

Essays on individuals' responses to climate change and technologies to counteract climate change

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Preface

The four chapters of my dissertation are a selection of papers I wrote during my time as a PhD-student working in the research area 'The Environment and Natural Resources' at the Kiel Institute for the World Economy.

The first chapter, *Exploring public perceptions of stratospheric sulfate injection* (Merk et al. 2015), is co-authored by Gert Pönitzsch, Carola Kniebes, Katrin Rehdanz, and Ulrich Schmidt. All coauthors participated in the development and design of the survey. I coordinated the fieldwork. The data were analyzed by Gert Pönitzsch, Katrin Rehdanz, and me. Gert Pönitzsch and I mainly wrote the paper. Carola Kniebes supported the literature review. The revisions were done by Gert Pönitzsch, Katrin Rehdanz, and me. The paper was first published as a Kiel Working Paper and is now published in a revised version in *Climatic Change*.

The second chapter, *The role of affect in attitude formation toward new technologies: The case of stratospheric aerosol injection* (Merk & Pönitzsch, 2016), is co-authored by Gert Pönitzsch. It is based on the same survey data as the first chapter. Both co-authors developed the idea and wrote the paper. I developed the analytical framework and conducted the statistical analysis. The paper is currently available as a Kiel Working Paper and it is to be revised and resubmitted to *Risk Analysis*.

The third chapter, *Knowledge about aerosol injection does not reduce individual mitigation efforts* (Merk et al., 2016), is co-authored by Gert Pönitzsch and Katrin Rehdanz. The initial idea for the study was mine. All authors contributed to the conceptualization and design of the experiment. I coordinated the fieldwork, while Gert Pönitzsch coordinated the payment of the subjects. All authors contributed to the analysis of the data which was led and mainly carried out by Gert Pönitzsch. He also wrote the respective part of the paper. The remainder of the paper was written by me with substantial comments and editing from Gert Pönitzsch and Katrin Rehdanz. The paper is available as Kiel Working Paper and is published in *Environmental Research Letters*.

The fourth chapter, *The impact of social information on individuals' climate change mitigation*, is single-authored. It is based on the same data set as the third chapter and there is thus an overlap in the payment procedure which was administered by Gert Pönitzsch.

Introduction

The United Nations (United Nations General Assembly, 2015) included the mitigation of climate change in its Sustainable Development Goals for 2030 as it will be one of the major global challenges until 2030 and beyond (Stern, 2015). The challenge is substantial as economic and population growth will continue to perform an upward pressure on greenhouse gas emissions; without further mitigation the temperature is expected to increase between 3.7°C and 4.8°C by 2100 compared to preindustrial levels (median values, IPCC, 2014). Successful mitigation will depend both on technological and behavioral change (IPCC, 2014).

Three of the four chapters of this dissertation look at the interaction between new technologies to counteract climate change and individual behavior or more specifically technology acceptance. The final chapter looks at social information as a way to influence individuals' mitigation behavior.

Technology acceptance

When talking about technologies to counteract climate change, usually low-carbon energy technologies and improvements in energy efficiency are meant (IPCC, 2014; Stern, 2015) but lately also climate engineering (CE) technologies are increasingly discussed and were even mentioned in the 5th IPCC assessment report (IPCC, 2013). CE technologies are either targeted at removing carbon dioxide from the atmosphere or at changing the Earth's radiative balance of incoming and outgoing radiation and thus at cooling the planet.

One of the most prominent CE technologies – which is also at the center of three of the four chapters – is stratospheric aerosol injection (SAI). The technology is supposed to be very effective in cooling the planet but it is also expected to involve major risks and side effects (Robock, 2008). Injecting sulfate aerosols into the stratosphere could quickly offset global warming caused by anthropogenic greenhouse gas emissions. Particles would be injected into high altitudes of the stratosphere where they would partially block incoming sunlight and thus cool the atmosphere below (Rickels et al. 2011). David Keith (2013), a major proponent of the technology, claims SAI would be cheap compared to mitigation and the damages from climate change it would prevent.¹

¹ His estimates are, however, rough and others argue that considerable price effects (Klepper & Rickels, 2014) and monitoring costs would make SAI a lot more expensive (National Research Council Division on Earth and Life Studies et al., 2015).

However, the risks and uncertainties around SAI are substantial and raise technological, political, ethical, and social concerns. Since 2009, these risks and uncertainties have been assessed three times in comprehensive, interdisciplinary reports: the Royal Society report (Shepherd, 2009), a scoping study for the German Federal Ministry for Education and Research (Rickels et al., 2011), and a report by the US National Research Council (National Research Council Division on Earth and Life Studies et al., 2015). Each gives an overview of the relevant issues and the latest research on the chances, risks, and uncertainties connected to CE technologies.

For example, precipitation patterns are expected to change and the recovery of the ozone layer would slow down. The negative side-effects would affect regions differently – thus conflicts over the deployment of SAI and the compensation of the negatively affected regions could break out. SAI could cause severe problems for humans and the environment. Though research can help to understand SAI's effects better actual deployment could have unexpected effects as the long-term, large-scale deployment is different from local, short-term trials (National Research Council Division on Earth and Life Studies et al., 2015; Rickels et al. 2011).

These issues also raise questions about climate justice, intergenerational justice, and morality. Changes in precipitation patterns would hit regions which are already very arid and negatively affected by climate change, while it would reduce mitigation pressures on industrialized countries. As the existence of SAI could be seen as an excuse to reduce mitigation efforts this would shift the risks of climate change and SAI into the future and would burden future generations. Furthermore, the question arises whether it is morally right that humans deliberately change the Earth's temperature (National Research Council Division on Earth and Life Studies et al., 2015; Rickels et al. 2011; Shepherd, 2009).

Among the public, SAI and CE are currently not well known (Mercer et al., 2011; Merk et al. 2015; Pidgeon et al., 2012; Spence et al., 2010), but the concern about CE technologies is substantial when survey respondents are informed about the technologies (Bellamy & Hulme, 2011; Borick & Rabe, 2012; Macnaghten & Szerszynski, 2013; Merk et al. 2015). In fact, there have already been protests against field testing an injection technology for SAI and ocean iron fertilization in the past (Schäfer et al., 2015; Stilgoe et al., 2013).

In my research, I examine more closely how laypersons perceive SAI, its risks and benefits. The studies look at the determinants of acceptance and the effect on mitigation preferences. They are based on individual-level data from a survey and an experiment. The studies are the first to (1) provide insights into people's perceptions of different forms of research and deployment

(Merk et al., 2015), (2) assess the interdependence of the determinants of acceptance (Merk & Pönitzsch, 2016) and (3) analyze the effect of information about SAI on revealed mitigation preferences (Merk et al., 2016)

Researching SAI acceptance and its determinants does not aim at making the technology acceptable but at identifying public concerns early on (Pidgeon et al., 2013), enable informed decisions on research and possible deployment (Carr et al., 2013), and improve communication strategies (Huijts et al., 2012). While expert assessments are necessary to inform the debate, CE technologies ultimately raise value-based questions that the public might evaluate differently than experts (Pidgeon et al. 2013). Public perceptions will shape the future portfolio of available ways to address climate change (Pidgeon et al., 2013). Knowledge about public acceptance can help to identify priorities and pathways for research and development of strategies to deal with climate change.

The first chapter of my dissertation, *Exploring public perceptions of stratospheric sulfate injection* (Merk et al.2015), provides a first overview of the important factors influencing the perception and the acceptance of research and deployment of SAI. This paper is the first to analyze the acceptance in Germany and overall the first to look at differences in the acceptance of lab and field research. We contribute to the debate on the acceptance of SAI especially by looking at the effect of trust in institutions and ecological attitudes on acceptance.

We conducted an online survey which is representative of the German internet population with respect to age, gender, and state of residence. Subjects were provided with baseline information on climate change and were told about SAI as well as its risks and benefits via a short video.

The survey data on the acceptance of different forms of research and deployment reveal a differentiated picture. Laboratory research on sulfate injection is broadly approved, whereas field research is much less approved. Immediate deployment is largely rejected. The acceptance of the technology is associated with the belief that climate change is a serious problem and that humans will eventually be able to control nature. It is also determined by the levels of trust in scientists and firms. Among the strongest objections against the technology is the belief that humans should not manipulate nature in the way injecting sulfate would.

Our results imply that in Germany public support for SAI is low and that research on sulfate injection should be accompanied by a global debate that incorporates public perceptions and concerns into the development and governance of the technology. Public acceptance might be a major limiting factor for research and development of SAI.

The second chapter, *The role of affect in attitude formation toward new technologies: The case of stratospheric aerosol injection* (Merk & Pönitzsch, 2016), takes a closer look at individuals' attitude formation with respect to SAI. This paper draws upon models from social psychology on the perception and acceptance of new technologies which are potentially connected to large risks. We propose a technology acceptance framework that captures the interplay between values, attitudes, affect, risk and benefit perception, and the acceptance of new technologies. It highlights the role of affect in attitude formation towards new technologies and examines how affect mediates the influence of stable psychological variables on technology acceptance.

We test the technology acceptance framework using the same data as in the first chapter. For the statistical analysis, we use structural equation modelling (e.g. Acock, 2013; Bollen, 1989) which helps to identify variables' direct and indirect effects on acceptance. Acceptance is directly influenced by the perception of the technologies' characteristics like risks and benefits. But those again are guided by situation transcendent stable psychological variables. In our study, we are especially interested in the mediation of the impact of stable psychological variables on acceptance by affect and perception and whether feelings or perceptions, i.e. affective or cognitive pathways, are more important in attitude formation.

Our data provide evidence of both affective and cognitive pathways in attitude formation. Acceptance is directly influenced by positive and negative affect, as well as perceived risks and benefits. People are, however, more strongly guided by affect than by their perception of risks and benefits. Furthermore, affect is the most important mediator between stable psychological variables – such as trust, values, and attitudes – and acceptance. All variables influence acceptance partly via their influence on the affective evaluation. Only trust, altruism, and state of nature change the perception of risks and benefits via affect and also directly. We thus find that a person's affective response is guided by her general attitudes and values which then influences risk and benefit perception and acceptance.

Our study adds to a growing literature about the importance of affect in guiding judgement (Finucane et al., 2000; Lerner et al., 2015; Loewenstein et al., 2001; Zajonc, 1980). In contrast to this literature, we not only show the relevance of affect, but also how affect is influenced by

a person's characteristics. We show that it is in part shaped by a person's values, attitudes, trust, and risk aversion. Hence, affect, as automatic emotional reaction, seems to express a person's core values and attitudes applied to a specific situation. In this sense, it is essential to and supports rational action. Our result also speaks to literature that shows reductions in the quality of decisions when affective evaluations are impaired (Bechara et al., 1997; Damasio, 1994; Wilson et al., 1993; Wilson & Schooler, 1991).

The third chapter, *Knowledge about aerosol injection does not reduce individual mitigation efforts* (Merk et al., 2016), addresses one of the main concerns about the potential effects of CE today: Even if CE and SAI in particular would never be used, the discussion about it could have a detrimental effect on the willingness to mitigate climate change today. In the CE literature this effect is called moral hazard, risk compensation, or mitigation obstruction concern (Betz & Cacean, 2012; Keith, 2013; Morrow, 2014). It implies that policymakers, interest groups or individuals might wrongly perceive SAI as an easy fix for climate change and accordingly reduce their mitigation efforts. This would exacerbate climate change and could increase the pressure to do more than just mitigation.

