lower, but additionally, if they felt that they had better understood the excerpts independent of actual understanding (i.e., they were overconfident; Fischer, Amelung & Said, submitted work). Interestingly, objective climate understanding, which was positively associated with donation behavior, was negatively associated with a chronic focus on prevention, $r(262)=-.36$, $p < .001$, while a chronic focus on promotion was associated with higher levels of subjective understanding, $r(261)=.41$, $p < .001$ (as measured with the regulatory focus scale by Lockwood, Jordan & Kunda, 2002; results not reported in Manuscript 3).

Furthermore, group comparisons between participants with a distinct promotion focus (high prevention orientation combined with low promotion orientation identified by median split) and a distinct prevention focus reveal a significant lower objective understanding for participants with a distinct prevention focus, $t(110)=-3.35$, $p=.001$.

In addition to this, overconfidence independent of actual understanding is associated with a stronger promotion focus, $r(261)=.43$, $p < .001$, and distinctly promotion-oriented participants were significantly more overconfident than distinctly prevention-oriented participants, $t(126)=-5.29$, $p < .001$. While an association between a chronic promotion focus and the overconfidence bias has so far not been empirically demonstrated, this latter finding is in line with existing results demonstrating an association between a stronger promotion focus and higher confidence in one's own success and an enhanced sense of control (Guo & Spina, 2015; van Vianen, Klehe, Koen & Dries, 2012).

While regulatory focus, as outlined earlier, is known to affect a range of cognitive skills and strategies with the potential to influence an adequate understanding of difficult climate science, including cognitive flexibility (Baas, De Dreu & Nijstad, 2008), (relational vs. item-specific) elaboration style (Zhu & Meyers-Levy, 2007), and problem representation strategies (Henker, Sonnentag & Unger, 2015; Liberman et al., 1999), the exact mechanism responsible for the lower understanding levels of prevention-oriented participants needs to be clarified in future work.

One possible explanation may include that the high levels of difficulty of the IPCC texts reduced prevention-oriented individuals' motivation to understand them, because they also perceived the texts as more difficult on average than promotion-focused individuals, $t(127)=3.18$, $p=.002$. This explanation is in line with the finding that prevention-oriented individuals show lower levels of perseverance in difficult tasks than promotion-oriented individuals, especially after failure (Crowe & Higgins, 1997).

In sum, our findings demonstrate the relevance of regulatory focus mechanisms for the understanding of climate science information and for resulting decision behavior. Also, this finding further underlines that an imbalance towards either a focus on prevention (lower objective understanding) or on promotion (higher levels of unjustified confidence) may not be adaptive.

Discussion

Drawing on theoretical and empirical findings within the three articles of this work, I have established that only a balanced focus on prevention as well as promotion may enable us to successfully address climate change.

Manuscript 1 establishes the preconditions for an effective management of climate change from a problem-solving point of view, preconditions for which a sole prevention focus may not be conducive, but may rather give rise to an unjustified endorsement of technological control strategies such as CE. Manuscript 2 demonstrates empirically that a perception of CE as a back-up strategy to control the risks of mitigation failure indeed makes CE appear a favorable strategy (possibly due to an implicit dominant focus on the prevention of risk). Manuscript 3 provides some empirical evidence for the importance of a balance between prevention and promotion also for climate science understanding, one of the prerequisites for the development of an adequate problem representation and therefore adequate control, as outlined in Manuscript 1.

The following sections will discuss avenues for future research on the application of regulatory focus theory to climate action barriers, climate risk perception and communication, and risk management behavior more generally.

Outlook: Future research on regulatory focus and climate change

Regulatory focus theory has proven to be a useful framework to explain behavior on different levels of analysis, such as the individual, and the group or organizational levels. Therefore, and albeit it has not been systematically applied to the field, it could provide a useful framework to direct future climate-related psychological and interdisciplinary research.

For instance, experimental work could further our understanding of the usefulness of a focus on promotion to address specific psychological barriers to climate change action that have been systemized by the 'American Psychological Association's Task Force on the Interface Between Psychology and Global Climate Change' in its report from 2009 and related articles (Gifford, 2011; Swim et al., 2009).

Regarding these barriers, including, among others, ignorance, reactance, and denial, the authors identify several avenues for further research. For example, the exact mechanism and emotional or motivational underpinnings of phenomena such as reactance or denial need to be better understood. Regulatory focus theory could be a useful framework to help explain the missing link between some of the identified psychological barriers and climate action.

For instance, if one understands denial as a defense mechanism resulting from worry over a perceived threat coupled with a feeling of powerlessness (cf. Aitken, Chapman & McClure, 2011), it would constitute a maladaptive coping mechanism in response to climate change because it leads to inaction. Since prevention focused individuals are more vigilant towards cues, which signal threats and losses (Sassenberg, Sassenrath & Fetterman, 2015), thus worry more over potential losses, and generally feel less in control than their promotion focused counterparts (Guo & Spina, 2015), they may exhibit higher degrees of denial.

Because on the other hand, worry over potential losses could also be associated with a higher motivation to engage in climate action, if it is coupled with the feeling of being more in control, a prevention focus does not necessarily lead to less climate action than a promotion focus. Regulatory focus could therefore help identify the conditions under which worry leads to more climate-related action and in what cases it leads to inaction.

Results could then inform the design of messages that inform about climate change in a way that reduces maladaptive and unnecessary response mechanisms of denial. For instance, based on the rationale as outlined above, balanced messages that do convey the scientific facts of climate change impacts but at the same time either indirectly enhance a focus on promotion or directly enhance prevention-oriented individuals' feelings of control (e.g., by stressing either easy ways to personally contribute to climate action, or other people's climate efforts to help achieve an empowering community sense, hereby highlighting the possibility of a non-loss) might help enhance climate action. Supporting evidence for this notion comes from one study, which found that highlighting possible non-losses as opposed to possible losses had a positive effect on pro-environmental behavior intentions mediated by higher feelings of efficacy (Morton, Rabinovich, Marshall & Bretschneider, 2011).

A crucial barrier to climate action is the way people deal with uncertainty and risk (Lorenzoni, Nicholson-Cole & Whitmarsh, 2007; Swim et al., 2009). This includes phenomena such as temporal discounting, or the discounting of uncomfortable information that is presented as scientifically uncertain, such as in the IPCC assessment reports (Budescu, Por & Broomell, 2012). Therefore, it also includes all aspects of public understanding of risk (e.g., the perception of not being at risk) and its implications for risk communication (Pidgeon & Fischhoff, 2011).

Behavior changes to address climate change often pose a dilemma between short-term losses and long-term gains leading to the temporal discounting of future rewards. Regulatory focus theory provides an interesting perspective on conflicting decisions of this type: One study has shown that a promotion focus can explain the connection between a higher tendency to consider future consequences and healthy eating and exercise behavior (Joireman et al., 2012). The authors explain this finding by a broader tendency of promotion-oriented individuals to focus on their ideals and hopes *for the future,* while prevention-oriented individuals are more vigilant towards *immediate* negative consequences of their behavior and are thus less focused on the future (cf. also Pennington & Roese, 2003). This could mean that a person with an active promotion focus would be more inclined than a person with a prevention focus to act in the pursuit of a future gain even if this means accepting smaller immediate losses.

However, climate actions are different from health-related actions in that future gains are not only personal, but also collective, whereas immediate losses are clearly personal. Conflicting decisions in the climate change domain therefore typically involve not only the temporal dimension (immediate vs. future consequences), but also the scope (affecting only the decision-maker vs. the collective) of any gains and losses involved. Therefore, it remains unclear whether a promotion-focused individual will under all circumstances exhibit a higher inclination towards climate-friendly behavior.

For example, one study involving conflicting decisions between personal vs. collective gains has shown that promotion-focused individuals were more likely than prevention-focused participants to act in their self-interest when personal goals and the goal of a group were in conflict, in fact, they pursued personal success at the expense of group success (Zaal et al., 2015). Therefore, future research could disentangle the effects of regulatory focus on (a) the temporal dimension and (b) the scope of gains and losses involved in climate-related decisions by directly manipulating the two aspects.

Regulatory focus theory has also been applied to the field of risk perception and decision-making, where it provides an explanation for different behavioral tendencies towards risks framed as losses and risks framed as gains (Bryant & Dunford, 2008). The authors' model of risky behavior predicts that risks framed as gains or as losses (the framing effect postulated by Tversky and Kahneman, 1981) can be perceived as either positive or negative, respectively, depending on the regulatory focus of the person, and depending on whether it is framed as an act of omission or an act of commission.

More specifically, an act of omission (e.g., not changing the status quo of one's household energy supply system, not supporting the adoption of some technological innovation) would be perceived as a positive risk from a prevention focus because it provides the chance of a non-loss, while from a promotion focus it would mean a chance of a non-gain and would therefore be rejected as negative. The opposite would be true for an act of commission. This could potentially explain null findings of a comparison between loss and gain framings of climate change messages (Bernauer & McGrath, 2016). It would therefore be worthwhile to investigate the effects of different climate messages with a manipulation of message framing (gains vs. losses) and action type (omission vs. commission) on risk perception dependent on regulatory focus.

Regulatory focus theory could provide an interesting framework not only for the identification of causal mechanisms behind climate action barriers, but also for a direct investigation of climate behaviors in organizational settings. On such an organizational level of analysis, studies could reveal if and under what conditions transformational leadership behaviors could be successful in inducing climate-friendly behaviors in organizations mediated by a promotion focus. Studies have so far concentrated on group creativity as an outcome of leadership behavior and regulatory focus in the business sector (e.g., Henker, Sonnentag & Unger, 2015). Because business organizations, for example in the industry sector, are especially required to change for more climate-friendly strategies if the climate policy goals of the Paris Agreement of 2015 are to be met (IPCC, 2014b), similar studies could reveal the conditions for change towards more sustainable business practices with regulatory focus as possible mediator.

Outlook: Regulatory focus as an explanation for risk management behavior

More generally, regulatory focus theory could provide an explanation for the difference between active or passive risk defusing within Oswald Huber's Risk Management Decision Theory (2012). In Manuscript 2 of this work, we have used this framework as a theoretical basis to track participants' decision behavior in a quasi-realistic scenario, which asked them to consider different CE technologies within the context of other climate strategies such as mitigation (Amelung & Funke, 2015).

For example, if a promotion focus is associated with a more relational elaboration style (Zhu & Meyers-Levy, 2007) and a higher tendency to find innovative opportunities (Tumasjan & Braun, 2012), promotion-focused individuals may be more likely to search for an additional action (such as CE) to defuse the risk of an attractive, but risky option (such as mitigation) based on an increased tendency to examine the relations between the different options (CE could constitute an insurance for failed mitigation efforts), rather than an assessment of each option individually. Following this rationale, one would assume a generally higher tendency to search for and identify a risk-defusing option from a promotion focus than from a prevention focus.

In addition to this, the following can be considered: Oswald Huber (2012) has argued that the two goals a decision-maker pursues in a risky decision making process are the achievement of attractive positive outcomes (which is a promotion goal) and the minimization of risks (a prevention goal). He assumes a sequential process in that a decision-maker is more concerned with the positive outcome first, after which the minimization of risk becomes more important in a second step.

However, such a sequential process may not pertain to everyone: a promotion-focused individual is generally more concerned with the achievement goal of step 1, while a prevention-focused individual will put more emphasis on step 2 of the process. Following this rationale, a prevention-focused individual will not identify the most attractive alternative first and then defuse the associated risk in a two-step process, but will quickly find the alternative with the least amount of risk (the MAXIMIN decision rule). In line with this, empirical studies show that some participants act according to the MAXIMIN heuristic rather than actively defusing the risks of a preferred option

(Amelung & Funke, 2015; Bär & Huber, 2008), a more passive way to reduce risks according to Huber.

Additional support for the assumption that active risk defusing may be more in line with the promotion focus can be drawn from the study by Liberman et al. (2001), which found that promotion-focused individuals are more likely to simultaneously hold in mind alternative ideas in the process of acquiring knowledge and thus engage less in causal discounting. It can therefore be assumed that they are less likely to unequivocally decide for one option early in the process and discount alternative options. Instead, promotion-oriented individuals will be more likely to simultaneously consider alternative options long enough to explore and identify possible connections between them.

On the other hand, one could also argue that from a prevention focus, a decision-maker should exhibit higher levels of active risk defusing since the minimization of the potential for a loss is their prime interest. Interestingly, Huber found in one of his studies that active risk defusing is more frequent if a negative frame is used (an uncertain loss or worsening of a situation) than if a positive frame is used (an uncertain gain or improvement of a situation) (Huber, Huber & Bär, 2014). Since a negative frame increases the saliency of a potential loss, such an appeal may increase the motivation to secure a non-loss especially by prevention-oriented individuals. Whether the risk of an option signifies a loss or a non-gain for the decision-maker may therefore determine his decision on whether he spends his resources on active risk defusing or not.

For example, mitigation failure signifies potential losses such as human lives, biodiversity, resources, economic power, stability etc., which renders it imperative for a prevention-oriented decision maker to re-establish the status quo and avert these losses by means of active risk defusing. If, on the other hand, the risk of an otherwise attractive alternative signifies a potential non-gain such as the risk of getting a rare disease from travelling to a foreign country for vacation, a promotion-oriented decision maker may be the most likely to show active risk-defusing (such as a vaccine).