Our study is the first to provide an empirical evaluation of this claim in the context of individual behavior. We conducted a large-scale framed field experiment with more than 650 participants who could mitigate climate change by buying voluntary carbon offsets. Subjects received a 10 Euro endowment which they could either take home or use to buy offsets. In the baseline treatment, subjects were only informed about climate change and its effects. In the SAI treatment, subjects learned about SAI, its potential risks and benefits.

The data show that people do not reduce mitigation when they learn that climate change could be partly addressed by deploying SAI. Instead, we observe that people who have been informed about SAI mitigate more than people who have not. Thus, we find no evidence for risk compensation at an individual level as a reaction to information about SAI. Furthermore, we find no reduction in mitigation for those who perceive SAI as an effective method against climate change, even though they should be the ones most likely to reduce mitigation. Our data suggest that the increase is driven by a perception of SAI as potential threat.

The study extends previous research by analyzing the effect of information on SAI using revealed preferences and it shows that the debate about the occurrence of risk compensation is far from being settled. Theoretical considerations strongly support the occurrence of risk compensation behavior (for an overview see Lin 2012; Morrow 2014) and both scientists (Lawrence & Crutzen 2013; Schneider 2001) and laypersons perceive it as a very convincing

scenario that people could use SAI as an excuse to continue with carbon-intensive lifestyles (Corner & Pidgeon, 2014; Ipsos MORI, 2010; Mercer et al., 2011; Merk et al., 2015; Wibeck et al., 2015; Winickoff et al., 2015). Instead, our results are the first to empirically support the intuition that subjects who have been informed about SAI will mitigate more (Betz & Cacean, 2012; Shepherd, 2009; Wibeck et al., 2015).

Behavioral changes

The final chapter of the dissertation explores ways to change individuals' mitigation behavior by informing them about their peers' behavior. To keep the temperature increase below 2°C, global emissions have to decrease between 40 to 70% until 2050 compared to 2010 (IPCC, 2014). With or without the development of CE technologies, research and development of more efficient technologies will be important for climate change mitigation. The bottleneck is, however, the human dimension: alongside technological changes, changes in consumer behavior and lifestyles are necessary to mitigate climate change.

But emissions reductions from improvements in energy efficiency are compensated by the rebound effect (Gillingham & Palmer, 2014) and potential energy efficiency gains are not realized due to consumers' investment constraints or behavioral failures like information asymmetries or hyperbolic discounting (Gillingham & Palmer, 2014). Even if there are individual costs savings from climate protection – like reductions in energy costs – these are often not sufficient to motivate people to change their behavior. Policymakers and researchers have therefore started to look for ways to complement conventional (monetary) policies to foster efficiency and conservation and thus support mitigation (Behavioural Insights Team, 2011).

Lately, the spotlight has been on the impact of social information on energy conservation (Behavioural Insights Team, 2011). Research indicates that informing people about their peers' behavior has a strong and lasting impact on their behavior with respect to environmental protection (Allcott & Rogers, 2014; Bhanot, 2015; Dolan & Metcalfe, 2015). It might even be more (cost) effective compared to conventional programs which provide financial incentives (Allcott & Greenstone, 2012).

Social norms motivate behavior because following the norm creates a positive social image and a good reputation while transgressions create stigma (Bénabou & Tirole, 2006). Messages about social norms such as telling people the majority of their peers conserved energy or water have a stronger impact on environmental conservation than messages which motivate

conservation with appeals to social responsibility, self-interest, or responsibility for the environment (Goldstein et al., 2008; Nolan et al., 2008). More often than people realize, their actions are driven by social norms than by self-serving justifications like saving the environment (Nolan et al., 2008).

So far, there is little work about peer effects on climate protection. Previous studies either analyze stated behavior (Araghi et al., 2014; Bolsen et al., 2014) or look at the impact of mean information (Löschel et al., 2013). Peer information might have a smaller or no impact on individual climate change mitigation decisions. Unlike water or energy conservation, it is not additionally connected to private payoffs. Furthermore, climate protection is a global public good where the identification with the group of beneficiaries might be low. (2009) showed that subjects act more prosocial towards in-group members compared to out-group members.

In the final chapter, *The impact of social information on individuals' climate change mitigation* (Merk, 2016), I analyze the effect of social information on individual climate change mitigation. The study especially analyses whether previous decisions can be changed by information on other subjects' behavior.

The study extends past research by disentangling the effects of good and bad examples on free-riding, the propensity to change behavior, and the extent of change in contributions. Furthermore, to the best of my knowledge, it is the first study to test the impact of relative peer information on contributions to climate protection.

In the experimental setup, subjects first stated how many voluntary carbon offsets they wanted to buy, then they were informed about how many offsets another randomly selected subject had bought and they had to reconsider their initial purchase decision. There was no interaction between subjects and any contribution as well as free-riding was anonymous. Thus, the main motivation for contributing should come from a warm glow of giving, i.e. a positive self-image of being the kind of person who does the morally 'right' thing (Andreoni, 1990; Bénabou & Tirole, 2006; Kahneman & Knetsch, 1992; Kraft-Todd et al., 2015).

According to the data, social information does not motivate free-riders to buy offsets. The effect on cooperators is twofold – good examples raise the probability to increase the purchase more than bad examples raise the probability to decrease the purchase. Especially, subjects with high beliefs about peers increase the amount of offsets when their initial purchase is low. But while good examples increase the probability to change more strongly, bad examples have a larger marginal effect on the change.

Introduction

The results imply that those who buy offsets derive positive self-image, i.e. warm glow, from mitigating climate change and complying with a perceived social norm. Consequently, free-riders are not affected by the social information while those who buy offsets are affected. Cooperators are more likely to change their decision when they see good examples; this could be caused by the wish to resolve the cognitive dissonance and to restore their self-image of being someone who does the 'right' thing.

For climate policy, this study identifies pitfalls and opportunities of informing about peers for increasing cooperation among those who are already willing to mitigate. It is important to provide realistic examples which are bad examples to as few people as possible. But the results also show that a substantial share of people is not affected by social information, i.e. social norms. Future research should thus look at ways to extend the reach of the social norm for contributing to climate protection to also motivate free-riders to contribute.

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Exploring public perceptions of stratospheric sulfate injection

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Abstract

Injecting sulfate aerosols into the stratosphere could quickly offset global warming caused by anthropogenic greenhouse gas emissions. Because the technology would have global side effects, it raises not only technological but also political, ethical, and social concerns. Therefore, research on sulfate injection should be accompanied by a global debate that incorporates public perceptions and concerns into the development and governance of the technology. Our paper provides insight into public perceptions and explores their underlying patterns using a survey conducted in Germany. The data reveal a differentiated picture. Laboratory research on sulfate injection is broadly approved, whereas field research is much less approved. Immediate deployment is largely rejected. The acceptance of the technology is associated with the belief that climate change is a serious problem and that humans will eventually be able to control nature. It is also determined by the levels of trust in scientists and firms. Among the strongest objections against the technology is the belief that humans should not manipulate nature in the way injecting sulfate would. The actual public perceptions of sulfate injection will, however, evolve along with the ongoing debate between the public, experts, and policymakers.

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1 Introduction

New technological options to reduce global warming are currently under discussion because international efforts to mitigate climate change continue to progress slowly. These options, known as climate engineering (CE) or geoengineering, involve deliberate large-scale interventions in the climate system to reduce global warming. They increasingly appear in mass media, enter political discussions (Mercer et al. 2011), and were recently mentioned in the Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC, 2013).

CE encompasses two approaches. The first approach, carbon dioxide removal (CDR), is to reduce atmospheric concentrations of carbon dioxide. The second approach, solar radiation management (SRM), is to increase the Earth's albedo to reflect more sunlight back into space. Our paper addresses the most prominent and controversial method of SRM, which is the injection of sulfate aerosols into the stratosphere. In contrast to other methods to counteract climate change, sulfate injection can be deployed quickly and causes direct reductions in global temperature (Robock et al. 2008). In addition, it has been suggested that it involves low operational costs (Barrett 2008). Such claims, however, ignore additional economic costs like price and external effects (Rickels and Klepper 2012). Especially external effects could result in very high total costs because the risks of sulfate injection are substantial and global (Royal Society 2009).

A comprehensive discussion is needed to support informed decisions on research and deployment of sulfate injection because the technology involves a deliberate manipulation of the Earth's environmental system, there are major uncertainties regarding its side effects, and the consequences of its use are global. The assessment of sulfate injection thus must address legal, political, ethical, and social issues (see Royal Society 2009 and Rickels et al. 2011 for an overview). While expert assessments are necessary to inform the debate, the issues ultimately raise value-based questions that the public might evaluate differently than experts (Pidgeon et al. 2013). Research on public perceptions can provide initial insights into public concerns and thereby inform decisions on future research and on the potential development of the technology. Its aim is not to influence public opinion in any particular direction or to replace legitimate democratic political decision-making but to better understand the public's sensitivities and its criteria for assessing the technology (Corner et al. 2012; Carr et al. 2013).

Based on a large-scale survey conducted in Germany, we contribute to the discussion on stratospheric sulfate injection by answering two important questions: (1) how does the public perceive different types of research and deployment of sulfate injection in different

circumstances? and (2) what factors drive public perceptions of sulfate injection?

Our first research question extends recent results on public perceptions of CE options: it includes the perceptions of different types of research on sulfate injection and it confirms previous findings on the perceptions of aerosol injection for a country in which public perceptions of sulfate injection have not previously been studied. Many earlier studies have investigated CE options in general and did not distinguish between different types of research or different circumstances of deployment. These studies also varied considerably in the level of detail they provided in describing the technology. Most referred only briefly to CE technologies as a climate change policy option (Borick and Babe 2012; Bostrom et al. 2012; Leiserowitz et al. 2012; Spence et al. 2010), while others provided more information on SRM as well as CDR technologies (Kahan et al. 2012; US GAO 2011). These studies were primarily conducted in the US and the UK. To date, two surveys have investigated public perceptions of aerosol injection and included a section with information on the technology. Mercer et al. (2011) surveyed respondents in Canada, the UK, and the US; Sugiyama and Fujiwara (2012) surveyed respondents in Japan. They assessed the perceptions of general research, immediate deployment of the technology, emergency deployment, and complete rejection of the use of the technology.

Public awareness of CE in general and of specific CE technologies remains low. The share of people who have never previously heard about climate engineering or geoengineering ranges from 65% (US GAO 2011), to 75% (Buck 2010; Spence et al. 2010; Mercer et al. 2011; Pidgeon et al. 2012¹), and 90% (Sugiyama and Fujiwara 2012). Overall, research on public perceptions finds a low level of support for these technologies (Bellamy and Hulme 2011; Borick and Rabe 2012; Bostrom et al. 2012; Macnaghten and Szerszynski 2013) and a preference for mitigation over CE as policy option against climate change (Pidgeon et al. 2012; US GAO 2011). Accordingly, survey respondents tend to agree that employing aerosol injection to counteract climate change would be the easy way out (Mercer et al. 2011; Sugiyama and Fujiwara 2012), and workshop participants tend to be concerned about the inability of aerosol injection to address increasing greenhouse gas emissions (Pidgeon et al. 2013).

Previous research indicates that public perceptions vary depending on the specific context. First, opinions toward deployment depend on the circumstance in which the technology would be deployed. Mercer et al. (2011) and Sugiyama and Fujiwara (2012) report higher acceptance of deployment of aerosol injection in the case of a climate emergency compared to the case in which the technology would be deployed as soon as it were technically feasible. Second, public

¹ Pidgeon et al. (2012) and Spence et al. (2010) analyze the same dataset.

support for research does not necessarily entail support for actual use of the technology. Pidgeon et al. (2013) note that participants in deliberative workshops often express negative views of stratospheric aerosol injection in general but express more nuanced views of the UK research project SPICE (Stratospheric Particle Injection for Climate Engineering), which was supposed to involve field tests.² Also surveys report that research on aerosol injection is more acceptable than actual deployment (Mercer et al. 2011; Sugiyama and Fujiwara 2012).