Also, especially in a more complex real life scenario such as the one we used in Manuscript 2, the same alternative may signify either a means to prevent a potential loss, or a means to achieve an uncertain gain. For example, from a prevention focus, mitigation (the attractive alternative) may have been understood in terms of the prevention of climate change risks of potential losses (as indicated by most of our participants). This may have made risk defusing by means of CE more probable to secure a non-loss. From a promotion focus, however, mitigation could have been understood as a means to achieve fundamental economic and societal change through innovation. From such a focus, active risk defusing by means of CE may either not seem necessary (e.g., because of a heightened sense of control (Guo & Spina, 2015), or even as a threat to change (the desired goal).

In sum, regulatory focus theory may serve as a framework to help explain the difference between active or passive risk defusing depending on whether the options signify potential gains or potential non-losses.

Psychological research in the climate change domain

The complex challenges posed by climate change can only be adequately understood and dealt with if different perspectives and fields of knowledge are brought together, which can only happen in combined multidisciplinary efforts (cf. Manuscript 1). These efforts also call for a flexible application of methodologies to help apply psychological insights to the relevant issues and questions in a problem-based approach rather than examining isolated psychological phenomena in a mere theory-driven approach.

In a similar vein, other authors have argued that for psychologists to make valuable contributions to the domain of environmental change, their research should be more problem-based than theory-based, less focused on decontextualized intrapsychic phenomena which are examined in isolation from a person's environment or situation, and more actively involved in transdisciplinary collaboration (Clayton et al., 2016). To make their contribution visible, this may also include efforts to integrate psychological theories and results with other social disciplines such as sociology, economics, or the political sciences.

Within the three manuscripts as part of the present work, I have adhered to these principles by employing a more problem-based approach, which was still grounded in theory but did not specifically aim at an advancement of a theoretical construct or the understanding of a specific intrapsychic phenomenon. Rather, I viewed the problem of climate change, and more specifically, of climate engineering, in a contextualized manner with the help of different methodological approaches (mixed quantitative-qualitative, experimental, and non-empirical) and by demonstrating relevant connections to other disciplines (such as sociology).

Conclusion

The idea of climate engineering may constitute the pinnacle expression of a deep-seated need to reduce the uncomfortable feeling of uncertainty associated with prospects of potential harm from an uncontrollable future. Such a need is reflected in our societal ways of dealing with uncertainty (cf. Beck, 2009). Especially against the background of accountability and justification pressures weighing on governments, institutions, and corporations, often involving large financial risks, risk management approaches for almost anything have been suggested, sparking the up-rise of a complete sphere of activity (Power, 2004).

I have proposed that such a societal emphasis on risk management and control may result from a prevention motivation and at the same time may be reinforcing a focus on a prevention motivation in the sense of Scholer and Higgins' self-regulatory model (2011). This is, in the example of climate change risk management, reflected in the fact that the undesirable end state (rise of global average temperature above 2 or even 1.5 degrees C), which we want to avoid reaching, and which we currently regulate our actions towards is overemphasized, while ideas about a desired end state (such as what an energy system could look like which might replace current emission emitting industries) are lacking on a global scale. In a similar way, Mike Hulme proposed: "Rather than asking 'How do we solve climate change?' we need to turn the question around and ask 'How does the idea of climate change alter the way we arrive at and achieve our personal aspirations and our collective social goals?'" (2014, p. 241).

A direct expression of the prevention focus in debates on international legal implications of CE may be the Precautionary Principle, an important subject of political, economic and legal debates around climate policies and policies of the European Union in general (Sunstein, 2005a). The Principle states that if there exists a threat of harm, precautionary measures should be taken also in the absence of scientifically agreed proof of harm. Interestingly, the Precautionary principle has been criticised by legal scholars for possibly preventing or hindering any (technological) innovation because risks can never be entirely ruled out (Sunstein, 2005a,b).

I therefore conclude that it might be crucial for our ability to develop important new solutions, to increasingly shift our focus away from a prevention focus to a promotion focus. This does not mean to discredit and drop any risk management activities in its entirety as both foci (prevention as well as promotion) need to co-exist. In fact, insights from regulatory focus theory have shown that not one of the decision making styles should be generally preferred over the other, because either one might produce better results depending on the task to be mastered (cf. Brockner, Higgins & Low, 2004; Scholer & Higgins, 2011). Also, both foci are assumed to be uncorrelated, that is the adoption of one focus does not preclude the other. The need for security is an understandable need in the face of climatic changes, and needs to be addressed. However, our focus as a society might have undergone a shift too far into one direction, which has caused an imbalance in our aspirations. Therefore, we should realign our focus to allow creative bottom-up solutions to emerge, and to be flexible and open enough for change to occur instead of rigidly holding on to the old ways of dealing with old problems.

Our current predominant focus also has moral implications. A prevention focus is stressed by the perspective that we as humans need to preserve our resources for survival and to prevent the risk of self-destruction. A promotion focus could imply a stronger focus on our human role to care for the planetary biodiversity for its own sake and to create a world much more worth living for future generations than it is now, rather than merely preventing its collapse.

Interestingly, in the literature on how a complex (economic, ecological and social) system is sustainably managed, we can find notions of a balanced partnership between the creation of opportunity (which would be the domain of a promotion focus) and protection mechanisms against destabilization (corresponding to a prevention focus) (Holling, 2001). Therefore, to deal with the complex problem of climate change, it seems to be best to focus both on promotion and on prevention, or to conclude with the words of Holling on the sustainable management of complex systems: we need to be “both creative and conserving” (2001, p. 390).

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Dealing with the uncertainties of climate engineering: Warnings from a psychological complex problem solving perspective

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ABSTRACT

Decision-makers in the context of climate politics are confronted with considerable uncertainties due to the complexities inherent in the relevant natural and social systems. Nonetheless, pressure on decision-makers to find solutions to dangerous climate change is rising due to the inertia in the climate system. Considering these pressures, technological options (climate engineering) have been proposed to counteract the effects of climatic change. However, introducing options that bear their own scientific uncertainties means further adding to the complexity of the situation. By adopting the psychological perspective of complex problem solving research, we analyze one frequently neglected source of uncertainty with regard to climate engineering: errors of the political problem-solver in his interaction with the situational demands of complex problems. More specifically, we examine the psychological sources for human error that are common in dealing with the uncertainties implied in this type of problem. We will conclude from the complex problem solving perspective that a consideration of climate engineering in the context of climate change can provide a dangerous illusion of controllability.

1. Introduction

Decisions in the context of climate politics are commonly regarded as decisions under uncertainty [1], even more so with the introduction of an additional possible strategy: the intentional technological intervention in the global climate system on a planetary scale (*geoengineering* or, more adequately, *climate engineering*, hereafter shortened to CE). From a psychological perspective, we can conceive of this decision situation as a complex problem because very generally speaking, complex problems require dealing with (psychological) uncertainty [2]. Therefore, in the present paper, we wish to stress the psychological problem solving perspective: in order to do so we will first give an introduction to the concept of complex problems and how it applies to the CE situation. We will proceed with the implications for the problem solver. We will put emphasis on explaining human errors and failures in the area of decisions under uncertainty given that this decision type is closely linked to human interaction with complex problems. These errors and failures can be considered in themselves as a new source of uncertainty that adds to the complexity of the situation. We will conclude from the complex problem solving perspective that a consideration of CE in the context of climate change at best offers an unjustified illusion of controllability.

2. Why finding a solution to climate change means solving a complex problem

Having a problem means having a goal (e.g., reducing the impacts of climatic change) while being uncertain about how to reach it. Solving a problem implies a search

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process for means with which to overcome the barrier imposed by the problem. In the case of climate politics, possible means to achieve the goal could be: (a) mitigating CO_2 emissions, (b) adapting to the consequences of climatic change, (c) deploying technological options (i.e. CE) or a combination of these. What is the central aspect that imposes barriers on the problem-solver within this context? In order to control the complex environment around them, problem-solvers need to reduce the uncertainties involved in the problem [2,3]. These uncertainties stem from certain characteristics of the problem that will be outlined in the following.

From a problem solving perspective, a situation in which a strategy to deal with climate change has to be chosen (e.g., a decision for or against a deployment of CE), can be described as a complex problem. A complex problem is said to occur when the following characteristics of it complicate the finding of a solution due to an enhanced level of uncertainty [4,5]: (a) the number of elements relevant to the solution process is large (complexity) as well as highly interconnected (connectivity), and (b) the system is dynamically changing over time (dynamics). In addition, (c) neither the decision structure nor its dynamics are fully disclosed to the actor (intransparency). Finally, (d) goals are not easily set: in dealing with a complex problem, a decision maker is confronted with a number of different goal facets that have to be weighted and coordinated (polytelic situation).

Let us say that, for instance, a nation state is faced with extreme weather phenomena such as storms or droughts that are attributable to climate change. The severity of these weather events threaten crop yields and thus the food supply, which results in an enhanced pressure on the government to decide on the deployment of a CE technique such as stratospheric aerosols [6]. The government of this state is now faced with a complex problem as we can show by reference to such a problem's five characteristics:

(a) *Complexity.* The number of items of information that need to be taken into account to come to an adequate solution is extremely large if one does not only include the physical variables (Is this specific technique effective enough to reduce the occurrence of extreme weather events? What are the risks that can be expected?), but also the psychological and social aspects (How will the voters of the government react to such a decision?), the economical aspects (Are the costs of deployment justified when compared to the benefits and risks?), and political or legal aspects (As the effects of this option will be global in extent, how can a consensus be reached with other states? Will other states eventually feel threatened by a deployment?).

(b) *Connectivity.* CE interacts with an already intensely connected network of variables: not only would such an option influence the already highly interconnected variables of the climate system, such as temperature, precipitation patterns and the ozone layer, it would also interact with, for example, social systems. For instance, the fear of anticipated negative side-effects of a deployment could lead to public mobilization processes in neighboring states which means that even in the (unlikely) absence of such negative side-effects the potential for conflict is expectably high.

(c) *Dynamics.* CE aims at influencing the intricate future trends of the climate system. In case of a deployment of stratospheric aerosols as described in our exemplifying scenario, the future trend with the targeted intervention would be hard to predict since the aerosols would curb temperature rise but would not alter the amount of CO_2 in the atmosphere. However, this is a previously unexperienced scenario.

(d) *Intransparency.* Not all manifestations of relevant variables and their interconnections can be directly assessed or observed (e.g., many of the climate system's intricacies still are not perfectly understood or only reproduced approximately in climate models) which is why the problem structure is not completely transparent to the problem solver. This also means that, for example, possible unintended consequences of a deployment of stratospheric aerosols could not adequately be determined in advance (e.g., with the help of experimental simulations).

(e) *Polytely.* As a deployment of stratospheric aerosols would have global effects, yet would involve regional variabilities, there would be winners and losers. Therefore, the goals and interests of other stakeholder groups and nations have to be considered in addition to the individual's goal prioritization process in the face of multiple and partly conflicting goals. In fact, different regional interests with regard to the effects of a CE deployment are one of the major sources of missing consensus.

In summary, these five characteristics of a complex problem imply uncertainties for the problem solver, a barrier that has to be overcome. We conclude, then, that CE within the broader climate politics context can be regarded as a prototype of a complex problem.

3. Psychological complex problem solving research in the context of climate politics

If this is the case, can we also conclude that it is useful to draw on psychological complex problem solving research in the context of climate politics? In psychological problem solving research, insights into the question of how individuals deal with complex problems mostly stem from the use of computer-based simulation scenarios [7]. In these scenarios, subjects are in charge of a complex situation for certain periods of time. Such situations can involve managing a company, dealing with a bush fire catastrophe, or finding a solution to the financial crisis in Europe [8]. In order to learn about the effects of different conditions (e.g., degree of complexity; type of semantic embedding; availability of previous knowledge), they are experimentally manipulated and the decision-making process is analyzed afterwards. Insights from this type of research can be relevant for climate politics because important characteristics of the simulation tasks resemble the situation we face in the context of climate politics.

The complex and dynamic environments in these studies need to be controlled by the participants. This requires them to make decisions in consecutive rounds. In other words, rather than taking one single decision in order to complete the task, the participants need to make a series of interdependent decisions over time. This not only means that they are confronted with uncertainties inherent in the situation and experienced on a psychological level. It also means that they need to remain capable of acting despite of these uncertainties. They are required to act under uncertainty or more specifically, they need to take decisions under uncertainty. All of these aspects are equally relevant in climate politics.

However, one could argue that it is objectionable to generalize from laboratory findings with non-experts to experts in the context of climate politics. One could also argue that, since political decision-makers can (a) rely on expert advice as well as (b) on computer-aided models and (c) are used to taking decisions under uncertainty, they would not be susceptible to the same errors as lay people (e.g., participants in psychological experiments) are.