Public perceptions are also likely to vary between the different types of research on sulfate injection. Research activities might be classified into laboratory research that involves the use of computer models and laboratory experiments and field research that involves the release of materials into the environment (SRMGI 2011). Different types of research involve different levels of interference with nature and potentially involve different perceived direct risks (e.g., threats to the environment) and perceived indirect risks (e.g., creating a slippery slope toward deployment). To address this issue, the present study distinguishes not only between different circumstances of deployment but also between different types of research.

Our second research question examines the factors that influence public acceptance, such as the perceived seriousness of climate change, risk aversion, attitudes toward sulfate injection, ecological attitudes, trust in institutions, religiosity, and socio-demographic variables. Previous studies have already investigated the importance of some of these factors. The perceived seriousness of climate change increases acceptance of sulfate injection as a potential solution to the problem (Mercer et al. 2011; Pidgeon et al. 2012; Sugiyama and Fujiwara 2012); although, the risks of massive climate change have to be weighed against the risks of sulfate injection. Thus, individuals' level of risk aversion might be a potentially contributing factor, but its influence has yet to be researched. It might increase or decrease acceptance of sulfate injection, depending on the extent to which individuals attribute a higher risk to massive climate change or to sulfate injection. Our survey also includes items to examine two previously suggested arguments against the technology: that humans should not manipulate nature in this way and that using sulfate injection to combat climate change would be the too easy way out (Mercer et al. 2011). These attitudes might also be related to beliefs about human technological ingenuity (Kahan et al. 2012) and the relationship between humans and nature (Corner et al. 2013). Thus, the survey includes items about these two aspects, which we collectively refer to as ecological attitudes. We expect that individuals with the belief that humans were meant to rule the Earth or that humans would eventually learn enough to control the environment would be more willing to accept sulfate injection, while individuals

² <http://www.spice.ac.uk/>.

expressing concerns about the fragility of the balance of nature might either reject or accept the technology, depending on whether it was viewed as disrupting or restoring nature (Corner et al. 2013). Another potential objection to the use of the technology is the perception that humans might be 'playing God' (Carr 2014); the survey, thus, includes religiosity to account for the role of religious beliefs.

Another relevant factor for the public perceptions of research and deployment is the governance framework and the extent to which people trust that different policy and decision makers will act responsibly. Findings from focus groups on solar radiation management indicate that confidence in the ability of research to forecast risks and benefits as well as confidence in effective and democratic governance are prerequisites for acceptance (Macnaghten and Szerszynski 2013). These results are consistent with prior findings on the positive effect of trust in institutions on the acceptance of large-scale risks (Earle 2010). Our study therefore examines the role of trust in different actors. Socio-demographic variables might also contribute to people's perceptions; for example, Pidgeon et al. (2012) report lower levels of support for climate engineering in general among women and individuals with a lower level of education. Our analysis therefore accounts for socio-demographic variables.

By addressing these two research questions, the study broadens and deepens the understanding of public perceptions of sulfate injection and contributes to the previous literature in a number of ways. First, our survey is the first to explicitly distinguish between perceptions of laboratory and field research. Second, our survey is the first to study perceptions of sulfate injection in a continental European country (Germany). Compared to other Europeans, Germans express more negative attitudes toward nuclear energy and carbon capture and storage but more positive attitudes toward wind and hydroelectric energy (European Commission 2011). Our survey provides insights into Germans' attitudes toward sulfate injection. Third, our survey investigates a wide range of factors that might influence public perceptions of sulfate injection. Finally, our study extends the descriptive analyses employed in previous studies (Mercer et al. 2011; Sugiyama and Fujiwara 2012) by employing a multiple regression framework to analyze the effect of these factors on public acceptance in different circumstances.

2 Survey design

We conducted an online survey to assess the perceptions of sulfate injection among the German population in December 2012. Survey respondents were recruited from an online panel and were sampled using quotas for the characteristics gender, age, and state of residence. The sample consisted of 1040 respondents; half of the respondents were female. Respondents ranged in age from 18 to 81 years, with an average age of 47 years. Half of the respondents had a higher education entrance certificate, while the other half of the respondents had completed only lower secondary education or had no degree. As a result, respondents with a high level of education are overrepresented in the sample.

All items used in the analysis are presented in table A-1 of the online appendix; responses to items were all assessed using Likert scales. The questionnaire consisted of three parts.

The first part contained questions assessing respondents' attitude toward risk, the perception of the seriousness of climate change, and ecological attitudes. The attitude toward risk was assessed on the scale from Dohmen et al. (2011) ranging from 0 ('risk averse') to 10 ('fully prepared to take risks'). In the analysis, the values were reversed to capture risk aversion. We also assessed the perception of the seriousness of climate change (Q3). Respondents' ecological attitudes were measured using 5 of the 15 items of the New Ecological Paradigm Scale (NEP, Dunlap et al. 2000). They assess attitudes toward limits to growth (Q4-1), anthropocentrism (Q4-2), the fragility of the balance of nature (Q4-3), human exemptionalism (Q4-4), and the possibility of an imminent eco-crisis (Q4-5). Both the seriousness of climate change and the NEP were measured using a four-point scale that ranged from 1 ('strongly disagree') to 4 ('strongly agree').

The second part contained a video explaining anthropogenic climate change and sulfate injection followed by questions about the respondents' perceptions. The video consisted of animated infographics and brief bullet points that were explained by an accompanying voice-over.³ First, respondents received information on the causes and likely consequences of climate change. Mitigation, adaptation, and sulfate injection were introduced as three options to address climate change.⁴ The video stated that sulfate injection would not prevent all consequences of climate change and that it was not a complete substitute for mitigation. The video then presented the risks and benefits of sulfate injection in greater detail. Because the goal

³ The German video together with the accompanying transcript in English is provided in the online appendix of the published paper.

⁴ The video initially described sulfate injection as 'spraying sulfate particles into the atmosphere at high altitude' to reflect sunlight. When subsequently referring to the technology, both the video and the survey used the term 'solar radiation management' or the abbreviation 'SRM'.

was to present currently available information on the topic in a clear, scientifically accurate and unbiased manner, the information presented was based on peer-reviewed papers and scientific reports (e.g., Crutzen 2006; IPCC 2007; IPCC 2012; Rickels et al. 2011; Robock 2008); it reflects the broad consensus on climate change and the risks and benefits of sulfate injection at the time. Information on the technology was based in part on previous work (Mercer et al. 2011). Independent experts reviewed the information presented for clarity and accuracy.

Before the video, participants' level of awareness of the technology was assessed (Q5). After the video, one item assessed the acceptance of laboratory research (Q10-1) and another item assessed the acceptance of field experiments (Q10-2). Following Mercer et al. (2011) and Sugiyama and Fujiwara (2012), respondents were asked about their acceptance of deployment in different circumstances: to avert massive and irreversible changes in the climate system due to climate change, i.e. in case of a climate emergency (Q10-3); as soon as the deployment of the technology was technically feasible, which we refer to as 'immediate deployment' (Q10-5); or never, under no circumstances (Q10-4). The response scale for all these items (Q10) ranged from 1 ('strongly disagree') to 4 ('strongly agree'). All these scenarios imply a continuation of mitigation efforts. The perception of overall benefit (Q11) and overall risk (Q12) was measured on a scale ranging from 1 ('very small') to 4 ('very large'). The specific risks (Q13) and benefits (Q14) appeared in the questionnaire with the same wording which was used in the video; respondents' perceptions were measured on a scale ranging from 1 ('negligible') to 4 ('very serious') (Q13) and from 1 ('very small') to 4 ('very large') (Q14), respectively. We also measured the extent to which respondents agreed with four items expressing different attitudes toward the injection of sulfate. For example, the statement 'Humans should not be manipulating nature in this way' (Q17-3) was assessed on a scale ranging from 1 ('strongly disagree') to 4 ('strongly agree'). Trust that different institutions or actors would act in the interest of society and the environment was measured on a scale ranging from 1 ('do not trust at all') to 4 ('trust completely').

The third part contained questions on respondents' socio-demographic characteristics that were not available from the panel's database. We have information on respondents' gender, age, and state of residence as well as other characteristics, such as the level of education⁵ or whether the respondent had children. In addition, we assessed respondents' religiosity (Q26) on a scale ranging from 1 ('not religious at all') to 4 ('very religious'). At the end of the questionnaire, respondents had the opportunity to make comments on sulfate injection (Q36). 78%

⁵ Respondents with a higher education entrance certificate were coded as having a high level of education in the analysis.

of the respondents made 1436 different statements in total. The statements were coded by a research assistant who was otherwise not involved in the research.

3 Descriptive results

In the following, we describe responses to the questionnaire. When appropriate, we aggregate responses from the four-point Likert scales into two categories. For example, we speak of agreement when respondents choose the categories 'strongly agree' or 'somewhat agree'. Correspondingly, we speak of disagreement when respondents choose the categories 'strongly disagree' or 'somewhat disagree'.

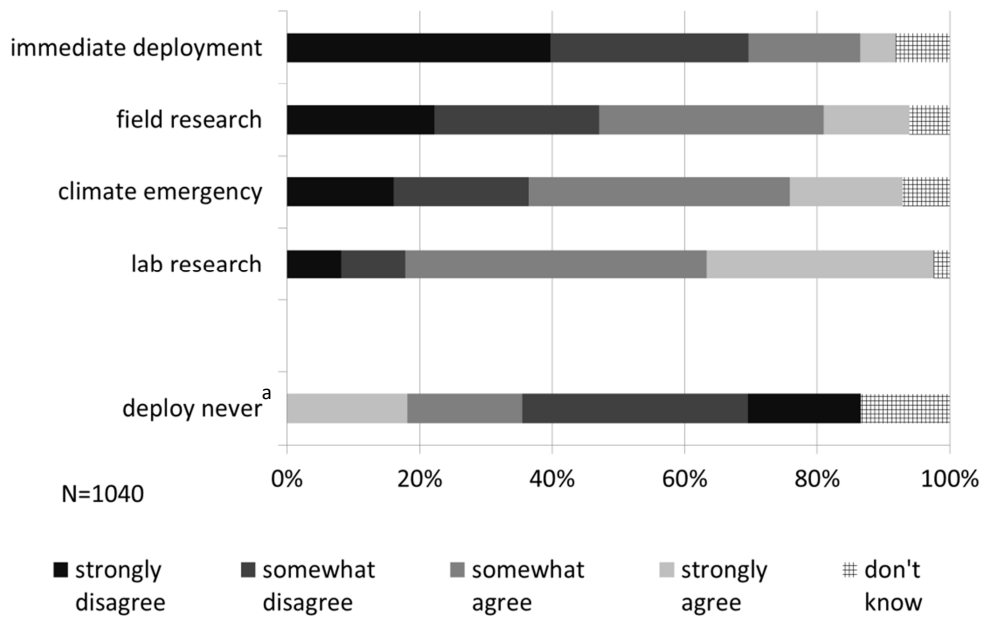
Public awareness and perceptions of the video

Currently, the German population does not exhibit widespread awareness of sulfate injection. Before watching the video, 80% of the respondents state that they have not previously heard about spraying sulfate particles into the atmosphere at a high altitude to counteract climate change; 17% recognize the technology and state that they had heard a little about it; and 3% state that they had heard a lot about it (Q5). After watching the video, 80% state that they perceived the video's position toward sulfate injection as neutral; 13% state that the video was biased in favor of the technology; and 1% states that the video was biased against it (Q9). Only ten of the 1040 respondents report difficulties in understanding the video (Q8).⁶

Acceptance

Figure 1 summarizes the findings regarding acceptance of the different types of research and acceptance of deployment in different circumstances. Laboratory research is widely accepted; with 80% of respondents agreeing that scientists should study sulfate injection through computer models and laboratory experiments (Q10-1). Acceptance of field research involving small-scale experiments in the atmosphere is markedly different; only 47% of the respondents are in favor of field research (Q10-2). This implies that approximately one-third of the respondents believe that research should be conducted in the laboratory but not in the field.