With regard to (a) expert advice, Philip Tetlock [9] has demonstrated in his long-term study that expert political predictions often are unimpressive and prone to failure, which does not support the assumption of expert advantages under conditions of uncertainty and in complex environments. It becomes clear why one would not assume significant differences between experts and novices as both groups try to control complex dynamic environments that also experts only have very little experience with (e.g., the climate system). This is because one has to (c) take decisions under uncertainty within this type of environment while expertise is characterized by a shift from a high level of experienced uncertainty to a reduced level of experienced uncertainty: “Both experts and novices are susceptible to biases, particularly under highly pressurized conditions […], or because there simply is not enough information to decide on, or to predict, the outcome in the environment” [2]. Clearly, there is a high level of experienced uncertainty among experts associated with a decision in the context of CE as one alternative in the fight against climate change, since relevant information is, and will likely always be, lacking [10].

So far, we have established that decisions under uncertainty are susceptible to errors regardless of expertise. With regard to (b) it is certainly true that computer-aided models advance our understanding of specific issues. However, the climate models we base our decisions on are not perfect representations of reality and are prone to errors themselves. We will come back to this point in the subsequent sections. We conclude that, as political decisions are commonly made on the basis of certain predictions and strategic forecasts and thus are commonly decisions under uncertainty, errors made by novices in complex and uncertain environments, are comparable to errors made by political experts in similar environments.

4. Implications of the complex problem solving perspective for the problem solver

We have argued that a decision in the context of climate politics is a decision under uncertainty. The uncertainties a decision-maker is confronted with in this context result from the characteristics of the problem structure: complexity, connectivity, intransparency, dynamics, and polytely.

What are the consequences for the problem solver, be they a scientist, a politician, or the general public? The different aspects of complex situations have specific demands to the problem solver: (1) complexity requires the reduction of information by means of model building; (2) intransparency requires creating transparency by means of information retrieval; (3) dynamics require the control of systems on the basis of predictions of future trends; (4) polytely requires solving goal conflicts by means of a goal setting process including value decisions and compromises.

We argue that all of these demands amount to the fact that the problem solver has to make decisions under uncertainty because these task characteristics are sources of uncertainty that are then experienced on a psychological level [2] as a “…sense of doubt that blocks or delays action.” [11]. This action-blocking sense of doubt is experienced because (1) in the model building process, information has to be reduced, (2) information that is required to create transparency can vary in its relevancy and quality, (3) predictions of future trends are made based on the models as mentioned in (1), and (4) value decisions and compromises between different stakeholder groups that might have been accepted in the face of a goal conflict are not necessarily stable and adequate. Human problem solvers are prone to errors in all four fields: errors in model building, errors in information retrieval, errors in prediction and control, and errors in goal setting.

With the help of an example commonly referred to by scientists in the field of CE, we will establish that a problem in this context features the characteristics complexity, intransparency, dynamics, and polytely. For each of these characteristics, we will exemplify the experienced uncertainties and common errors that result from a human problem solvers’ interaction with them. We will discuss each of the four dimensions separately for the reason of clarity. In practice, they can hardly be separated, however, as the demands for the problem solver resulting from the dimensions are intertwined [12].

4.1. Example of a CE related complex decision

To illustrate our points, we will consider an example that is commonly referred to by CE scientists: Political decision makers need to decide about the budget that will be spent on CE related research programs. This can be seen as an intervention to gain control over the climate situation. According to Bellamy and colleagues [13], a common line of thought or framing that is found in the peer-reviewed and gray scientific literature on CE is the following: Mitigation policies are likely to 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. The implementation of a CE technique, and more specifically one of the so-called Solar Radiation Management (SRM) techniques, is the only presently known way to quickly curb the effects of such a climate emergency. This is because SRM techniques aim at blocking incident solar radiation hereby offsetting global warming. Thus, these techniques represent a temporary back-up plan in a future climate emergency scenario that would enable politicians and scientists to work on a more sustainable solution to climate change. Among the more intensively discussed SRM techniques is the stratospheric aerosol option which aims at blocking the radiation by means of tiny sulfur particles that are injected into the higher atmosphere [6]. Given the large time frames still needed to research and develop SRM techniques, a decision for spending money on the development of SRM to have it available in the future needs to be made now. An optimal decision framework from an economic perspective for this situation has been explored in a (simplified) model by Moreno-Cruz & Keith [14].

4.2. Connectivity as a characteristic of a CE related complex decision

A CE deployment would interact with an intensely connected network of variables in the climate system as well as relevant political and social systems. In our example, we focus on the seemingly much simpler decision whether to fund a research and development program of one specific SRM technique (stratospheric aerosols) to have it available as a back-up plan in the future. However, the decision that is made today with regard to research and development is not independent of a future decision for or against deployment as strategic economic deliberations demonstrate [14]. Facing a *complex* situation means that a range of highly interconnected variables needs to be considered. In taking a decision for allocating parts of the available budget on an SRM research program, our decision maker is faced with the interconnectedness of the available climate strategies mitigation, adaptation and CE (SRM). This is best exemplified by the so-called *moral hazard* problem, a systemic response comparable to a rebound effect, that refers to the idea that the prospect of having a fast and seemingly simple technological solution like CE available in the future could undermine present mitigation efforts [15] as well as its counterpart (the possibility that this very notion could scare the public into heightened mitigation efforts [6]).

However, the decision maker also needs to take the anticipated interactions of the method he wants to support (e.g., the stratospheric aerosols) with the climate system's variables into account, even if he does not intend to implement this technique at this point in time. This is because it would be a waste to spend limited resources on a technique that could already be ruled out as a potentially effective means to counteract detrimental climate change effects.

4.2.1. Human error as a result from connectivity

The task of dealing with the interconnected variables as illustrated in the preceding section transcends the capacity of human memory. Therefore, our decision maker needs to draw on computer models and simulations that are run by climate experts. Apart from the fact that this reliance on outside expertise poses its own challenges regarding effective communication [cf.[16]], there are restrictions set by limited computational power, human ignorance of important factors, or simply a lack of available data, which render the models imperfect. As a result, the human problem solver is likely to be confronted with the uncertainty whether a future targeted intervention with stratospheric aerosols in case of an emergency would be effective enough [cf.[2]], as climate changes are not likely to be entirely reversible with the aerosol technique [17,18], anticipated outcomes are highly dependent on a multitude of input variables such as aerosol size, altitude of injection, or aerosol material [19,20], and anticipated outcomes are likely to be regionally diverse so that, for example, a climate crisis in the tropics could be avoided but not a polar crisis [17,18].

Even without reliance on scientific climate models, the mind of our decision maker obviously is no “blank slate” which means that he has a mental model of his environment, of the complex problem he wants to solve that necessarily reduces information [21]. Among the typical errors human problem solvers face when reducing information to build mental models to deal with many largely interconnected variables, are the ignorance against *side effects* [22,23], and *tipping points* [24]. As a result, the decision maker is likely to experience uncertainty with regard to his ability to adequately predict the state of his environment.

Accumulated *side effects* can significantly disrupt the intended main effects. In this context the term *policy resistance* refers to the “…tendency for interventions to be defeated by the system's response to the intervention itself.” [25] Sterman argues that policy resistance is a common phenomenon due to the boundaries of our mental models. Let us assume that, in our example, the problem solver decides to invest a certain amount of the climate budget into the research and development of the strategy of stratospheric aerosols. The research program includes a field experiment. His intended main effect is having the option available in a future emergency scenario. However, due to coupled processes, one action has rarely only one effect: he has not anticipated the strong reactions of the people who reside near the site of the field experiment. The locals demonstrate and stop the field test. But this is only one outcome in a chain of effects that accumulate in ultimately leading to the decision maker's resignation from his position because he has lost the confidence of his voters. His successor does not consider CE again. This example shows how unanticipated side effects can deeply disrupt the intended main effect.

Complex dynamic systems, ranging from financial markets to ecosystems and the climate, can have tipping points at which a sudden shift to a contrasting dynamical regime may occur [26]. The prediction of such tipping points is very difficult, even with complex computer-aided models. Therefore, the search for early warning signals is essential which is why the endeavor to find indicators for a system that approaches a critical threshold becomes increasingly recognized [27]. Potential tipping points complicate our political decision maker's ability to assess the likelihood as well as the severity of a future emergency scenario for which he wants to prepare.

4.3. Intransparency as a characteristic of a CE related complex decision

Our decision maker is confronted with the fact that not all variables, which are relevant to his decision are known to him. Furthermore, the manifestations of the known variables are not necessarily established, or only by approximation. Latent variables often are estimated on the basis of inferences from observations. This is certainly true for the climate system. Climate scientists have to historically reconstruct temperature from tree rings or glacier geometry [28] or infer the permafrost's sensitivity to future global warming from past historical reactions to temperature changes by analyzing relict ground ice [29]. But intransparency can also arise from the fact that a decision maker has to rely on outside expertise: not everything a problem solver can possibly know of is communicated to him by scientists or other experts, not due to intentional concealment but because time is limited and complex information needs to be condensed in some way (on the issue of adequately communicating climate related issues to political decision-makers, see Ref. [16]). Furthermore, there might be intransparency with regard to the preferences of different stakeholder groups, among them our decision maker's voters.

4.3.1. Human error as a result of intransparency

The human reaction to intransparency is experienced (psychological) uncertainty, which in turn provokes fear (and other negative emotions) and which usually leads to a more intensive information search [30]. Thus, our emotional state serves as a signal to guide our attention to problems and to regulate our behavior answering these problems. As we retrieve more information about the situation, thus reducing the experienced uncertainty, we should gain confidence and feel better. However, we have established that the connectivity and complexity of the situation necessarily requires the reduction of information to form an adequate model (see Section 4.2.1). This means that the identification of relevant information as opposed to irrelevant information is a crucial aspect of a successful interaction with complex systems [31,32]. For example, it will be less relevant for our decision maker to know if the mayor of a small town in a neighboring country supports his plans on funding SRM research, than to know the position of his country's tax payers. As a consequence, our decision maker is confronted with a considerable amount of uncertainty with regard to the relevancy and completeness of the information he bases his decision on.

However, a piece of information that is relevant for the decision is not necessarily reliable either because it contains errors or it is based on erroneous assumptions. For example, the Special Report on Emission Scenarios (SERS) of the IPCC specifically deals with four different scenario groups developed by Nakicenovic and Swart [33]. These emission scenarios are based on different assumptions concerning the demographic, societal, economic, and technological changes that the world might face in the future. Climate Change Scenarios based on these four different sets of assumptions necessarily yield different prognoses [34]. Some of these assumptions and their corresponding scenarios will necessarily prove to be erroneous. However, this is the best available data our decision maker can get at this point in time.

In climate change, the issue of the time frame or quantity of information is of great importance when assessing the reliability of information: Is the time period long enough that we consider to differentiate the signal (anthropogenic climate change or the effects of an SRM implementation) from the noise (natural variations in the global climate)? For example, if our decision maker decides to test the stratospheric aerosols in the field to assess the potential positive effects on temperature as well as the risks before full-scale implementation, he would need to separate the effects from natural fluctuations as well. Therefore, with such a test, a trade-off decision would be needed between the duration of it, the magnitude of it and the uncertainty of any estimated climate response: “Accurate estimates at a local scale would require greater time or larger forcing”. If our decision maker wants to restrict the magnitude of the test (for example, because with larger forcings, the line between field test and full implementation becomes blurry, possibly also threatening his relations with neighboring states) he would want to plan many years ahead: “…accurate estimates could require several decades or longer” [35].

In summary, our decision maker needs to assess whether the information he bases his decisions on is sufficient, relevant and of good enough quality or if additional or different information has to be gathered, all of which adds to his experienced uncertainty and the possibility for failure.

4.4. Dynamics as a characteristic of a CE related complex decision

Our decision maker needs to deal with an environment that constantly changes with and without his interference. The inertia in the climate system is responsible for long time delays, contributing to the fact that these changes do not occur in a rapid manner. This means that neither the decision makers nor those who will be affected by the decisions are constants in our equation: Our political decision maker who decides the direction we take today in climate politics (e.g., over the funding of research programs on stratospheric aerosols) is not necessarily the one who will be affected by this direction, nor the one who is going to decide over the strategies in the future (e.g., over a possible deployment of the stratospheric aerosol method in case of a climate emergency). Thus, the dynamics of the situation give rise to questions concerning, for example, intergenerational justice and the question what the preferences of future generations might look like [36–38].

4.4.1. Human error as a result of dynamics

Complex dynamic systems require making predictions about future events to exercise adequate control over them. Based on projections of the climate characteristics we can expect in the future, our problem solver takes decisions to influence the situation. Thus, these predictions affect his ability to control. Furthermore, to adequately predict changes of the environment with and without interventions, he needs to draw on his mental model to support his decisions, which necessarily has to reduce information (see Section 4.2.1).

Because, as we have already outlined, both mental and computer-aided models are not reality and have their shortcomings, the problem solver needs to assess the validity of the predictions based on these models. This is especially true given the long time perspectives in the climate change problem as with larger time frames, the vagueness of predictions increases [39]. Coming back to the example of an SRM field test, if our decision maker decides to carry it out only for a short duration, effects would need to be extrapolated from the effects found during the time frame of the test, yielding significant uncertainties [35]. Thus, the uncertainties that are associated with the climate models he bases his predictions on make it more difficult to control the complex system. More specifically, difficulties as well as errors in prediction represent a source of uncertainty that impedes adequate control.