⁶ Respondents were not able to skip or fast forward the video.

Figure 1: Acceptance of different types of research and of deployment in different circumstances

^a Agreement with this item reflects the rejection of sulfate injection.

The most accepted circumstance for deployment is in case of a climate emergency. Slightly more than half of the respondents (56%) agree with deployment in this case (Q10-3). The relatively high acceptance of emergency deployment indicates that some respondents support emergency deployment despite their opposition to field research. The most immediate form of deployment is as soon as it is technically feasible (Q10-5). 22% of the respondents support immediate deployment, while 70% of the respondents disagree – many of them indicating strong disagreement. 35% of the respondents agree that sulfate injection should never be used regardless of the situation (Q10-4), with 18% of all respondents strongly agreeing that the technology should never be used. In summary, the respondents' opinions regarding sulfate injection vary across types of research and circumstances of deployment.

Attitudes toward sulfate injection

We explore key attitudes toward sulfate injection using further questions. More than 70% of the respondents think both that humans should not be manipulating nature in this way (Q17-3) and that using the technology to counteract climate change would mean to take the too easy way out (Q17-1).⁷ Both attitudes also feature prominently in the free-form comments made at the end of the survey. Many respondents voice concerns that humans should respect

⁷ The connotation of the German expression for taking the too easy way out is that sulfate injection cannot be right; taking the too easy way out is considered to shirk one's responsibility or to be thoughtless.

nature and 'not play God'. Others state that the causes rather than the symptoms of climate change should be addressed.

A strong concern in the discussion about the technology is about the final decision regarding implementation. Specifically, research on sulfate injection might create a slippery slope toward its implementation. Respondents express the belief that research into the technology would lead to its deployment no matter what the public thinks (Q17-2); 71% of the respondents agree with this statement. The strong concern about the deployment decision is also visible in the free-form comments. The comments express the need to involve all nations as well as the general public in the decision-making process.

Perceptions of risks and benefits

We asked respondents to judge the extent of the overall risk of sulfate injection and the severity of its specific risks. The overall risk (Q12) is perceived as large; 81% of the respondents view the risk as very large or somewhat large, and 42% view the risk as very large.

Respondents exhibit the most concern about the abrupt temperature change that would be caused by a sudden termination of sulfate injection (Q13-4) and the risk of yet unknown and unpredictable consequences (Q13-3). For both these risks, at least 88% of the respondents perceive them as serious. 85% of the respondents perceive changes in precipitation as a serious risk (Q13-1). Respondents exhibit only slightly less concern about the persistence of carbon-intensive lifestyles if sulfate injection were deployed (Q13-2). Finally, international conflicts caused by trans-boundary side effects (Q13-5) are perceived as a serious risk by 72% of the respondents.

The perception that the risks are serious is dominant; any specific risk is viewed as serious by more than 72% of the respondents. Moreover, apart from the risk of international conflict, 45% of the respondents view each specific risk as very serious. Concerns about specific risks are also frequently mentioned in the free-form comments.

Similarly, we asked respondents to judge the extent of the overall benefit and specific benefits of sulfate injection. In contrast to the perceptions of risks, the perceptions of benefits show a higher variance across respondents. The overall benefit (Q11) is perceived to be small by 51% of the respondents, and perceived to be large by 41% of the respondents. Only few responses fall into the categories 'very large' (6%) or 'very small' (12%); respondents do not display extremely positive or negative opinions regarding the overall benefit of sulfate injection.

The evaluation of specific benefits yields a differentiated picture. The possibility of preventing massive, irreversible changes in the climate (Q14-2) is most often perceived as a large benefit of the technology; 54% of respondents perceive this benefit as large. The speed at which the climate can be cooled (Q14-1) comes second; 51% perceive this benefit as large. The possibility of unilaterally deploying sulfate injection (Q14-4) and the comparatively low costs of implementation (Q14-3) are less often rated as beneficial; 42% and 35% of the respondents perceive these benefits as large, respectively.

4 Regression analysis

To further analyze public acceptance of sulfate injection and its underlying patterns, we conducted a regression analysis.

As predictors of acceptance, we used the variables that were discussed in Section 1 and described in Section 2. The econometric model thus includes independent variables capturing risk aversion, perceived seriousness of climate change, ecological attitudes, trust in different institutions, attitudes toward sulfate injection, religiosity, and socio-demographic factors.⁸ We did not include the awareness of sulfate injection because the variable shows too little variation. The dependent variables capture acceptance in different circumstances and take ordered values ranging from 1 ('strongly disagree') to 4 ('strongly agree'). We hence used ordered logistic regression as the estimation procedure.

Table 1 presents the regression results. The columns display regression results for (1) laboratory research, (2) field research, (3) deployment in case of a climate emergency, and (4) immediate deployment.

Most of the explanatory variables have a significant effect on acceptance. Risk aversion (Q2) negatively affects the acceptance of field research and immediate deployment. The perceived seriousness of climate change (Q3) increases the acceptance of field research and of deployment in case of a climate emergency. In contrast, the perceived seriousness of climate change does not increase the acceptance of immediate deployment. This finding is in line with the consequences of climate change primarily occurring in the future and the belief that serious consequences might still be averted by other means.

⁸ Summary statistics are available in table A-2 in the online appendix.

Table 1: Results obtained from ordered logistic regressions

	(1) lab research	(2) field research	(3) emergency deployment	(4) immediate deployment
(Q2) risk aversion	-0.04	-0.07**	-0.01	-0.06*
(Q3) seriousness of climate change	0.16	0.28**	0.41***	0.11
<i>Ecological attitudes</i>				
(Q4-2) limits to growth	0.20*	0.03	0.08	-0.02
(Q4-3) anthropocentrism	0.18*	0.11	0.04	0.18
(Q4-4) balance of nature	0.36***	-0.03	-0.03	-0.16
(Q4-5) hum exemptionalism	0.09	0.33***	0.53***	0.28**
(Q4-6) risk of an eco-crisis	0.06	0.24*	0.17	0.67***
<i>Attitudes</i>				
(Q17-1) is too easy way out	0.04	-0.13	-0.01	-0.52***
(Q17-3) not manipulate this way	-0.66***	-0.83***	-0.93***	-0.73***
<i>Trust</i>				
(Q23-1) government	-0.17	0.34***	0.16	0.13
(Q23-2) firms involved	0.01	0.37***	0.19	0.79***
(Q23-3) environmental org	0.22**	-0.02	0.08	-0.19
(Q23-4) media	0.09	0.08	0.09	-0.03
(Q23-5) scientists	0.91***	0.68***	0.88***	0.40***
(Q23-6) United Nations	-0.08	-0.09	0.05	0.00
(Q23-7) European Union	0.21	0.02	-0.01	0.37**
<i>Socio-demographics</i>				
(Q26) religiosity	-0.10	-0.09	0.05	-0.01
(DB) female	-0.20	0.14	0.09	-0.14
(Q34) high education	0.02	-0.27*	-0.31*	-0.70***
(DB) age	-0.01	0.00	-0.01*	0.01**
(Q32) children	-0.15	0.26	0.13	0.31
N	682	682	682	682
Pseudo R ²	0.17	0.23	0.25	0.30

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; Scales are from 1 to 4. Exceptions are dummy variables (female, high education, and children), risk attitude (scale is from 0 to 10), and age. Variables indicated by (DB) are part of the panel's database.

With respect to ecological attitudes, the belief in human exemptionalism (Q4-5), i.e. humans' ability to control the environment, displays the strongest predictive power. It has a strong positive effect on people's acceptance of field research and deployment. The risk of an eco-crisis (Q4-6) predicts acceptance of immediate deployment. Because the item reflects beliefs about the imminence of a crisis, it captures the perceived need for timely action. The belief that the balance of nature is fragile and easily upset (Q4-4) increases acceptance of laboratory research, but it does not affect acceptance of implementation. Anthropocentrism (Q4-3), i.e. the belief in humans' designation to rule over nature, and the belief in limits to growth (Q4-2) only have a minor impact on acceptance. Religiosity (Q26) does not have additional explanatory power on top of the other attitudinal items in the model.

Apart from general attitudes toward the environment and the human-environment interaction, the belief that humans should not manipulate nature in this way (Q17-3) strongly decreases acceptance of research and deployment. It also decreases acceptance of the technology as a way to counteract a climate emergency. The attitude that injecting sulfate would be the too easy way out (Q17-1) decreases the acceptance of immediate deployment. This result is consistent with the notion that deployment should only be considered when every other option has been exhausted.

Trust that different institutions or actors would act in the interest of society and the environment significantly affects acceptance. The most important determinant from this group of variables is trust in scientists (Q23-5) who perform research on sulfate injection. Another important determinant is trust in firms (Q23-2) involved in sulfate injection projects. Trust in firms is a prerequisite for the acceptance of field research and immediate deployment. For the acceptance of laboratory research, however, in which firms' involvement is likely to be low, trust in firms is not a significant predictor. Trust in firms is also not a significant predictor for the acceptance of deployment in case of a climate emergency. In this circumstance, typical problems with respect to firms, such as vested interests, might be expected to play a minor role. Trust in government (Q23-1) is another predictor of acceptance, although it is not as important as trust in scientists or firms. First, trust in the federal government is positively associated with the acceptance of field research. This relationship might reflect trust in the rules for research set by the government. Second, trust in the EU is positively associated with the acceptance of immediate deployment. Trust in environmental organizations (Q23-3) is only modestly associated with acceptance after controlling for ecological attitudes. Trust in environmental organizations is positively associated with the acceptance of laboratory research, which may reflect a lower perceived risk of hasty deployment. Trust in the media (Q23-4) does not predict acceptance.

In addition, the socio-demographic variables education and age exhibit explanatory power. A high level of education (Q34) reduces the acceptance of field research and deployment. This finding might reflect differences in information processing, in dealing with complexity, or in socio-economic status. The level of education most strongly affects the acceptance of immediate deployment. The effect of age depends on the circumstance of deployment. Age is positively related to the acceptance of immediate deployment but negatively related to the acceptance of emergency deployment. These relationships are not consistent with an intertemporal risk-risk tradeoff and thus point to particular intergenerational differences in the

perceptions of sulfate injection. Neither gender nor having children (Q32) are related to acceptance of the technology.

Our results proved to be robust to alternative specifications. First, we checked whether it is appropriate to include the independent variables as continuous variables by running regressions using binary indicators for the levels of these variables. The results confirm that the effects of the independent variables are linear.⁹ Second, we checked for differences in acceptance across German states to control for interregional differences in factors, such as religious composition or population density. The results are not significantly different. Finally, we ran regressions using binary and multinomial logistic models. The direction and the significance of the coefficients remain similar.

5 Discussion and conclusion

Overall, German respondents are highly skeptical of sulfate injection. The views depend on the type of research and the circumstance of deployment. First, respondents' higher acceptance of laboratory research compared to field research reveals their concern regarding the negative side effects of field research. The finding highlights the importance of (1) identifying what can be learned without actually intervening in the Earth's environmental system (Robock et al. 2013), (2) identifying the type of research to be performed when communicating with the public and (3) establishing a governance framework for research (SRMGI 2011). Second, the higher level of acceptance of emergency deployment compared to immediate deployment reflects respondents' belief that climate change might still be averted by other means. Finally, the higher level of acceptance of laboratory research compared to any type of deployment suggests that respondents perceive laboratory research as a means to better understand the technology's side effects or as a way to develop an insurance against massive and irreversible climate change.

The distinction between different circumstances and their implications is also relevant when examining the factors influencing acceptance of the technology. The perceived seriousness of climate change is positively associated with acceptance of research and emergency deployment. Faced with the risk-risk trade-off between climate change and sulfate injection, respondents who are more concerned about climate change seem not to want to dismiss the technology out of hand. Additionally, the perception that sulfate injection would be taking the too easy way out, i.e. shirking the responsibility for climate change, decreases the acceptance

⁹ Results of this robustness check are presented in table A-3 in the online appendix.

of immediate deployment but does not reduce the acceptance of research. This suggests that spending money on researching sulfate injection rather than mitigation is not currently viewed as problematic.

We also examine beliefs about the relationship between humans and nature as potential determinants of acceptance. The perceived fragility of the balance of nature, however, is neither positively nor negatively associated with the acceptance of the deployment of sulfate injection, which reflects the unresolved debate on whether the technology is beneficial or detrimental to nature (Corner et al. 2013; Rickels et al. 2011). However, the positive association of this belief with the acceptance of laboratory research again reveals the perceived value of sulfate injection as a way to insure against climate change. In contrast, the belief about human interaction with nature strongly influences acceptance. Respondents who believe that humans will eventually be able to control the environment are more accepting of the technology, which might reflect a trust in technology and humans' ability to devise a technological solution to the problem.

The belief that humans should not manipulate nature in this way exhibits the strongest downward impact on acceptance for all types of research and circumstances of deployment. This belief might be interpreted in various ways. It is not associated with religious concerns (Spearman's $\rho = -.02$; $p = .6$) but it is positively correlated with risk aversion (Q2; $\rho = .11$; $p < .01$) and negatively correlated with the beliefs that humans should govern nature (Q4-3; $\rho = -.22$; $p < .001$) and that humans were able to control nature (Q4-4; $\rho = -.23$; $p < .001$). It is also strongly correlated with the belief that climate change should be dealt with differently (Q17-1; $\rho = 0.50$, $p < .001$). Because these factors were controlled for in the regression analysis, the belief that humans should not manipulate nature in this way is likely to represent further aspects that influence acceptance, such as the novelty or the perceived naturalness of the technology. Once people become familiar with the concept of sulfate injection, they might perceive the technology differently. In particular, this change in familiarity might be accompanied by a change in the public's conceptualization of nature and the human-environment interaction (Hansen 2006). The dynamics of people's attitudes toward sulfate injection provide an interesting avenue for future research.

Among the socio-demographic variables, both the level of education and age are significantly associated with acceptance. The specific mechanisms underlying these relationships merit further research as well.

As expected, trust in relevant actors is an important determinant of acceptance. Trust in scientists is the most important prerequisite. This is consistent with the high level of uncertainty regarding the risks of sulfate injection. Trust in firms is important with respect to field research and immediate deployment because the vested interests of firms and a lack of public involvement might create a slippery slope in which research leads to deployment of the technology. These findings indicate that transparency in research and technology use must be a key component of any governance framework and thus highlight one of the Oxford Principles (Rayner et al. 2009).

Overall, our results indicate that sulfate injection is primarily acceptable when it is viewed as an insurance against massive climate change, i.e. a risk management tool. This is consistent with previous research findings that mitigation is preferred to aerosol injection (Pidgeon et al. 2012; US GAO 2011). At the same time, our results reveal that the technology cannot be easily dismissed on the grounds of public acceptance. They highlight the need for appropriate decision-making structures to ensure democratic legitimacy (Victor 2008; Virgoe 2009), to improve decision making, to establish trust, and to respect ethical standards (Carr et al. 2013).

We examine public concerns in Germany, a country in which public perceptions of sulfate injection have not previously been studied. Compared to the results of similar surveys in other countries (Mercer et al. 2011; Fujiwara and Sugiyama 2012), our findings exhibit either a similar pattern of responses or somewhat more critical responses. Our respondents are more likely to perceive sulfate injection the too easy way out and less likely to accept immediate deployment of the technology. However, the comparability of the studies is limited due to differences in the information presented, the wording of the questions, and the questionnaire design. To ensure a broad and comprehensive dialogue regarding sulfate injection, it is critical to identify public perceptions and concerns for a wide range of countries and cultures. Future surveys should allow for direct comparison of results from a representative set of countries that includes developing countries and the countries that are most vulnerable to the effects of climate change. In addition, our survey investigates several factors influencing public perceptions. These factors might be expected to vary for different countries, such as the level of trust in institutions (WVS 2013) and concern for the environment (Marquart-Pyatt 2012). Conflict lines are thus likely to occur at both the national and international level.

As other survey results, our findings must be interpreted cautiously. Corner et al. (2012: 454) note that respondents' lack of prior knowledge of the topic creates the risk that "...participants have been told what they are responding to rather than deciding for themselves how to interpret the item." We therefore paid specific attention to ask balanced questions without leading

cues. In addition, the 'don't know' option was included in every item to signal that not answering was acceptable. The sequence of items within the questions was randomized, and we arranged the questions in a way that prevents or minimizes bias due to order effects. We also consulted with experts on survey design to ensure that our questionnaire met current quality standards. We paid specific attention to frame the video in a balanced and neutral way. It must be noted, however, that the way in which information is framed might influence responses (Corner and Pidgeon 2015). Our results thus provide a snapshot of public perceptions obtained in a highly controlled setting in which the video was the main reference point for respondents' perceptions. Although our sample is broadly representative of the German population, our respondents' views may not reflect actual public perceptions once the technology is more widely known and different framings enter the public discourse.

Despite these limitations, our survey makes a valuable contribution to the emerging public debate on sulfate injection. With regard to future research, our results provide a useful reference point because our respondents' perceptions were not influenced by previous public discourse or extensive media coverage but by a well-documented video. Our results provide information about public concerns that should prove useful for experts and policymakers and that could be incorporated into the formal assessment of the technology and development of a governance framework. To avoid a slippery slope toward premature deployment, it is imperative that public concerns about sulfate injection be explored at an early stage (Carr et al. 2013; Corner et al. 2012) because the public can identify and discuss critical aspects of a technology even when relatively little information on the topic is available (Corner et al. 2012; Macnaghten and Szerszynski 2013). Our results thus provide a first glimpse of public concerns and opinions regarding stratospheric sulfate injection that is relevant for public opinion researchers, experts and policymakers.

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Appendix

Table A-1: Items from the questionnaire

<i>Question and items</i>	<i>response scale</i>
<p>Q2: Risk attitude Are you generally a person who is fully prepared to take risks or do you try to avoid taking risks?</p>	risk averse (0) - fully prepared to take risks (10), reversed
<p>Q3: Seriousness of climate change Global warming is a serious problem.</p>	strongly disagree (1) - strongly agree (4)
<p>Q4: New Ecological Paradigm</p> <ol style="list-style-type: none"> 1 The Earth is like a spaceship with very limited room and resources. 2 Humans were meant to rule over the rest of nature. 3 The balance of nature is very delicate and easily upset. 4 Humans will eventually learn enough about how nature works to be able to control it. 5 If things continue on their present course, we will soon experience a major ecological catastrophe. 	strongly disagree (1) - strongly agree (4)
<p>Q5: Knowledge about SRM Have you ever heard about Solar Radiation Management before or have you never heard about it before?</p> <ul style="list-style-type: none"> • No, I have never heard about it. • Yes, I have heard a little about it. • Yes, I have heard a lot about it. 	
<p>Q10: Acceptance of SRM</p> <ol style="list-style-type: none"> 1 Scientists should research SRM using theoretical models, simulations and lab experiments. 2 Scientists should test SRM using field trials. 3 SRM should be used when massive and irreversible changes in the climate system are approaching which cannot be averted otherwise. 4 SRM should never be used, no matter the situation. 5 If SRM was possible today, we should use it immediately. 	strongly disagree (1) - strongly agree (4)
<p>Q11: Benefit in general Overall, what do you think about the benefits of SRM?</p>	very small (1) - very large (4)
<p>Q12: Risk in general Overall, what do you think about the risks of SRM?</p>	very small (1) - very large (4)
<p>Q13: Specific risks</p> <ol style="list-style-type: none"> 1 It changes the amount of precipitation. 2 It can take away people's motivation to change their lifestyle. 3 There is the possibility of further unknown and unforeseeable risks. 4 The abrupt increase of Earth's temperature in case of a sudden stop of SRM can lead to severe problems for humans and the environment. 5 The use of SRM could cause international conflicts. 	negligible (1) - very serious (4)

Continue →

Table A-1 continued

Question and items	response scale
Q14: Specific benefits	
1 Global warming is slowed down quicker than by cutting greenhouse gas emissions.	very small (1) - very large (4)
2 Massive and irreversible changes in the climate can be stopped before too much damage is done.	
3 It is cheaper than reducing the consumption of fossil fuels.	
4 Even if certain countries do not want to reduce their greenhouse gas emissions, it is possible to stop climate change.	
Q17: Attitude toward SRM	strongly disagree (1) - strongly agree (4)
1 SRM is the too easy way out.	
2 Research into SRM will lead to a technology that will be used no matter what the public thinks.	
3 Humans should not be manipulating nature in this way.	
4 If scientists find that SRM can stop global warming with minimal side effects, then I would support its use.	
Q23: Trust in institutions	do not trust at all (1) - trust completely (4)
How strongly do you trust that these groups will act in the interest of society and the environment?	
1 Federal government	
2 Companies involved in SRM projects	
3 Environmental organizations	
4 Media	
5 Researchers studying SRM at publicly funded research institutes	
6 United Nations	
7 European Union	

Table A-2: Summary statistics

<i>variables</i>	<i>mean</i>	<i>median</i>	<i>standard deviation</i>	<i>min</i>	<i>max</i>
acceptance					
lab research	3.1	3	0.91	1	4
field research	2.4	2	1	1	4
emergency deployment	2.6	3	1	1	4
immediate deployment	1.9	2	0.95	1	4
risk aversion	5.5	5	2.3	0	10
seriousness of climate change	3.5	4	0.76	1	4
New Ecological Paradigm					
limits of growth	3.5	4	0.72	1	4
anthropocentrism	1.8	2	0.86	1	4
balance of nature	3.5	4	0.68	1	4
human exemptionalism	2.2	2	0.86	1	4
risk of an eco-crisis	3.2	3	0.77	1	4
attitude toward SRM					
SRM is too easy way out	3.2	3	0.89	1	4
Should not manipulate nature in this way	3.2	3	0.91	1	4
trust in...					
federal government	2.1	2	0.84	1	4
firms involved	1.8	2	0.82	1	4
environmental org	3	3	0.82	1	4
media	2	2	0.78	1	4
scientists	2.4	3	0.87	1	4
United Nations	2.3	2	0.84	1	4
European Union	2.2	2	0.84	1	4
religiosity	2	2	0.93	1	4
age	48	50	15	18	81
female (no/yes)	43%				
higher education entrance cert. (no/yes)	50%				
having kids (no/yes)	58%				
N=682					