Where do these difficulties stem from? Regarding his mental model, our human problem solver will have the general tendency to base predictions on simplified linear models that face difficulties when dealing with nonlinearities, cyclic processes, long time delays, and stock and flow principles [4,40–42]. The dynamics of a complex system require learning to improve predictions [43]. It is possible for the human mind to learn to effectively control complex environments [44,45]. However, certain preconditions have to be met to enable adequate learning: Learning requires feedback [21,46] while frequent feedback in fast consecutive cycles (with short decision delays) is better suited than less rapid and less frequent feedback response, which is why more frequent policy strategy interventions to improve learning in the context of climate politics have been suggested [47]. However, with climate change, there are no fast feedback responses. Therefore, one needs to rely on simulations.

Of course, feedback can also vary in its quality [22]. This is similar to the issue of the *quality of information* that we base our decisions on and to the *intransparency* dimension of a complex problem: as the feedback we observe in the environment often is ambiguous and intransparent, we have to infer from these observations the underlying variables: For example, if our decision maker, after giving funds to his SRM research program, observes that the companies in his region are not meeting their CO_2 emissions targets anymore, he might attribute this failure to their managers' reduced motivation to do so because of them relying on the prospect of a climate emergency insurance option, even if the reason might lie elsewhere. For example, the companies' managements might have been waiting for the upcoming annual United Nations Framework on Climate Change meeting's negotiation results with regard to long-term emission targets.

4.5. Polytely as a characteristic of a CE related complex decision

Our decision maker is confronted with several goals: he wants to find a solution to climate change in the short and in the long run, he wants to reduce costs, he wants to stay on peaceful terms with neighboring states, and be re-elected at the end of his term of office. All of these goals can be further subdivided into subgoals, for example "finding a solution to climate change" can mean a multitude of things: working with other countries on global treaties to reduce emissions, taking part in carbon trading, promoting climate programs to change the behavior of citizens, reducing the costs of climate damages in the long run, preparing for a possible climate emergency in the future etc. The decision for allocating funds to an SRM research program could be expedient to prepare for a possible climate emergency in the future but it might be conflicting with regard to his re-election or with his behavior change programs (as the notion of an "insurance" against dangerous climate change effects could undermine people's motivation to change their behavior to reduce emissions). The polytelic nature of this situation necessitates setting up priorities and balancing conflicting values and goals. Therefore, in a first step, goals need to be identified (this can be confusing enough for the individual as values have to be prioritized in the face of a hierarchy of numerous goals on different levels of abstraction [48]). However, as soon as our decision maker has identified his own goals, the latter still have to be negotiated with other affected individuals or groups in a second step. Concerning this large-scale emergent technology, what level of risk does a society as a whole wish to accept when balanced against the risks of climate change [49]? Are the stratospheric aerosols an acceptable method, even in case of an emergency, as they are likely to introduce new risks to the environment, for example ozone depletion [50]? Can CE be brought into accordance with a nation's values as well as its cultural and natural belief systems, is it morally justifiable [51]?

4.5.1. Human error as a result of polytely

Goals can be shifting in the light of new information or because the conditions in the environment have changed, for example, the preferences of stakeholders. However, this adds to the experienced uncertainty of a political decision maker with regard to his ability to predict and control his environment [cf.[2]] since the stability of any compromise within his nation and between nations largely depends on the stability of the stakeholder groups' interests and goals. Psychological research with complex dynamic systems has shown that people are more successful in the long-term control of these systems with an open-minded learning attitude: the pursuit of a non-specific goal such as to learn as much as possible about the system helps provide the decision maker with the flexibility needed to cope with changing demands of the system and thus changing goals [52–54]. Thus, a more specific goal such as the preparation for a climate emergency does not necessarily allow for this flexibility when the decision maker focuses on it.

The goals of a decision maker largely depend on the mental model he has of the problem: if he views the climate change problem as a risk management issue as opposed to an economic efficiency issue [49], his goals are likely to shift accordingly. This highlights how the different characteristics of a complex problem relate to each other: The connectivity, intransparency, and dynamics of the situation impede the building of an adequate mental model which in turn influences the goal setting process. This also underlines the importance for a decision maker to constantly update his mental model on the basis of new information and feedback hereby being open for the possibility to reframe the entire problem rather than to simply integrate new knowledge into the existing model. This type of learning which implies the open-mindedness to challenge existing problem framings, is emphasized by Sterman [21] as an important way of dealing with complex systems. He argues that this type of learning requires the use of simulations for decision makers as well as training of decision makers in scientific reasoning skills.

In addition to this, an open learning attitude can be promoted by the integration of different perspectives. This can apply to the integration of the perspectives of multiple scientific disciplines or the integration of different stakeholders' perspectives. It certainly is essential that the complexity of CE research is dealt with in terms of multiple scientific disciplines to allow for an evaluation of the potential benefits, the risks and uncertainties of CE according to the principle of multiperspectivity [55,56]. This is necessary because adopting a complex system's perspective we argue that single perspectives often are too fragmented to adequately understand the intricacies of a system. Moreover, simply aggregating the different perspectives does not necessarily lead to a correct understanding of the system [57]. With regard to the goal negotiation process between stakeholders, a participatory approach involving important stakeholders seems to be appropriate because next to the fact that multiple perspectives likely converge to more appropriate solution proposals, those solutions arising from a transparent participatory process might also be more acceptable to a broader community than single-perspective solutions [58–63].

5. Discussion

By adopting the complex problem solving perspective, we were able to identify and systematize the theoretically relevant uncertainties together with common areas of failure that arise from the interaction with the characteristics of a CE related political problem. More specifically, we have argued that human problem solvers face difficulties in model building, retrieving the right amount of relevant items of reliable information, predicting future trends, as well as selecting goals, all of which are basic prerequisites to controlling a complex environment. Climate scientists and experts in CE related fields have argued before that human error in dealing with complex systems should be regarded as one important non-technical risk factor in the emergence of CE [64]. Psychological research in complex problem solving further substantiates this notion because by human errors in model building, information search, prediction, and goal setting, uncertainties are introduced into an adequate decision-making process regarding CE technology.

However, does this mean that, from a psychological complex problem-solving point of view, the risk of human error outweighs potential benefits of CE? Might there be any hope to overcome the different sources of error and failure in complex problem solving and in decision-making under uncertainty, respectively? The uncertainties we are faced with in our climate models and thus also in the future scenarios upon which political decisions are based, are continuously reduced, for example, with the help of better resolutions, enhanced computational power, or new insights into important factors of influence. However, they are unlikely to be ever completely resolved and new uncertainties might emerge as our understanding of the relevant systems is advanced.

Is it hybris, then, to think humans could safely intervene in the climate system, turning it to their advantage? We have established that learning is the only way of coming to terms with the uncertainty in the management of complex dynamic systems. Therefore, as an important precondition for any problem solver to make effective decisions in the context of CE is an awareness, an active scrutinizing and constant updating of his mental model of the problem structure. Closely linked to this is the need for effective communication strategies between scientists, political decision makers as well as other stakeholders that involve simulation techniques and mapping tools [16], and an open-minded attitude with the true willingness to learn on all sides.

Moreover, to enable learning, goals as well as their underlying models should not be too narrowly defined: framing the issue of climate change around catastrophic scenarios, therefore focusing on the goal of climate emergency preparation should not prevent a decision maker from exploring and learning about other options such as carbon capture and storage or adaptation strategies. A focus on too narrowly defined goals could lead to premature (intellectual) lock-in to any specific technology [cf.[65]].

However, in the CE context, we are faced with multiple situational characteristics that hinder effective learning: decade-long time delays do not allow us to obtain immediate feedback from our actions in fast learning cycles, intransparent processes, and process couplings hinder the unambiguous attribution of cause to effect, ethical considerations as well as the globality of effects make real life experimentation impossible and reliance on imperfect models a necessity. Under these difficult learning conditions, aspirations to adequately predict and control a system, must be exaggerated. However, CE technology specifically aims at controlling a system.

Members of the scientific community have, of course, acknowledged the risks and uncertainties associated with CE and have fundamentally challenged the idea of trying to interfere with the global climate system by technological means [64]. However, common justifications of pursuing the idea despite all objections involve the argument that the overall goal of CE is not the control of the climate system (as it is acknowledged that this is not possible) but rather that CE might be the lesser evil compared to a future of catastrophic climate change effects and that therefore future generations need to be provided with the option of it [66]. The superficial attractiveness of this argument has already been challenged from an ethical point of view [67]. The complex problem solving perspective adds to these reservations by the following rationale: Even if the case for CE as a long-term strategy of controlling the climate system is not made, by adopting a mental model following these arguments, the impression is made that the climate system can be controlled at least in the short term until more sustainable solutions have been achieved, for example, by mitigation strategies. This in turn enhances the perceived controllability of the system, at the same time reducing psychological uncertainty. We argue that this perceived controllability due to a simplified mental model of the situation (along the lines of “if the worst case happens, we will have a plan b available”) might have a reassuring effect on political problem solvers, but is illusionary.

The present article has outlined the reasons for our claim: Let us assume that political problem solvers adopt an open learning attitude and perfectly communicate with the experts they rely on, thus having an updated mental model of the problem structure at their disposal, allowing them to (a) base their decisions on the best available predictions and (b) to set adequate goals and achieve stable compromises with stakeholders. Even under these idealized conditions, we are still faced with the so-called “unknown unknowns” [68,69]: one unforeseen process can significantly disrupt all well-intentioned actions. However, our analysis of the characteristics of a CE related policy problem has shown that erroneous decisions due to inaccurate information, mental models and/or goals are not the exception but can be expected and idealized conditions can therefore not be assumed. Moreover, as our ability to learn to control the complex climate system is dramatically reduced by its inherent characteristics, the complex problem solving perspective severely challenges the illusory assumption of CE being a justifiable control strategy even in the short run and in the case of a climate emergency.

6. Conclusion

The present article presents human errors in the interaction with a complex problem of taking uncertain policy decisions with regard to CE technology. By such an adoption of the complex problem solving perspective, these errors can be systematized and practical implications for decision-making can be derived. However, as we have established, dealing with complex dynamic systems requires learning, which is severely complicated by the characteristics of the climate system. Under these conditions, control is likely to be corrupted by the limitations of the human mind. Thus, the psychological complex problem solving perspective calls for a cautious approach to arguments that frame CE as an option of temporary emergency control because such a control is illusionary.

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

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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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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/bher.

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	—	

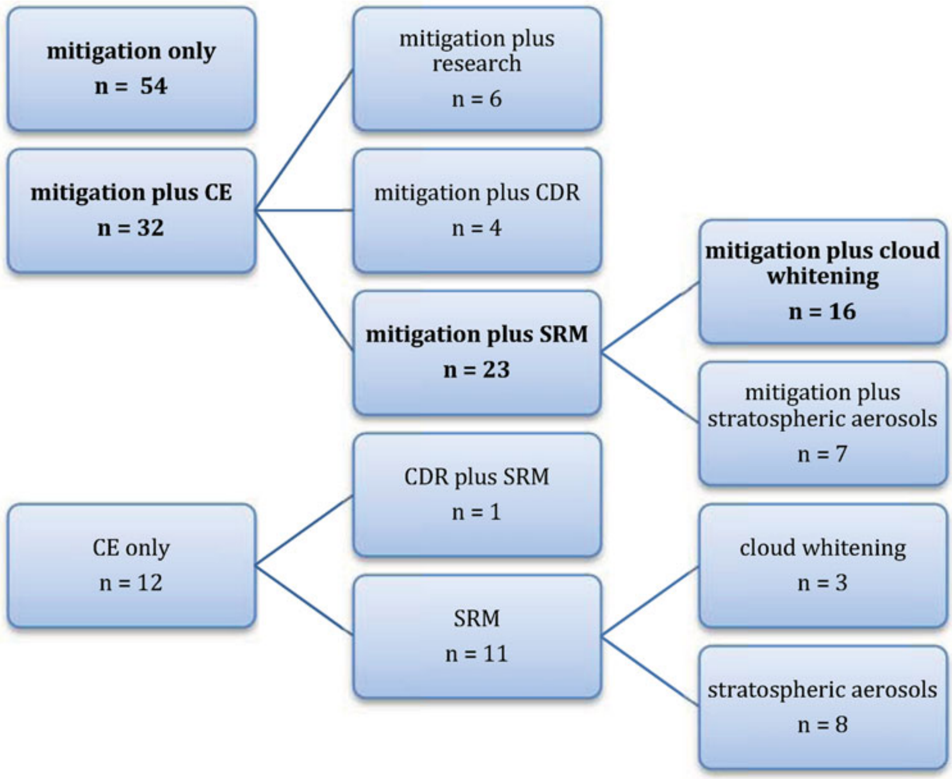

Figure 1. Overview of decision types. The most common decisions are printed in bold type. Note that the subcodes for *mitigation plus CE* do not add up to n = 32 but to n = 33. This is due to the fact that one participant decided for *mitigation plus one CDR option plus one SRM option. Mitigation plus 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