Table A-3: Regressions results with categorical variables

	(1) lab research	(2) field research	(3) emergency deployment	(4) immediate deployment
risk aversion	-0.06*	-0.09**	-0.02	-0.08*
1.climate change serious	-0.31	-0.39	-0.78	-0.11
2.climate change serious	0.15	-0.91**	-1.01***	-0.77*
3.climate change serious	-0.24	-0.13	-0.27	0.28
1.NEP: limits to growth	-0.11	-0.09	-0.83	-0.39
2.NEP: limits to growth	-0.42	-0.40	0.03	0.22
3.NEP: limits to growth	-0.57***	-0.01	-0.10	0.01
2.NEP: anthropocentrism	-0.16	0.07	-0.21	0.23
3.NEP: anthropocentrism	0.30	0.38	0.08	0.26
4.NEP: anthropocentrism	1.26**	-0.24	0.16	0.37
1.NEP: balance of nature	-1.48*	0.14	1.60*	1.30
2.NEP: balance of nature	-0.52	0.42	0.24	0.12
3.NEP: balance of nature	-0.39**	-0.18	-0.27	0.11
1.NEP: human exempt.	0.06	-0.59***	-0.60***	-0.38
3.NEP: human exempt.	0.30	0.27	0.22	0.07
4.NEP: human exempt.	0.28	0.71**	1.76***	1.04***
1.NEP: eco-crisis	-1.11*	-1.59**	-1.74**	-1.13
2.NEP: eco-crisis	0.11	0.16	-0.05	-0.66**
4.NEP: eco-crisis	-0.08	0.44**	0.03	0.80***
1.too easy way out	-0.39	0.33	-0.36	1.16***
2.too easy way out	-0.04	0.39	0.20	1.50***
3.too easy way out	0.27	0.23	0.42**	0.76***
1.don't manipulate nature	2.67***	2.68***	3.46***	1.74***
2.don't manipulate nature	1.18***	1.53***	1.77***	1.66***
3.don't manipulate nature	0.74***	1.45***	1.11***	1.17***
1.trust: government	-0.24	-0.43*	-0.44*	0.10
3.trust: government	-0.66***	0.22	-0.03	0.15
4.trust: government	-0.95*	0.65	-0.06	0.32
2.trust: firms	-0.22	0.37*	0.32	0.78***
3.trust: firms	0.21	0.74**	0.58**	1.55***
4.trust: firms	-0.51	1.19**	0.29	2.39***
1.trust: environmental org	-0.97***	-0.54	-0.55	0.12
2.trust: environmental org	-0.09	0.12	-0.33	0.04
4.trust: environmental org	0.03	-0.12	-0.06	-0.23
1.trust: media	0.15	0.13	0.40*	0.09
3.trust: media	0.25	0.12	0.49**	-0.17
4.trust: media	0.31	0.97*	0.46	0.95
1.trust: scientists	-2.14***	-1.89***	-2.28***	-1.13***
2.trust: scientists	-0.66***	-0.95***	-0.74***	-0.37*
4.trust: scientists	1.01**	-0.25	0.33	0.15

Continue →

Table A-3 continued

	(1) lab research	(2) field research	(3) emergency deployment	(4) immediate deployment
1.trust: UN	-0.07	0.07	0.20	-0.27
3.trust: UN	-0.12	-0.02	0.06	-0.23
4.trust: UN	-0.56	-0.61	-0.02	-0.41
1.trust: EU	-0.11	0.10	0.07	-0.47
3.trust: EU	0.16	-0.04	-0.07	0.32
4.trust: EU	1.34**	0.40	0.46	0.62
religiosity	-0.10	-0.09	0.09	0.05
female	-0.22	0.16	0.08	-0.11
high education	0.03	-0.34**	-0.27	-0.76***
age	-0.01	0.01	-0.01	0.01**
children	-0.23	0.18	0.09	0.33
N	682	682	682	682
Pseudo R ²	0.21	0.26	0.28	0.32

p-values * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The base category is the category with the highest frequency count.

Information provided in the video

Slide 1

Sunlight warms the Earth and the Earth's atmosphere. Greenhouse gases in the atmosphere, such as CO₂, ensure that a certain amount of heat remains close to the Earth's surface. This makes the Earth warm enough for humans, animals, and plants to survive.

Slide 2

Since the beginning of industrialization around the year 1850, humans have emitted large amounts of greenhouse gases, for example, by burning coal, oil, and gas. These gases trap additional heat in the atmosphere and cause a gradual increase in the average global temperature.

Slide 3 – 8

Since 1900, the global temperature has risen on average by approximately 0.8°C. Almost all countries agree that the increase in the average global temperature should not exceed 2°C compared to the temperature at the beginning of the industrialization. This is referred to as the 2°C goal.

A future temperature increase between 0.9°C and 5.4°C is expected by 2100. The outcome depends especially on the amount of greenhouse gases emitted in the future. To reach the 2°C goal, the current level of emissions would have to decrease by more than half by 2050. By 2100, almost no greenhouse gases should be emitted.

Slide 9

Climate change will almost certainly cause a rise in sea levels. It is very likely that both the frequency of heat waves and the number of heavy precipitation events will increase in many regions. In the future, it is likely that more areas will be affected by longer droughts and that the frequency and the intensity of tropical cyclones will increase. In addition, because oceans absorb some of the CO₂ in the atmosphere, they will become more acidic.

Slide 10

There are different ways to deal with climate change:

We can reduce greenhouse gas emissions or adapt to the new climate – for example, by building dikes or using more robust plants in agriculture. Another option is to reduce the global temperature by deploying solar radiation management (SRM).

Slide 11

Through SRM, a portion of the sunlight is reflected before it can warm the Earth. This can be achieved by, for example, spraying sulfate particles into the atmosphere at a high altitude.

A similar phenomenon is observed in nature. When large volcanoes erupt, similar particles are distributed across wide areas of the Earth's atmosphere, which cools the Earth.

Slide 12

The particles remain in the higher regions of the atmosphere for about two years. To prevent the Earth from heating up again, spraying would have to be continued until the cause of global warming is removed. Because the emitted CO₂ stays in the atmosphere for a very long time, SRM might have to be used for several centuries. Ocean acidification will not be halted by using SRM. However, the 2°C goal could be met regardless of future greenhouse gas emissions by deploying SRM. Currently, researchers are investigating the risks, benefits, and feasibility of SRM.

Slide 13

The use of SRM entails benefits as well as risks. One benefit is that global warming might be slowed more quickly compared to cutting greenhouse gas emissions. This would provide mankind with additional time to remove the cause of climate change, i.e. the high concentration of greenhouse gases in the atmosphere. Massive and irreversible changes in the climate could be stopped before too much damage is done. Furthermore, it would be possible to stop climate change even if certain countries refused to reduce their greenhouse gas emissions. Deploying SRM would be cheaper than reducing the consumption of fossil fuels.

Slide 14

The risks include a change in the amount of precipitation in most regions. In particular, arid regions would have to cope with even less rain. If the deployment of SRM were suddenly halted, the global temperature would rise abruptly. The speed of this temperature rise might lead to severe problems for humans and the environment. Because possible side effects would occur across international boundaries, the use of SRM might cause international conflicts. Once used, SRM might take away people's motivation to change their lifestyle and the emission of greenhouse gases would continue to increase. Furthermore, there would be the threat of other unknown and unforeseeable risks.

**The role of affect in attitude formation toward new technologies:
The case of stratospheric aerosol injection**

Christine Merk & Gert Pönitzsch

Abstract

This paper analyzes determinants of technology acceptance and their interdependence. It highlights the role of affect in attitude formation toward new technologies and examines how it mediates the influence of stable psychological variables on technology acceptance. Based on theory and previous empirical evidence, we develop an analytical framework of attitude formation. We test this framework using survey data on the acceptance of stratospheric aerosol injection (SAI), a technology that could be used to counteract global warming. The results from the structural equation model show that affect is more important than risk and benefit perception in forming judgment about SAI. Negative and positive affect directly alter the perception of risks and benefits of SAI and its acceptability. Furthermore, affect is an important mediator between stable psychological variables – like trust in government, values, and attitudes – and acceptance. A person’s affective response is thus guided by her general attitudes and values.

This paper is available as *Kiel Working Paper No. 2024*.

1 Introduction

Mitigating climate change is one of the major global challenges of the 21st century. However, even timely and substantial cuts in greenhouse gas emissions may fail to limit global warming to 2°C above preindustrial levels (IPCC, 2014). Against this background, new technologies to limit global warming, known as climate engineering or geoengineering, entered the scientific and political debate. Climate engineering technologies could be an effective way to cool atmospheric temperatures and prevent massive damages from climate change. However, many of these technologies carry substantial risks. Stratospheric aerosol injection (SAI), for example, could change precipitation patterns or induce abrupt temperature changes in case of its termination (for an overview see Rickels et al., 2011).

Public concern about climate engineering technologies is substantial (Bellamy & Hulme, 2011; Borick & Rabe, 2012; Macnaghten & Szerszynski, 2013; Merk et al., 2015) and has been voiced in protests against research projects on SAI and ocean iron fertilization (Schäfer et al., 2015; Stilgoe et al., 2013). Given the far reaching social, ethical, and environmental implications of research or deployment of climate engineering, public perceptions will remain influential in the debate about it (Pidgeon et al., 2013). The aim of studying public acceptance is not to guarantee acceptance but to identify public concerns early on (Pidgeon et al., 2013), enable informed decisions on research and possible deployment (Carr et al., 2013), and improve communication strategies (Huijts et al., 2012).

In the present study, we analyze the factors that determine the acceptability of climate engineering for the case of SAI. This paper extends previous research and develops a new framework describing attitude formation toward new technologies that carry potentially large risks. We use German survey data and apply structural equation modelling to test the framework. Our analysis is guided by the following questions:

- (1) How do stable psychological variables – i.e., values, environmental attitudes and risk attitudes, and trust in government – influence technology acceptance? Do they enter attitude formation via cognitive or affective pathways?
- (2) What is the relative importance of affect and the perception of risks and benefits in attitude formation?