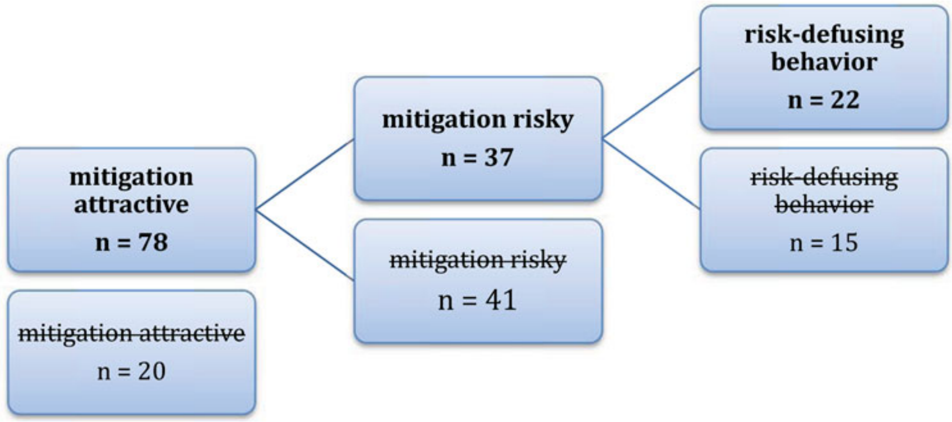

Figure 2. Frequencies of process variables "mitigation attractive," "mitigation risky," and "risk-defusing behavior." The frequencies of the crossed-out variables indicate the amount of participants who were not coded with the respective process code. Of the 20 participants who were not coded with "mitigation 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

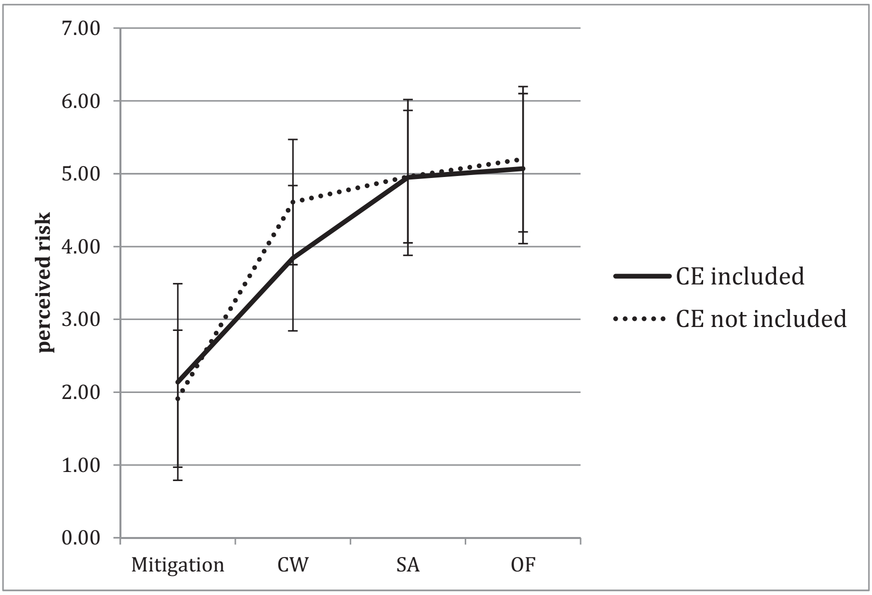

Figure 3. Mean perceived risk of the four options mitigation, cloud whitening (CW), stratospheric aerosols (SA), and ocean fertilization (OF), separately for those participants who included CE into their decision (CE included) and those who did not (CE not included). Error bars represent standard deviations.

$\eta^2 = .15$ 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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Climate Change and the problem with overconfidence: The difference between perceived and actual understanding

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Abstract

Empirical results linking understanding of climate change to relevant outcome variables such as concern or willingness to take action are inconclusive, with some studies finding positive, and others mixed or even negative effects. We propose that contradictory results can be explained by subjective versus objective measures of understanding, and more importantly, the systematic difference between the two: overconfidence. In a two-alternative forced choice paradigm (N=264), participants read original excerpts from the 2014 IPCC report's Summary for Policymakers, and objective and subjective understanding was assessed. Results show that (i) people on average overestimate their true understanding of climate change information; (ii) subjective understanding is systematically miscalibrated as a function of actual understanding in that overestimation increases as actual understanding decreases; and (iii) higher overconfidence is related to a lower willingness to sacrifice personal gains to contribute to mitigation, even when controlling for actual understanding. We conclude that subjective understanding is not tantamount to objective understanding. Implications for climate communication are discussed.

Keywords: overconfidence, Dunning-Kruger effect, climate change, objective understanding, subjective understanding, public engagement

Accurate world knowledge is vital as it allows us to understand, predict, and control the environment, be it to effectively manage the planet's resources or to mitigate the risks of climate change (CC). Inaccurate world knowledge, in contrast, can lead to erroneous conclusions, faulty predictions, and unfounded decisions. Particularly devastating effects may result from inaccurate knowledge when paired with high subjective confidence in its accuracy: People are ready to act on the grounds of knowledge they should have little confidence in (Shiller, 2015). Unfortunately, overconfidence--the subjective overestimation of one's true understanding, control over events, or invulnerability to risk--is one of the most prevalent human biases (Alba & Hutchinson, 2000; Armor & Taylor, 1998; Benoit, Dubra & Moore, 2015; Keren, 1991; Mamassian, 2008; Moore & Healy, 2000; Simons, 2013; Weinstein & Klein, 2002). Albeit these positive illusions confer important advantages by enabling individuals to "distort reality in a direction that enhances self-esteem, maintains beliefs in personal efficacy, and promotes an optimistic view of the future" (Taylor & Brown, 1988, p. 204), and overconfident individuals were probably favored evolutionarily in the past (Johnson & Fowler, 2011), overconfidence can also lead to unrealistically positive expectations, risk blindness, collective hubris, and costly disasters. In fact, research suggests that overconfidence contributed to the Vietnam war, the war in Iraq 2003, the financial crisis of 2008, and the Deepwater Horizon oil spill 2010 (Camerer & Lovallo, 1999; Johnson, 2004; Johnson & Tierney, 2011; Johnson et al., 2006; Malmendier & Tate, 2005; Sylves & Comfort, 2012; Tuchman, 1984). In the present article, we show that (1) people tend to be overconfident about their understanding of one of the arguably biggest threats of our time as well: global climate change; and that (2) higher overconfidence in one's understanding is associated with lowering willingness to sacrifice egoistic rewards to mitigate climate change independent of actual understanding.

Studying overconfidence

The most common approach to measuring the calibration of subjective knowledge is the 2-alternative forced choice paradigm (Moore, Tenney & Haran, 2015). Participants answer whether a statement is correct or incorrect (e.g., ”Alcohol kills brain cells”; Parker & Fischhoff, 2005), and indicate their confidence that they answered correctly (e.g., on a 50%-100% scale). Overconfidence is quantified as the signed difference between accuracy and confidence. When data from these experiments are visualized in calibration curves plotting confidence against accuracy (e.g., Yates, 1990), the typical result is that average calibration deviates considerably from perfect calibration (the diagonal), specifically, that the calibration curve is too flat: Participants tend to be too confident in their degree of accuracy.

In addition to investigating the degree of miscalibration of subjective estimates of knowledge (overconfidence as an outcome), there is a multitude of research demonstrating the importance of overconfidence as a predictor of real-world correlates, particularly in areas characterized by high amounts of uncertainty such as managerial (Russo & Schoemaker, 1992), medical (Berner & Graber, 2008), or political decision-making (Johnson, 2004). Overconfidence was found to be associated with reduced perceptions of risk and higher risk-taking propensity (Broihanne, Merli & Roger, 2014), increased feelings of being in control (Stotz & von Nitzsch, 2005), and increased tendency to overlook potential problems (“blind spots”; Ng, Westgren & Sonka, 2009). As a consequence, overconfidence can also be associated to suboptimal decisions. Venture capitalists’ overconfidence was found to be negatively associated with decision accuracy, the success of the funded company (Zacharakis & Shepherd, 2001), investors with higher overconfidence trade more frequently but achieve lower returns (Park, Konana, Gu, Kumar & Raghunathan, 2010), and physicians tend to underestimate the possibility of their diagnoses being wrong, leading to premature narrowing of the choice of diagnostic hypotheses, and diagnostic error (Berner & Graber, 2008). Drawing on these findings, the conjecture that we would like to put forth in this article is that overconfidence in one’s understanding of climate science may be linked to perceiving

CC as less risky, as less of a problem, and consequently, to a reduced willingness to contribute to mitigation.

Overconfidence and Climate Change

Subjective estimates of understanding (e.g., “How much do you feel you know about…?”) are not only less reliable compared to objective measures (e.g., multiple-choice tests). Subjective estimates are also biased. Subjective measures tend to be systematically mis-calibrated in that the discrepancy between subjective and objective measures is a function of the level of actual understanding (Raju, Lonial & Mangold, 1995). Ironically, people tend to be overconfident when their actual understanding is low, and people are likely to be better calibrated, or even underconfident when their actual understanding is higher; a phenomenon termed Dunning-Kruger-effect (Dunning, 2011; Schlösser, Dunning, Johnson & Kruger, 2013; Simons, 2013). Several explanations exist for why this effect occurs, both psychological and statistical. The classic explanation is that due to domain-specific misbeliefs or knowledge gaps (“unknown unknowns”), people are unaware of the scope of their ignorance, and hence a *double-curse of ignorance* arises: The lacking knowledge itself, and the lacking ability to recognize it (Dunning, 2011). Overconfidence was also shown to arise from imperfect information processing, such as selective dismissal of (unpleasant) information (for a review, Sanbonmatsu, Posavac, Kardes & Mantel, 1998), confusion of heuristical inferences with remembered facts (Block & Harper, 1991), or the tendency to underweigh conflicting information to confirm prior beliefs (confirmation bias; Ortoleva & Snowberg, 2015; Park, Konana, Gu, Kumar & Raghunathan, 2010). The statistical explanation holds that because people cannot directly access their true level of understanding--and hence any estimation thereof contains error--subjective estimates regress towards the mean, and the estimates of more extreme levels of (mis)understanding do so mores strongly. (discrepancy is positively correlated to overconfidence) (Erev, Wallsten & Budescu, 1994; Krueger & Mueller, 2002).

There is reason to fear that overconfidence in one's knowledge may be particularly prevalent in the climate change domain. Distant events, complex interdependencies, and long time lags are inherent characteristics of the climate system, rendering direct and immediate feedback about the veracity of one's beliefs rare (if not impossible). Hence, there is ample room for domain-specific "unknown unknowns". Reports in classical media (Antilla, 2005) as well as skeptical blogs (Sharman, 2014) can be found to substantiate basically all sorts of subjective beliefs, no matter how distorted or how far from scientific consensus. Even the sheer magnitude of scientific knowledge itself--ironically--,allows one to assemble sets of evidence supporting prior beliefs (Sarewitz, 2004). People can live in the constant bliss of unchallenged CC beliefs. Hence, there is ample room for domain-specific misbeliefs. In fact, the idea that overconfidence might prevail in the context of CC is not new: Johnson and Fowler (2011) conclude from their evolutionary model that overconfidence should prevail about uncertain, rare, and unpredictable phenomena such as natural disasters and CC.

How does understanding of CC relate to concern and action?

It makes intuitive sense to assume that understanding CC--acquiring and employing factually correct knowledge of CC (cf. Wolf & Moser, 2011)--is a necessary precondition to adequately assess the risks associated with CC, and for deciding upon policy alternatives (Stoutenborough, Vedlitz & Liu, 2015), particularly in a topic as complex as CC where far-reaching and potentially irreversible impacts reside not only in itself (e.g., extreme weather events or risks to food security; IPCC, 2014), but also in means to address it (e.g., carbon capture and storage, geoengineering; Amelung & Funke, 2013, 2015). A lack of knowledge on climate change risks has been identified as a major barrier to climate action (Lata & Nunn, 2012). Moreover, understanding should serve as a link between attitudes and individual action (Meinhold & Malkus, 2005), as environmental knowledge enables people with pro-environmental attitudes to act in accordance with their attitudes, whereas lacking knowledge is a major cause for inaction or unsuited "token actions" (Attari, DeKay, Davidson

& De Bruin, 2010; Gifford, 2011; Semenza, Hall, Wilson, Bontempo, Sailor & George, 2008; Whitmarsh, 2009).

Given these rather fundamental reasons of why understanding should be a precondition for climate-related action, it seems puzzling that existing results are far from conclusive, with some studies finding positive, and others mixed, or even negative relationships. We offer an explanation for these contradictory findings: The *systematic* mis-calibration of subjective understanding of CC.

Let us suppose that higher levels of objective understanding of CC are associated with higher concern, or higher willingness to take action. Let us also suppose that perceived CC knowledge is systematically miscalibrated as predicted by the Dunning-Kruger effect, so that those who understand most tend to underestimate their understanding, and those who understand the least tend to overestimate it. It follows from these simple assumptions that a relationship between true understanding and the dependent variable, albeit in fact positive, can appear zero or even negative when a subjective measure of understanding is used. Furthermore, these assumptions can explain why the relationship between subjective understanding and CC outcomes such as concern appears to vary depending on partisanship (Malka, Krosnick & Langer, 2009; McCright, 2011, 2008): If political conservatives possess less scientifically correct understanding of CC than liberals (McCright, 2010), they should overestimate their understanding more, and hence, for them, the relationship between (perceived) understanding and concern, beliefs or action would appear non-existing or negative.

Existing empirical results are largely in line with these theoretical arguments. Using subjective measures, Kellstedt, Zahran and Vedlitz (2008) find that those who claim to be more informed about global warming ("How informed do you consider yourself to be about global warming?") feel less personally responsible, and show less concern. Malka, Krosnick and Langer (2009) find that the feeling to know more about global warming is positively associated with concern for Democrats, but unrelated for Republicans. Also, greater self-reported understanding of CC was positively associated with objective understanding and concern for liberals and democrats, but negatively so for Republicans. Similarly, McCright and Dunlap (2011a) find within 10 nationally representative US polls between 2001 and 2010 that self-reported understanding is positively associated with concern over climate change for liberals and democrats, and more weakly so or even negatively for conservatives and Republicans. Drawing on the same data, McCright and Dunlap report that denial of climate change is highest among white male conservatives who claim to understand climate change very well (2011b).

Using objective measures of understanding, in contrast, Tobler, Visschers & Siegrist (2012) find that those who understand more about CC tend to be more concerned and feel less powerless. Likewise, understanding of the causes of global warming was the single best predictor of behavioral intentions to act on global warming among 1218 Americans (Bord, O'Connor & Fisher, 2000), understanding CC and global warming was positively associated with responsibility to act on CC among 269 New Zealandians, (Milfont, 2012), knowledge about the causes of CC was a significant predictor for concern about CC in six politically and culturally diverse countries (Shi, Visschers, Siegrist & Arvai, 2016), in 119 countries, understanding the anthropogenicity of CC proved the strongest predictor of climate change risk perceptions (Lee, Markowitz, Howe, Ko & Leiserowitz, 2015), and within one and the same study sample, subjective knowledge was a negative, and objective knowledge a positive predictor of concern (Stoutenborough & Vedlitz, 2014).

The present study

The present study assesses whether the degree of participants' confidence in their understanding of CC is justified by their actual understanding (overconfidence as an outcome). Moreover, we investigate whether unjustified confidence in one's understanding can predict willingness to contribute to CC mitigation, even when controlling for actual understanding (overconfidence as a predictor). In a two-alternative forced choice paradigm, participants read a total of ten excerpts from the IPCC's 2014 Summary for Policymakers (IPCC, 2014), and both objective and perceived understanding was assessed. For each of

20 statements on the IPCC excerpts, each starting with “Does the text say that…”, participants indicated whether the statement was correct or incorrect, and then indicated their subjective confidence that they answered accurately. Measuring both objective and subjective understanding in one study allowed us to investigate the degree of calibration of perceived understanding of CC, and how participants’ degree of calibration and overconfidence is associated to their willingness to contribute to CC mitigation. In order to assess willingness to contribute to CC mitigation, participants took part in a lottery as part of their compensation. Participants could win an amazon or cinema voucher worth a maximum of 20$, and indicated how much of this prize--if anything--they wanted to donate to a non-profit organization (Atmosfair) to offset CO_2.

Importantly, since subjective and objective understanding are correlated, we differentiate between two operationalizations of overconfidence in our analyses: The typically used signed *difference* between understanding and confidence (overconfidence) that treats subjective and objective understanding as equally important; and the *residual* confidence that controls for actual understanding by regressing participants’ subjective understanding on their actual understanding, and retaining the standardized residuals (residual confidence). In line with the recommendations by Parker and Stone (2014), we use overconfidence as an intuitive and signed measure to address the difference between subjective and actual understanding, and when overconfidence is the outcome. We use residual confidence when overconfidence is a predictor to address the impact of confidence *that cannot be accounted for by actual understanding.* This approach allows us to investigate both whether overconfidence varies with understanding, and whether overconfidence exerts behavioral effects independent of understanding.

To assess the unique and incremental effects of (perceived) understanding and overconfidence about CC, we controlled for a comprehensive list of established predictors: prior knowledge about the state, causes, and consequences of CC; perceived persuasiveness of the information; perceived competency of the authors; gender, age, level of education, and political orientation (Achtnicht, 2011; Daziano & Bolduc, 2013; Hansla, Gamble, Juliusson & Gärling, 2008; Hersch & Viscusi, 2006; Hunter, Hatch & Johnson, 2004; Israel & Levinson, 2004; Zelezny, Chua & Aldrich, 2000).

We expected:

1. In general, participants overestimate their understanding of CC information (overconfidence).
2. Subjective understanding of CC information is systematically miscalibrated as a function of actual understanding (Dunning-Kruger effect).
3. Higher overconfidence in one's understanding of CC is associated with reduced willingness to contribute to CC mitigation.

Method and Materials

Participants

The sample consisted of a total of N=264 participants (*n*=119 female) from the US (*n*=110), India (*n*=107), and Germany (*n*=47). Participants from different countries were selected to achieve a heterogeneous sample with varying political and educational backgrounds. Participants from USA and India were recruited via Amazon Mechanical Turk (MTurk), participants from Germany were recruited via university mailing lists. The vast majority of participants (84%) held at least a Bachelor's degree, 23% held a Master's degree, and 2% a PhD. Only 1 participant indicated their level of education to be "less than high school". The average level of English proficiency was high (*M*=5.17, *SD*=1.07, on a 6-point scale). 10% of participants indicated membership of an environmental group. Participants who were recruited via MTurk received a monetary compensation of a typical amount of 0.80 $. Participants recruited via university mailing lists also received course credit if they were Heidelberg university students. As part of their compensation, all participants could additionally take part in a lottery to win a voucher worth a maximum of 20$.

IPCC text excerpts

10 text excerpts were taken from the main outlet for integrated climate science information, the IPCC's Fifth Assessment Report (AR5) Synthesis Report Summary for Policymakers (cite 2014). This report arguably constitutes the most relevant source of climate science information. The excerpts were taken from the report's text boxes as those constitute important and stand-alone information that is--due to its salient character within the report--most likely to be read. We included the two very first boxes of the report (page 2), and then the text boxes from all uneven page numbers (pp. 7-31) to ensure their representativity for a wide range of topics covered in the report, yielding a total sample of 10 excerpts (supplementary file A).

Objective and subjective understanding

Objective understanding. For each of the ten excerpts, two statements were presented that participants evaluated as either correct or incorrect according to the information presented in the excerpt: "Does the text say that …?" (Yes/No). Only unambiguous statements clearly reflecting the information presented in the excerpts, and jointly covering a range of difficulties were selected based on pre-testing. Participants' objective understanding score was the proportion of accurately evaluated statements (i.e., 0-20). For an example item, see Figure 1; all statements together with their respective text boxes can be found in supplementary file A.

Subjective understanding. After evaluating a statement as correct or incorrect, participants indicated their subjective confidence that they answered accurately: "*How certain are you that the answer you just gave is correct?"* (1=*not at all certain;* 6= *extremely certain*; Radecki & Jaccard, 1995).

Political climate action preferences

We used the items adapted by Guy et al. (2013) from a Lowy Institute national survey (Hanson, 2011) to assess whether participants perceive CC as a problem that should be addressed even if this involves costs: (1) “Climate change is a serious and pressing problem. We should begin taking steps now even if this involves significant costs.” (act now) (2) “The problems of climate change should be addressed, but its effects will be gradual, so we can deal with the problem gradually by taking steps that are low in cost.” (wait-and-see) (3) “Until we are sure that climate change is really a problem, we should not take any steps that would have significant costs.” (go slow).

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (high confidence). Mitigation involves some level of co-benefits and of risks due to adverse side effects, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change, increasing the benefits from near-term mitigation efforts.

Please note: Mitigation = Emissions reduction, Adaptation = Adaptation to climate change

8. Does the text say that...?

	yes	no
Mitigation also involves risks	○	○

9. How certain are you that the answer you gave above is correct?

	not at all 1	2	3	4	5	extremely 6
I am ...... certain that my answer is correct.	○	○	○	○	○	○

10. Does the text say that...?

	yes	no
The risks of mitigation are lower than the risks of climate change.	○	○

11. How certain are you that the answer you gave above is correct?

	not at all 1	2	3	4	5	extremely 6
I am ...... certain that my answer is correct.	○	○	○	○	○	○

Figure 1. Screenshot of an exemplary item assessing objective and subjective understanding of information on climate change. Participants are given an excerpt from the IPCC Summary for policymakers, 2014 (above). Participants then indicate whether a statement on the excerpt is correct or incorrect, and indicate their subjective confidence that they answered correctly (below).

Willingness to contribute to mitigation

To measure participants willingness to contribute to CC mitigation, participants took part in a lottery to win a prize. Participants were told that the prize was worth 20$. Participants then indicated how they wanted to split up their prize: Participants indicated the share (if anything) of the fixed amount of 20$ they wanted to allocate to (a) a donation to *Atmosfair* to offset CO_2; and the share (if anything) they wanted to allocate to (b) an amazon voucher (participants recruited via MTurk) or cinema voucher (participants recruited via mailing lists) for themselves. Participants were told that any combination of integer numbers was allowed. The share allocated to Atmosfair was counted as participants' willingness to contribute to CC mitigation, the share allocated to the voucher as their degree of egoistic behavior.

Albeit it may appear redundant at first, we opted for a separate assessment of allocations to Atmosfair and the voucher, respectively. In this way, a separate assessment of egoistic and pro-environmental tendencies was made possible in case they were treated differently by our participants, so as to disentangle differential mechanisms leading up to the two. A comprehensive list of additional control variables used in the study can be found in Table 1.

Procedure

The study was conducted online. After participants were informed about the anonymity of data collection and their right to withdraw at any time during the study, participants were told about the possibility to take part in a lottery as part of their compensation. Participants were informed that they were eligible to take part in the lottery only if they answered at least 10% of the text comprehension statements correctly. This was done to ensure that participants were motivated to complete the objective understanding questions for 10 difficult-to-read excerpts. We then assessed participants' level of English proficiency, environmental group membership, political orientation, prior beliefs in the existence and anthropogenicity of CC, behavioral intentions to change behavior in an environmental-friendly manner and to engage with climate science, and prior knowledge on climate change (Table 1).

Table 1. *List of control variables in the study*

Variable label	***Wording*** **Answer format**
difficult	*How difficult is the text?* 6-point rating scale (1=not at all/6=extremely)
qualified	*How qualified are the authors? Please guess.* 6-point rating scale (1=not at all/6=extremely)
convincing	*How convincing is the text?* 6-point rating scale (1=not at all/6=extremely)
CCexists_pre & *CC exists_post*	*How convinced are you that climate change exists?* 6-point rating scale (1=not at all/6=extremely)
CCman_pre & *CCman_post*	*How convinced are you that climate change is caused by human activity?* 6-point rating scale (1=not at all/6=extremely)
Info_pre & *info_post*	*How motivated are you to look for further information about climate change?* 6-point rating scale (1=not at all/6=extremely)
Change_pre & *change_post*	*How determined are you to change your own behavior in order to act environmental friendly?* 6-point rating scale (1=not at all/6=extremely)
*know**	*Are the following statements true or false?* 6-point rating scale (1=certainly false/6=certainly true)
Political view	*How would you characterise your political views?* 6-point rating scale (1=left/6=right)
English	*How fluent is your English?* 6-point rating scale (1=a1(beginner)/6=c2(proficient)
envgroup	*Are you a member of an environmental group?* Binary (Yes/No)

Note. *adapted from Sundblad, Biel & Gärling (2009): Three items were chosen from each of the three knowledge domains *state, causes*, and *consequences* such that at least one statement within each domain was incorrect.

Next, participants went through the total of 10 excerpts from the IPCC report. Each excerpt was presented on a separate page. Objective and subjective understanding and participants' perceptions of each excerpt were assessed on the page following the respective excerpt, without the possibility to get back and re-read it. This was done to assess whether participants had understood the information enough to actually make use of it.

Upon completion of all 10 excerpts, participants completed the regulatory focus questionnaire (Lockwood, Jordan & Kunda, 2002; results are not reported here), indicated their political climate action preferences, and were assessed for their post beliefs in the existence and anthropogenicity of CC, and their behavioral intentions to change behavior in an environmental-friendly manner, and to engage with climate science. Prior and post beliefs and behavioral intentions were assessed for two reasons. First, to ensure that reading the IPCC excerpts exerted any influence on participants at all, and second, to investigate whether subjective and objective understanding and overconfidence exert an influence above and beyond prior and post beliefs and behavioral intentions. Participants then indicated their demographics (age, sex, nationality, occupation, education).

In a final step, we assessed participants' willingness to contribute to mitigation with the lottery. Participants were then thanked and told to re-visit the webpage in two weeks time as then the winner (anonymised personal code) of the lottery would be announced.

Results

For the descriptive statistics of all variables used in this study, see Table 2.

Measures of overconfidence

To measure *overconfidence*, we converted subjective understanding into a score ranging from 0 to 1 akin to objective understanding by dividing each participant's mean by 6. Overconfidence was the signed difference between the subjective understanding score and the objective understanding score for each participant such that positive values denote overconfidence, and negative values denote underconfidence. To measure *residual* *confidence*, we regressed subjective understanding on objective understanding, and retained the standardized residual for each participant. Subjective understanding was able to explain only 7% of the total variance of objective understanding, R^2=.07.