Previous studies of the acceptability of new technologies often highlighted the isolated impact of a single stable psychological variable like trust in institutions (Siegrist et al., 2000; Siegrist, 2000; Terwel et al., 2009; van Dongen et al., 2013) or values (De Groot et al., 2013). Recent

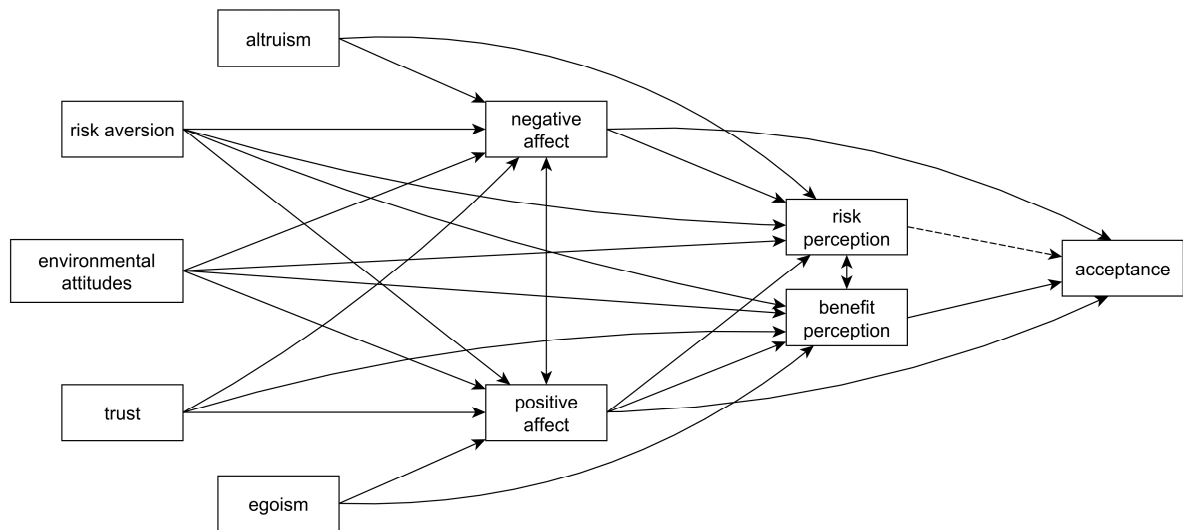
advances incorporated several determinants into the analysis of technology acceptance and allowed for mediation between different determinants in attitude formation (Huijts et al., 2014; Midden & Huijts, 2009; Whitfield et al., 2009). However, none of these studies looked more closely at the relationship between affect, the perception of risks and benefits, and several stable psychological variables. Furthermore, the relative importance of these factors in attitude formation has remained unclear.

The rest of the paper is structured as follows. In Section 2, we derive the analytical framework for our analysis. We lay out the survey, the measurement concepts, and the details of the analysis in Section 3. The results are shown and discussed in Section 4. Section 5 concludes and discusses implications for future research.

2 Analytical framework

Our model builds on established theories of risk perception and attitude formation and combines them into a comprehensive framework. It accommodates the value-belief-norm theory (Stern, 2000) and the theory of planned behavior (Ajzen, 1985) in assuming that the acceptance of a technology is determined by domain-specific beliefs – i.e. perceived benefits and risks of the technology – that derive from a person’s values. These domain-specific beliefs, in turn, may be influenced by stable psychological variables, such as values, environmental attitudes, and trust. In addition, the framework accommodates the affect heuristic (Finucane et al., 2000) and the risk-as-feeling hypothesis (Loewenstein et al., 2001) that highlight the influence of affect in decision making. It hence allows positive and negative affect to influence acceptance. It is further assumed that affect, in turn, may be influenced by stable psychological variables.

By including both domain-specific beliefs and affect, the framework can address whether a person’s stable psychological variables – her altruistic and egoistic values, her environmental attitudes, her trust, and her risk attitude – influence attitude formation via the cognitive pathway, the affective pathway, or both. The full framework is depicted in Figure 1. Its components are described below together with previous empirical evidence.

Figure 1: Analytical framework for the acceptance of environmental technologies

2.1. Risk and benefit perception

Attitudes toward technologies form in part from a weighing of risks and benefits (Ajzen, 1985). Consequently, the perceptions of risks and benefits of a technology are direct antecedents of acceptance. Their impact, however, is not equally strong. De Groot et al. (2013) found a positive impact of perceived benefits as well as a negative impact of perceived risks on the acceptance of nuclear power. The effect of perceived risks, however, was smaller. Terwel et al. (2009) demonstrated that perceived benefits are more relevant than perceived risks for predicting CCS acceptance. In the context of SAI, Mercer et al. (2011) showed that the rating of the importance of risks is not significantly different between respondents who are in favor of SAI and those who are against it. The rated importance of benefits, however, was higher for supporters of the technology than for opponents.

A precise account of the relationship between acceptance and perceived risks and benefits, however, relies on the consideration of affective pathways. Accounting for affect in attitude formation, Midden and Huijts (2009) showed that perceived risks do not significantly impact acceptance of CO₂-storage. Acceptance of CO₂-storage in general is based only on perceived benefits and affect. Acceptance of local storage, by contrast, is completely determined by affect. To test the relevance of both risk and benefit perception when affect is accounted for, we include paths from both variables to acceptance in our analytical model. We thereby deviate from Huijts et al. (2014), who aggregate perceived risks and benefits in one variable.

2.2. Affect

Affect is an important component determining the perception of risks and benefits of new technologies. In particular when knowledge about a technology is low, people tend to rely on affect rather than cognition evaluating risks and benefits of a technology (Lee et al., 2005; Midden & Huijts, 2009; Slovic et al., 2007). Affect serves as an initial overall evaluation of the technology that provides a basis for the assessment of its risks and benefits (Alhakami & Slovic, 1994; Finucane et al., 2000; Loewenstein et al., 2001; Slovic et al., 2004; Slovic et al., 2007; Zajonc, 1980).

Affect toward objects can simultaneously be positive and negative (Peters & Slovic, 2007). Both affective directions should be analyzed separately, as they each have a distinct role in shaping technology acceptance. Midden and Huijts (2009), for example, found that positive affect toward CO₂-storage increases perceived benefits and reduces perceived risks of storage, while negative affect only increases perceived risks but does not influence perceived benefits. Also the strength of the affective directions is asymmetric. Huijts et al. (2014) showed that perceived costs, risks, and benefits of a local hydrogen fuel station depend more strongly on positive affect than on negative affect.

In addition to influencing domain-specific beliefs, affect also influences attitudes directly (Ajzen, 2001). This direct pathway has also been demonstrated in the context of technology acceptance. Midden and Huijts (2009) found that both positive and negative affect directly influence attitudes toward CO₂-storage. Explaining attitude toward acting in favor of a local hydrogen fuel station, Huijts et al. (2014) found that positive affect but not negative affect has a direct influence on attitudes. Our model allows for direct and indirect pathways and hence includes paths from positive and negative affect to risk and benefit perception and to acceptance.

2.3. Trust in government

Trust in institutions associated with the technology is a consistent predictor of technology acceptance (Earle, 2010; Flynn et al., 1993; Midden & Huijts, 2009; Siegrist et al., 2000). Especially when knowledge about the technology is insufficient, trust stemming from a perceived similarity of values (e.g. Siegrist et al., 2000) or from a positive assessment of organizational competence (e.g. Terwel et al., 2009) is used to assess a technology's risks and benefits. Trust in relevant institutions generally increases acceptance, as it increases benefit perception and reduces risk perception. This has been shown for the acceptance of gene technology (Barnett et al., 2007; Siegrist, 2000), nuclear power (Siegrist et al., 2000; Siegrist &

Cvetkovich, 2000; Visschers & Siegrist, 2013), hydroelectric power (Siegrist & Cvetkovich, 2000), and CCS (Terwel et al., 2009).

The influence of trust on risk and benefit perception is likely mediated by affect. Analyzing purchase decisions of nanotechnology foods, Siegrist et al. (2007) suggested that trust in government influences risk and benefit perception indirectly via affect. Their model, however, does not allow for a direct effect of trust on risk and benefit perception. In a model explaining attitudes toward CO₂-storage, Midden and Huijts (2009) also found that trust in government influences affect. Over and above the influence via affect, trust directly influences perceived benefits, but does not directly influence perceived risks of CO₂-storage. Montijn-Dorgelo and Midden (2008) demonstrated the same pattern in perceptions of hydrogen systems. Huijts et al. (2014) showed both direct and indirect effects of trust in the municipality on perceived risks and benefits of hydrogen fuel stations, but combined perceived risks and benefits into one factor. Our model includes paths from trust to perceived risks and benefits and to positive and negative affect.¹ As government agencies are the only institutions that would currently be involved in international decision-making regarding SAI, our model focuses on trust toward government.

2.4. Egoistic and altruistic values

Values are guiding principles in the life of a person (Schwartz, 1992). As stable characteristics they direct attention and form beliefs and attitudes across an array of contexts (Stern, Kalof et al., 1995). For environmental behavior, egoistic and altruistic values are particularly relevant (Stern, 2000). In attitude formation toward technologies with environmental consequences, these values guide a person's focus in weighing perceived risks and benefits (De Groot & Steg, 2007, 2008). People with strong egoistic values display a preference for social power, wealth, authority, and influence; they tend to mainly consider perceived risks and benefits for themselves. By contrast, people with strong altruistic values display a preference for equality, world peace, and social justice and tend to focus on perceived risks and benefits for others.

The influence of values on technology acceptance will thus depend on the technology's distribution of risks and benefits. In the context of nuclear energy, which is cheap but carries health risks for many people, egoistic values have been shown to increase its perceived

¹ This causal model of trust is particularly suitable for assessments of new technologies on which people have little information but are knowledgeable about the actors involved (Earle, 2010). The associationist model of trust, by contrast, supposes that the acceptability of a hazard influences perceived risks and trust in authorities. The associationist model is particularly suitable if people are knowledgeable about a hazard, but not about actors involved. For example, the acceptability of a hazard may be used to assess the trustworthiness of regulatory authorities (Poortinga & Pidgeon, 2005; Bronfman et al., 2008).

benefits, while altruistic values increase its perceived risks (De Groot et al., 2013). Other studies found no effect of egoistic values but showed that altruistic values reduce the acceptability of nuclear energy (Whitfield et al., 2009) and increase concern about different ecological risks (Slimak & Dietz, 2006). In the context of climate engineering, Corner and Pidgeon (2015) demonstrated a positive effect of egoistic (or self-enhancing) values on the support of climate engineering, but no effect of altruistic (or self-transcending) values. However, they did not include perceived risks or benefits in their analysis.

Based on previous findings, we expect a positive influence of egoistic values on the perceived benefits of SAI and a positive influence of altruistic values on the perceived risks of SAI. It remains an open question, whether values acting as cognitive filters not only influence perceived risks and benefits directly, but also indirectly via affect. Our model allows for both pathways.

2.5. Environmental attitudes

The assessment of environmental consequences is shaped by environmental attitudes (De Groot et al., 2013; De Groot & Steg, 2008; Stern, 2000). These attitudes are often measured by the New Ecological Paradigm – NEP (Dunlap et al., 2000; Dunlap & van Liere, 1978). It encompasses attitudes toward the following facets: (1) balance of nature, (2) limits to growth, (3) risk of an eco-crisis, (4) anthropocentrism and (5) humans' ability to control nature.

The NEP's facets are significantly correlated with risk ratings of environmental hazards, such as global warming (Sjöberg, 2003). The NEP, as a combined measure, also helps to explain concern about ecological risks and has strong explanatory power in the evaluation of global risks (Slimak & Dietz, 2006). In addition, respondents with higher NEP scores, i.e., a stronger environmental concern, focus more strongly on ecological impacts when evaluating environmental hazards (Willis & Dekay, 2007) and are more willing to take pro-environmental action (Stern, Dietz et al., 1995).

The NEP's facets should also influence the attitude toward SAI. Involving massive human intervention into the climate system, its risks and benefits are intricately linked to beliefs about the balance of nature, limits to growth, the risk of an eco-crisis, anthropocentrism and humans' ability to control nature. Environmental attitudes may have an ambiguous effect on the acceptance of new technologies like SAI that carry environmental benefits and environmental risks at the same time. SAI could reduce global warming, but may, for example, significantly alter the hydrological cycle (Rickels et al., 2011). It also manipulates nature to an extent that is often perceived as unacceptable (Corner et al., 2013; Mercer et al., 2011; Merk

et al., 2015). Despite an acute concern about climate change, environmentalists might therefore remain skeptical about SAI. Yet, previous studies show a small positive effect of environmental values on the support of solar radiation management, in general, (Pidgeon et al., 2012) and SAI, in particular (Merk et al., 2015).