Table 2. *Descriptives*

Variable	***N***	**Scale range**	**Min**	**Max**	***M***	***SD***
Atmosfair	264	0-20	0	20	7.2	6.9
Voucher	264	0-20	0	20	12.0	7.2
Objective understanding	264	0-1	0.20	1	0.65	0.17
Subjective understanding	263	0-1	0.17	1	0.77	0.14
Overconfidence (residuals)	263	-∞/+∞	-4.4	2.0	0	1
difficulty	264	1-6	1	6	3.3	1.1
qualified	264	1-6	1	6	4.3	0.9
convincing	264	1-6	1	6	4.2	1.0
prior belief in CC (existence)	261	1-6	1	6	5.0	1.2
post belief in CC (existence)	262	1-6	1	6	5.1	1.2
prior belief in CC (anthropogenicity)	260	1-6	1	6	4.8	1.3
post belief in CC (anthropogenicity)	262	1-6	1	6	5.0	1.3
prior intention to engage in climate science information	263	1-6	1	6	4.4	1.2
post intention to engage in climate science information	263	1-6	1	6	4.6	1.2
prior intention to change behavior in a pro-environmental way	264	1-6	1	6	4.5	1.3
post intention to change behavior in a pro-environmental way	263	1-6	1	6	4.7	1.3
prior knowledge	264	0-54	20	50	35.6	4.6

Note. Atmosfair=pro-environmental choice; *Voucher*=egoistic choice; *difficulty*=perceived difficulty of text; *qualified*=perceived qualification of authors; *convincing*=perceived persuasiveness of the text.

We first controlled whether working through the IPCC excerpts exerted any influence on participants' beliefs and intentions. A repeated-measures ANOVA revealed that, while belief in the existence of CC did not change after reading the IPCC text excerpts, *F*(1, 258)=0.91, p=.340, part. η^2=.00, belief in the anthropogenicity of CC, $F(1, 258)$=6.41, p=.012, part. η^2=.02, and behavioral intentions to engage with climate science information, $F(1, 258)$=9.10, p=.003, part. η^2=.03, and to change behavior in an environmental-friendly manner, $F(1, 258)$=9.52, p=.002, part. η^2=.04, increased slightly (see Table 2 for descriptive values). These results are in line with general findings that attribution skepticism (Is CC man-made?) is more common than trend skepticism (Does CC exist?) (Leiserowitz, Maibach, Roser-Renouf, Feinberg & Howe, 2013; cf. Rahmstorf, 2004).

Objective understanding, subjective understanding, and overconfidence

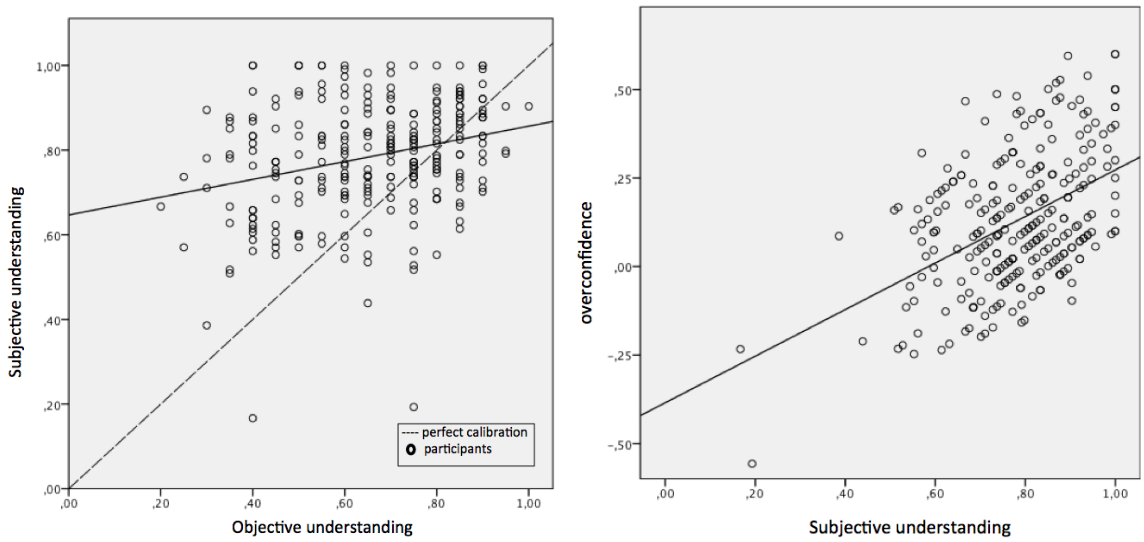

Figure 2. *Left panel*: Relation of objective and subjective understanding. The diagonal displays perfect calibration, values above the diagonal denote overconfidence, values below denote underconfidence. *Right panel*: Relation of subjective understanding and overconfidence.

Figure 2 displays participants' calibration compared to the ideal calibration of subjective understanding. Participants were generally overconfident about their understanding. The mean difference between subjective understanding scores (M=.78, SD=.14) and objective understanding scores (M=.65, SD=.17) was positive (M=.13, SD=.19), and significantly different from zero, $t(262)$=11.2, p >.001. In line with the Dunning-Kruger effect, overconfidence increased as objective understanding decreased, $r(263)$=-.72, p <.001. The absolute degree of discrepancy between subjective and objective understanding (discrepancy = |subjective understanding score-objective understanding score|) was higher for the *n*=200 overconfident participants (overconfidence >0, discrepancy *M*=.21,*SD*=.15) compared to the *n*=63 underconfident (overconfidence <0; discrepancy *M*=.09,*SD*=.09) participants, *t*(168.99)=6.5, *p* <.001. As opposed to objective understanding, subjective understanding was a strong positive predictor for overconfidence, *r*(261)=.61, *p* <.001 (Figure 2, right panel).

Subjective and objective understanding were moderately correlated in the overall sample, *r*(262)=.22, *p* < .001. This relationship was strongly dependent on political orientation. Only for self-rated left-wing participants (<=3 on 6-point rating scale), objective and subjective understanding were significantly correlated, *r*(140)=.38, *p* < .001, whereas for self-rated right-wing participants (>=4 on 6-point rating scale), both measures were unrelated *r*(119)=.08, *p*=.36. In line with our theoretical arguments, however, increasing right-wing orientation was associated to lower objective understanding, *r*(262)=-.38, *p* < .001, while subjective understanding was unrelated to political attitude, resulting in a positive association between increasingly right-wing political orientation and overconfidence, *r*(263)=.33, *p* < .001.

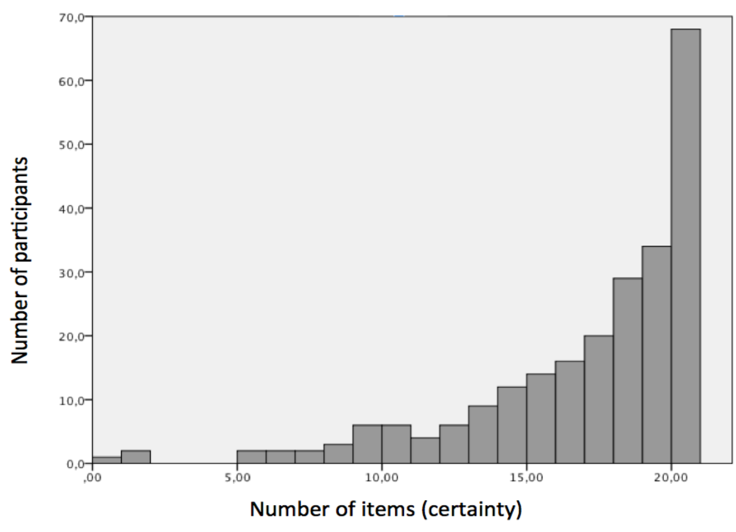

Figure 3. Frequency with which any given number of the 20 items was indicated as more certainly correct.

To assess how participants' subjective understanding was distributed on the level of individual items, we dichotomized the subjective understanding scale. Values above the scale's midpoint (3) indicate being more certain, values below the midpoint indicate being more uncertain. The frequencies of participants who indicated being more certain for any of the 20 statements are displayed in Figure 3. The figure demonstrates that the distribution has a strong negative skew such that that there are much more participants in the sample who indicate to be certain with most or all items than participants who indicate to be certain with only a small subset of items.

Overconfidence and perceptions of the IPCC excerpts

Higher residual confidence was related to perceiving the texts as more convincing, $r(263)=.52$, $p < .001$, and the authors as more qualified, $r(263)=.53$, $p < .001$. Objective understanding, in contrast, was unrelated to either perceived persuasiveness, $r(262)=-.09$, $p=.13$, or perceived qualification of the authors, $r(262)=-.05$, $p=.46$.

Overconfidence as a predictor I: Is higher overconfidence associated to lower perception of CC as a serious problem?

In our sample, 67% perceived CC as a serious and pressing problem (act-now), 24% perceived CC as a problem that can be addressed gradually (wait-and-see), and 7% state that no costly climate action should be taken until we are sure that CC really is a problem (go-slow). These frequencies roughly correspond to the numbers found in representative polls (Leiserowitz, Maibach & Roser-Renouf, 2009). Higher residual confidence in understanding the IPCC excerpts was associated to higher post-reading preferences for wait-and-see or go-slow policies controlling for prior beliefs in the anthropogenicity of CC, prior motivation to change behavior to act environmental-friendly, prior knowledge, perceptions of the excerpts, and political attitude; partial rank correlation $r_s(247)=.16$, $p=.01$.

Overconfidence as a predictor II: Is overconfidence linked to willingness to contribute to mitigation?

Willingness to contribute to mitigation was operationalized as the share participants allocated to the pro-environmental option (Atmosfair) as opposed to the egoistic option (voucher). The modal allocation of shares was a fully egoistic one, with a 0$ donation to

Atmosfair and 20$ attributed to the voucher (25% of participants), followed by an even assignment of 10$ to each option (21%), a 5$-donation to Atmosfair (16%), a fully pro-environmental allocation of shares (13%).

Table 4a. *Correlations between full list of predictors, part I*

	sex	*age*	*Engl*	*CC exists*	*CC man*	*info*	*change*	*know*
age	.11 .085							
Engl	.06 .314	-.10 .125						
CCexists	.01 .875	-.23*** <.001	.01 .844					
CCman	-.05 .473	-.23*** <.001	-.00 .985	.72*** <.001				
info	-.08 .179	-.18** .003	-.03 .663	.51*** <.001	.50*** <.001			
change	-.10 .096	-.14* .024	.01 .869	.48*** <.001	.50*** <.001	.71*** <.001		
know	.02 .712	-.15* .018	.11 .085	.58*** <.001	.54*** <.001	.35*** <.001	.38*** <.001	
polit	-.01 .816	-.07 .293	-.14* .021	-.30*** <.001	-.25** <.001	-.00 .966	-.05 .404	-.33*** <.001
qual	-.08 .217	-.14* .028	.06 .340	.38*** <.001	.40*** <.001	.32*** <.00	.39*** <.001	.29*** <.001
conv	-.08 .226	-.14* .027	.06 .302	.36*** <.001	.41*** <.001	.39*** <.001	.45*** <.001	.32*** <.001
diff	-.01 .934	-.14* .027	-.03 .653	-.01 .827	.08 .159	.04 .481	.04 .534	-.01 .879
OU	-.01 .847	-.05 .425	.22*** <.001	.31*** <.001	.18** .003	-.08 .210	.04 .562	.30*** <.001
SU	.01 .941	-.16** .008	.15* .013	.38*** <.001	.30*** <.001	.27*** <.001	.35*** <.001	.29*** <.001
OCres	.01 <.001	-.16* <.001	-.11 <.001	.32*** <.001	.27*** <.001	.30*** <.001	.35*** <.001	.23*** <.001

Note. N=259-264. *Engl*=English proficiency; *CCexists*=prior belief in the existence of climate change; *CCman*=prior belief in anthropogenicity of climate change; *info*=prior motivation to look for further information; *change*=prior motivation to change behavior; *know*=prior

knowledge on climate change; *polit*=political view (higher values indicate more right-wing orientations); *qual*=perceived qualification of authors; *conv*=perception of how convincing the text was; *diff*=perceived difficulty of text; *OU*=objective understanding; *SU*=subjective understanding; *OCres*=overconfidence (residuals).
**p* ≤ 05. ***p* ≤ .01. ****p* ≤ .001

Table 4b.*Correlations between full list of predictors, part II*

	polit	*qual*	*conv*	*diff*	*OU*	*SU*
qual	.06 .314					
conv	.06 .376	.85*** <.001				
diff	.17** .006	.08 .189	.16** .010			
OU	-.38*** <.001	-.05 .461	-.09 .129	-.26*** <.001		
SU	.02 .747	.53*** <.001	.51*** <.001	-.10 .098	.22*** <.001	
OCres	.32*** <.001	.55*** <.001	.54*** <.001	-.05 .438	.00 1.00	.98*** <.001

Note. N=259-264. *polit*=political view (higher values indicate more right-wing orientations); *qual*=perceived qualification of authors; *conv*=perceived persuasiveness of the text; *diff*=perceived difficulty of text; *OU*=objective understanding; *SU*=subjective understanding; *OCres*=overconfidence (residuals).
**p* ≤ 05. ***p* ≤ .01. ****p* ≤ .000

Both the allocation to Atmosfair, and to the voucher served each as the dependent variable in separate multiple stepwise regression analyses on the list of predictors. The full list of predictors can be found in Tables 4a and 4b including all correlations between them. *Subjective understanding* was not included as a predictor since *residual confidence* was computed to reflect participants' subjective confidence independent of actual understanding. The highest Variance Inflation Factor (VIF) was found for *the prior motivation for behavior change* in a regression with the egoistic choice as dependent variable, but was well below 10 (VIF_{change}=2.21), therefore, no problem with multicollinearity was assumed (cf. Chatterjee, Hadi & Price, 2000).

Higher allocation to Atmosfair was predicted by higher objective understanding beyond english proficiency, sex, age, and prior willingness to engage with climate science. Higher allocation to the voucher, in contrast, was predicted by lower objective understanding and higher levels of residual confidence beyond English proficiency, sex, age, and prior knowledge on CC (Table 5).

Table 5. *Stepwise regression analyses of egoistic and pro-environmental allocations on the list of predictors.*

	Egoistic allocation			*Pro-environmental allocation*		
	B (*SE*)	*t*	*p*	*B* (*SE*)	*t*	*p*
Constant	8.37 (1.35)	6.20	<.001 (***)	11.49 (1.25)	9.23	<.001 (***)
English	1.90 (0.43)	4.41	<.001 (***)	-2.25 (0.40)	-5.67	<.001 (***)
Sex	2.29 (0.83)	2.74	.007 (**)	-2.75 (0.77)	-3.57	<.001 (***)
Age	1.01 (0.42)	2.39	.018 (*)	-0.96 (0.39)	-2.48	.014 (*)
information	-1.19 (0.44)	-2.74	.007 (**)	-	-	-
prior knowledge	-	-	-	0.95 (0.40)	2.37	.019 (*)
Objective understanding	**-1.18 (0.43)**	**-2.73**	**.007 (**)**	**1.04 (0.40)**	**2.58**	**.011 (*)**
Residual confidence	**0.8 (0.43)**	**2.02**	**.044 (*)**	-	-	-
Adj. R^2		**.15**			**.20**	

Note. B=unstandardized regression coefficient; *SE*=standard error; *English*=English proficiency; *information*=prior motivation to look for further information; *prior knowledge*=prior knowledge on climate change; Adj. R^2=adjusted R^2. All continuous predictors were z-standardized prior to analysis, therefore, standardized regression coefficients are not reported.
**p* ≤ 05. ***p* ≤ .01. ****p* ≤ .001

Discussion

The present study shows that on average, people overestimate their levels of understanding of climate change information. The discrepancy between objective and subjective understanding increases as actual understanding decreases, whereas people who objectively understand more are better-calibrated, or even underconfident. The average difference between subjective confidence and objective understanding scores was positive and different from zero, and participants who were confident about their understanding tended to indicate their certainty for most or all items, not only for a subset. In other words, participants' subjective estimates of their understanding tended to be both positively biased towards an overconfidence in understanding, and systematically biased as a function of understanding.

Differential effects of subjective and objective measures of understanding have only rarely been systematically analyzed in one study (for an exception, see Stoutenborough and Vedlitz, 2014), and in particular, the unique effect of overconfidence has not been addressed at all. The present results can help explain the previously contradictory results of some studies finding positive, negative, or mixed effects of understanding on CC concern and action. As suggested in our theoretical arguments, and in line with the Dunning-Kruger effect, a negative correlation between subjective understanding and willingness to act cannot per se be interpreted as a detrimental backfiring of higher understanding on action. Subjective understanding can be negatively associated *even though actual understanding is positively associated* because of the systematic miscalibration of subjective understanding as a function of actual understanding. Subjective understanding is not tantamount to understanding.

Furthermore, the systematic miscalibration of subjective measures of understanding CC may at least partially explain why self-reported understanding is positively associated with actual understanding and concern for some groups of participants, but unrelated or negatively so for others (for example, those with a left- as opposed to right-wing political orientation; Malka, Krosnick & Langer, 2009; McCright & Dunlap, 2011a). When objective understanding of CC varies between groups, relative overconfidence should be higher for the group with lower understanding, and hence the relationship between subjective understanding and the outcome of interest would appear non-existent or even negative.

Besides its systematic bias, our results also reveal that subjective understanding is not a particularly strong predictor of objective understanding. In fact, only 7% of the total variance of objective understanding was explained by subjective understanding. Taken together, the present results suggest that people have only very limited access to a realistic estimation of their level of understanding of CC, and may be particularly convinced of the accuracy of their understanding when it is low.

The systematic difference between subjective and objective understanding, and particularly overconfidence, may be an important predictor of cognitive and behavioral outcome variables relevant for the climate change debate. It has been shown that people who are too sure of their understanding of a risky situation tend to understate its risks (Broihanne, Merli & Roger, 2014), and do not take precautions against them (Silver, 2012).

In the present study, higher residual confidence in one's understanding--the degree of variation that cannot be accounted for by actual understanding--was associated to a reduced perception of climate change as a risky problem, and lower support for costly political action. This held while controlling for political orientation, prior climate-related beliefs and behavioral intentions, and prior knowledge. Higher residual confidence was also positively associated to a lower willingness to contribute to mitigation as assessed with the lottery: Participants allocated higher shares to the egoistic option (cinema or amazon voucher) when they had objectively understood less and showed more unjustified confidence in their understanding. That is, participants who were too certain of their understanding of CC tended to choose egoistic rewards over investments into precautionary measures (mitigation). The result that both lower understanding and higher residual confidence served as independent predictors in one and the same regression equation suggests that it is not as much a lack of understanding of CC that predicts whether someone is unwilling to contribute to mitigation. Much rather, it is a lack of understanding *coupled with* being too sure of one's understanding. To adequately respond to climate change, we do not only need to understand more, we also seem to need an awareness of the limits of our understanding.

Implications for climate communication

It seems crucial to note that--as a cognitive variable--overconfidence constitutes a potential point of leverage. While other established predictors of CC concern and action such as sex, age, education, and political attitude are hardly subject to change, overconfidence may be malleable. The present results therefore bear important implications for the communication of climate science. With higher degrees of overconfidence, people may tend to selectively process climate information in favor of their prior beliefs (cf. Innocenti, Rufa & Semmoloni, 2010), may generally seek less--especially conflicting--information (Zacharakis & Shepherd, 2001), and may tend to focus on information in support of their prior beliefs (Berner & Graber, 2008).

Overconfidence can thus further exacerbate ongoing polarization of public opinion on climate change (McCright & Dunlap, 2011a). Albeit it is difficult to reduce unjustified confidence, it has been successfully accomplished in the past. Successful methods include, for example, counter-argumentation (Russo & Schoemaker, 1992), and, as our results and a substantial amount of other research on the negative relationship between knowledge and overconfidence suggests (Dunning, 2011; Schlösser, Dunning, Johnson & Kruger, 2013; Simons, 2013), increasing actual understanding. Higher actual understanding appears to protect us from excessive overconfidence in our understanding. An adequate estimation of what one does not understand already requires substantial understanding.

It was found that, counterintuitively, more information can backfire in that, for example, uncertainty about possible outcomes increases (Moore, Tenney, Haran, 2015; Peterson & Pitz, 1988). Taking the phenomenon of overconfidence into account, an alternative explanation may include that more information can help people construct coherent explanations, so that confidence may increase more quickly than accuracy. What backfires, then, is not the information: it is the possibility to construct stories in line with prior beliefs that ultimately strengthen overconfidence in those beliefs ("I knew it all along"). Hence, rather than simply providing the public with more information, information needs to be presented in a way that facilitates *true* (not subjective) understanding.

Is overconfidence always bad?

As already discussed in the introduction, it is typically found that overconfidence endows both advantages and disadvantages (e.g. Johnson & Fowler, 2011; Johnson & Tierney, 2011). In our case, overconfidence turns out to be a double-edged sword as it is also associated to finding excerpts more convincing.

Subjective feelings of understanding have been shown to exert positive effects on the judged persuasiveness of texts and qualification of authors, not only in previous research (Kahneman, 2011) but also in our own findings (in which participants seem to use their subjective understanding as a proxy for its quality). One possible explanation for these findings is that subjective understanding of a text may be used as a proxy for how valid the argumentation is (cf. Amelung, Fischer, Kruse & Sauerborn, forthcoming).

This is especially noteworthy if one assumes that a higher subjective understanding is the result of higher processing ease (lower difficulty with which the presented information is processed), because it has been shown that lower processing ease corrupts attempts to debias overconfidence: if, for example, people are asked to find arguments counter to their current position (counter-argumentation), but these arguments do not come to mind easily (lower processing fluency), overconfidence is not likely to be reduced (Schwarz, Sanna, Skurnik & Yoon, 2007).

This may imply that texts which are very difficult to read such as the IPCC texts (Barkemeyer, Dessai, Monge-Sanz, Renzi & Napolitano, 2016), and thus reduce processing fluency, are exceptionally unsuited to debias overconfidence in prior beliefs about CC.

This also further underlines the importance of improving the readability of climate information to address issues of low processing ease as well as low actual understanding, given that in our study, only real understanding (as opposed to subjective feelings of understanding) was predictive of actual behavior.

Further research could also reveal potential benefits of overconfidence in the domain of climate change. For example, overconfidence in the likelihood of future success or future rewards could diminish temporal discounting (Shapira-Ettinger & Shapira, 2008), and thus improve the acceptance of immediate small losses in order to achieve a long-term gain, a dilemma often posed by efforts to achieve more sustainability (Ascher, 2006).

Implications for studying the effects of climate change understanding

Results underline the importance of using subjective and objective measures of understanding in the same study. This is because not only both measures, but also their difference can independently predict different outcomes, such as persuasiveness of IPCC texts, or pro-environmental as opposed to egoistic allocations of a limited resource. The difference between subjective and objective understanding may prove an independent predictor in areas where systematic miscalibration can prevail due to high degrees of uncertainty, the possibility of unknown unknowns, or where subjectively unpleasant information predisposes for selective information processing.

Conclusion

The present results offer a new answer to an age-old problem, the relationship between understanding and action (Arbuthnot, 1977; Bord, O'Connor & Fisher, 2000). Willingness to contribute to CC mitigation is not only a question of subjective and objective understanding. It is also question of the difference between the two.

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Supplement A. *IPCC text excerpts with their respective objective understanding test statements*

Page no.	IPCC text excerpt	True/False statements	% of right answers
2	Human influence on the climate system is clear, and recent anthropogenic emissions of green-house gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems.	Recent climate changes have affected natural systems more than human systems. (false)	59 %
		Recent natural emissions of greenhouse gases are the highest in history. (false)	18 %
2	Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.	We have less snow and lower sea-levels than ever before. (false)	58 %
		Warming of the climate since the 1950s is disputed. (false)	67 %
7	Changes in many extreme weather and climate events have been observed since about 1950. Some of these changes have been linked to human influences, including a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea levels and an increase in the number of heavy precipitation events in a number of regions.	Since about 1950, we experience less cold weather. (true)	68 %
		Since about 1950, we experience less rainfall. (false)	69 %
13	Climate change will amplify existing risks	The risks will be comparable for all	57 %

	and create new risks for natural and human systems. Risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development.	countries at all levels of development. (false)	
		Climate change will increase existing risks. (true)	94 %
17	Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (high confidence). Mitigation involves some level of co-benefits and of risks due to adverse side effects, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change, increasing the benefits from near-term mitigation efforts.	Mitigation also involves risks. (true)	90 %
		The risks of mitigation are lower than the risks of climate change. (true)	75 %
17	Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial emissions reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term and contribute to	Mitigation and adaptation strategies are difficult to combine. (false)	73 %
		Mitigation supports sustainable development. (true)	80 %

	climate-resilient pathways for sustainable development.		
17	Effective decision-making to limit climate change and its effects can be informed by a wide range of analytical approaches for evaluating expected risks and benefits, recognizing the importance of governance, ethical dimensions, equity, value judgments, economic assessments and diverse perceptions and responses to risk and uncertainty.	It is adaptation that should include the aspects of governance, equity, value judgments and economic assessments. (false)	32 %
		Decisions on climate change should only be based on risks and benefits. (false)	58 %
19	Adaptation can reduce the risks of climate change impacts, but there are limits to its effectiveness, especially with greater magnitudes and rates of climate change. Taking a longer-term perspective, in the context of sustainable development, increases the likelihood that more immediate adaptation actions will also enhance future options and preparedness.	Adaptation is a useful strategy in the context of climate change. (true)	85 %
		There is no limit to the usefulness of adaptation. (false)	66 %
29	Effective adaptation and mitigation responses will depend on policies and measures across multiple scales: international, regional, national and sub-national. Policies across all scales supporting technology	International policies that promote adaptation and mitigation will be most effective in combating climate change. (false)	35 %
		Technological responses to climate change are effective. (true)	73 %

	development, diffusion and transfer, as well as finance for responses to climate change, can complement and enhance the effectiveness of policies that directly promote adaptation and mitigation.		
31	Climate change is a threat to sustainable development. Nonetheless, there are many opportunities to link mitigation, adaptation and the pursuit of other societal objectives through integrated responses (high confidence). Successful implementation relies on relevant tools, suitable governance structures and enhanced capacity to respond (medium confidence).	It is useful to combine different options to enhance sustainable development. (true)	86 %
		Our capacity to respond is sufficient. (false)	62 %