Studies that looked at the interdependency between determinants showed no direct effect of environmental values on risk or benefit perception. De Groot et al. (2013) found that biospheric values, like preventing pollution and protecting the environment, explain neither benefit nor risk perception of nuclear energy directly. They are linked to acceptance only via their correlation with altruistic values. Also Whitfield et al. (2009) found no direct effect of environmental attitudes, measured by the NEP, on the perception of nuclear risk or the acceptability of nuclear energy. Their model suggests a negative indirect effect via a reduction in trust. However, these models do not include affective pathways and thus cannot show whether environmental attitudes enter attitude formation via affect. We include environmental attitudes, measured by the 5 facets of the NEP into our model and allow them to influence both negative and positive affect and risk and benefit perception.

2.6. Risk aversion

Acceptance of technologies involving risk should also be influenced by a person's risk aversion. Risk aversion has previously been shown to impact general risk taking behavior (Dohmen et al., 2011) and, more specifically, occupational choice (Bonin et al., 2007) as well as migration decisions (Jaeger et al., 2010). It is also related to the acceptance of field research on SAI (Merk et al., 2015). Risk aversion may enter attitude formation either via cognitive reasoning – risk and benefit perception – or via feelings – positive or negative affect (Loewenstein et al., 2001). We include both possibilities in our model.

2.7. Acceptance

SAI is yet only little known and protesting or supporting behavior has not yet evolved. We hence follow the approach of L'Orange Seigo et al. (2014) and focus on expressed preference for the technology as the single outcome variable, which we call acceptance.

3 Method

To test the analytical framework, we designed and conducted a survey. The data was analyzed using structural equation modelling. In the following, we will describe the information material, the measures for our theoretical concepts, the procedures and the analysis.

3.1. Information material

A video informed respondents about climate change and stratospheric aerosol injection during the survey.² The video contained infographics that were accompanied by a German voice-over with the following content³:

Sunlight warms the Earth and the Earth's atmosphere. Greenhouse gases in the atmosphere, such as CO₂, ensure that a certain amount of heat remains close to the Earth's surface. This makes the Earth warm enough for humans, animals, and plants to survive.

Since the beginning of industrialization around the year 1850, humans have emitted large amounts of greenhouse gases, for example, by burning coal, oil, and gas. These gases trap additional heat in the atmosphere and cause a gradual increase in the average global temperature.

Since 1900, the global temperature has risen on average by approximately 0.8°C. Almost all countries agree that the increase in the average global temperature should not exceed 2°C compared to the temperature at the beginning of the industrialization. This is referred to as the 2°C goal.

A future temperature increase between 0.9°C and 5.4°C is expected by 2100. The outcome depends especially on the amount of greenhouse gases emitted in the future. To reach the 2°C goal, the current level of emissions would have to decrease by more than half by 2050. By 2100, almost no greenhouse gases should be emitted.

Climate change will almost certainly cause a rise in sea levels. It is very likely that both the frequency of heat waves and the number of heavy precipitation events will increase in many regions. In the future, it is likely that more areas will be affected by longer droughts and that the frequency and the intensity of tropical cyclones will increase. In addition, because oceans absorb some of the CO₂ in the atmosphere, they will become more acidic.

There are different ways to deal with climate change:

We can reduce greenhouse gas emissions or adapt to the new climate – for example, by building dikes or using more robust plants in agriculture. Another option is to reduce the global temperature by deploying solar radiation management (SRM).

Through SRM, a portion of the sunlight is reflected before it can warm the Earth. This can be achieved by, for example, spraying sulfate particles into the atmosphere at a high altitude.

A similar phenomenon is observed in nature. When large volcanoes erupt, similar particles are distributed across wide areas of the Earth's atmosphere, which cools the Earth.

The particles remain in the higher regions of the atmosphere for about two years. To prevent the Earth from heating up again, spraying would have to be continued until the cause of global warming is removed. Because the emitted CO₂ stays in the atmosphere for a very long time, SRM might have to be used for several centuries. Ocean acidification will not be halted by using SRM. However, the 2°C goal could be met regardless of future greenhouse gas emissions by deploying SRM. Currently, researchers are investigating the risks, benefits, and feasibility of SRM.

² Participants were not able to skip or fast forward the video. Participants, whose technical devices were not apt to show the video or play the voiceover, were screened out at the beginning of the survey.

³ The survey used the broader term solar radiation management to refer to the technology of stratospheric aerosol injection.

The use of SRM entails benefits as well as risks. One benefit is that global warming might be slowed more quickly compared to cutting greenhouse gas emissions. This would provide humankind with additional time to remove the cause of climate change, i.e., the high concentration of greenhouse gases in the atmosphere. Massive and irreversible changes in the climate could be stopped before too much damage is done. Furthermore, it would be possible to stop climate change even if certain countries refused to reduce their greenhouse gas emissions. Deploying SRM would be cheaper than reducing the consumption of fossil fuels.

The risks include a change in the amount of precipitation in most regions. In particular, arid regions would have to cope with even less rain. If the deployment of SRM were suddenly halted, the global temperature would rise abruptly. The speed of this temperature rise might lead to severe problems for humans and the environment. Because possible side effects would occur across international boundaries, the use of SRM might cause international conflicts. Once used, SRM might take away people's motivation to change their lifestyle and the emission of greenhouse gases would continue to increase. Furthermore, there would be the threat of other unknown and unforeseeable risks.

The aim was to present respondents with a neutrally framed and clear description of the technology. When asked whether the video was clearly understandable⁴ and whether respondents thought it was neutral or biased in favor or against SAI⁵, only 7 out of 927 participants thought the video was not clearly understandable. 13% said it was biased in favor of the technology, while less than 1% perceived video as biased against SAI. 81% of respondents understood the video at least well and thought it was neutral toward aerosol injection. For more information on the sources for the video's content see Merk et al. (2015).

3.2. Measures

Risk aversion and environmental beliefs were elicited before the video. After the video, respondents were asked about their acceptance, their risk and benefit perception as well as their affective response to SAI. Finally, altruistic and egoistic values were elicited.

All variables except for trust in government and risk aversion were measured via several items; they are included in the analysis as unweighted, standardized mean scores. The analysis adjusts for the reliability of these exogenous variables via Cronbach's α .

3.2.1. Risk and benefit perception

We measured the risk and benefit perception via the respondents' ratings of five specific risks and four specific benefits. The risks and benefits were introduced and explained in the video.

⁴ "Do you think the information you just saw was clear or do you think it was unclear? completely clear (1) – completely unclear (4)".

⁵ "Do you think the information you just saw was biased in favor or against solar radiation management or was it neutral? - It was biased in favor of solar radiation management. - It was neutral. - It was bias against solar radiation management."

Risks ($\alpha=.71$) were rated on a scale from 'negligible' (1) to 'very serious' (4). Benefits ($\alpha=.85$) were rated from 'very small' (1) to 'very large' (4).

Risks

It changes the amount of precipitation.

It can take away people's motivation to change their lifestyle.

There is the possibility of further unknown and unforeseeable risks.

The abrupt increase of Earth's temperature in case of a sudden stop of SRM can lead to severe problems for humans and the environment.

The use of SRM could cause international conflicts.

Benefits

Global warming is slowed down more quickly than by cutting greenhouse gas emissions.

Massive and irreversible changes in the climate can be stopped before too much damage is done.

It is cheaper than reducing the consumption of fossil fuels.

Even if certain countries do not want to reduce their greenhouse gas emissions, it is possible to stop climate change.

3.2.2. Positive and negative affect

We measured positive and negative affect by asking respondents how strongly they felt 11 different positive and negative emotions when thinking about SAI. In line with Midden and Huijts (2009), we combine worry, fear, sadness, powerlessness, anger, and annoyance into 'negative affect' ($\alpha=.88$) and delight, happiness, satisfaction, hopefulness, and relief into 'positive affect' ($\alpha=.93$). The response scale ranged from 'not at all' (1) to 'very strongly' (4).

3.2.3. Trust in government

Trust in government was measured by the question 'How much do you trust that the federal government will act in the interest of the environment and the society?' We thus used a broad definition of general trust in good intentions for society and the environment. The 4-point response scale ranged from 'do not trust at all' (1) to 'trust completely' (4).

3.2.4. Egoistic and altruistic values

Egoistic and altruistic values were assessed with the Schwartz Personal Value Questionnaire (PVQ5X) (Schwartz et al., 2012). In the PVQ5X, persons with distinct characteristics, which stand for a specific aspect of a value, are described in one sentence. Respondents had to state their similarity with the person described on a 4-point Likert scale from 'dissimilar' (1) to 'similar' (4). Each value was measured by 4 items (see Table A-1 in the appendix). Egoistic values contained the aspects social power, wealth, authority, and influential ($\alpha=.80$). Altruistic

values contained the aspects equality, world at peace, social justice, and helpful ($\alpha=.74$). The items correspond to the items used by De Groot et al. (2013)⁶.

3.2.5. *Environmental attitudes*

Environmental attitudes were assessed via the facets of the NEP scale. The NEP measures a pro-ecological worldview encompassing perspectives on humankind's relationship with nature and was developed and revised by Dunlap et al. (2000). We used 5 of the instrument's 15 items, each representing one of the NEP's 5 facets: (1) 'Humans were meant to rule over the rest of nature.' for anthropocentrism, (2) 'Humans will eventually learn enough about how nature works to be able to control it.' for humans' ability to control nature, (3) 'The Earth is like a spaceship with very limited room and resources.' for limits to growth, (4) 'The balance of nature is very delicate and easily upset.' for the perceived fragility of nature's balance, and (5) 'If things continue on their present course, we will soon experience a major ecological catastrophe.' for the possibility of an eco-crisis. The response scale ranged from 'strongly disagree' (1) to 'strongly agree' (4).

An auxiliary factor analysis led to inconclusive results. The Kaiser-Meyer-Olkin-criterion, i.e. the number of eigenvalues larger than 1, supported the existence of one single factor while the scree plot suggested two distinct factors. We use two factors to capture a distinction relevant for SAI: One factor reflects respondents' perspective of humans' relationship with nature, which we call 'control over nature' ($\alpha=.63$). It is measured by items (1) and (2) on anthropocentrism and humans' ability to control nature. The other factor reflects the perceived state of nature ($\alpha=.63$), which we call 'state of nature'. It is measured by items (3) to (5) on limits to growth, the fragility of nature, and the possibility of an eco-crisis.

3.2.6. *Risk aversion*

To assess risk aversion, respondents were asked 'Are you generally a person who is fully prepared to take risks or do you try to avoid taking risks?' on an 11-point Likert-scale from 'risk averse' (0) to 'fully prepared to take risks' (10). This question is used in the German Socioeconomic Panel (GSOEP) and has been shown to correlate well with actual risk taking in several domains (Dohmen et al., 2011). The item was reversely coded for the analysis. Thus, higher values indicate a higher level of risk aversion.

⁶ The paper used an older version of the Schwartz value scale.

3.2.7. *Acceptance*

Acceptance was measured via 5 items that capture the acceptance of different types of research and deployment of aerosol injection ($\alpha=.88$). Participants responded to the following items on 4-point Likert scales from 'strongly disagree' (1) to 'strongly agree' (4):

We should cool the Earth by using SRM.

Scientists should research SRM using theoretical models, simulations and lab experiments.

Scientists should test SRM using field trials.

SRM should be used when massive and irreversible changes in the climate system are approaching which cannot be averted otherwise.

If SRM was possible today, we should use it immediately.

3.3. Procedure and respondents

Respondents were recruited using a German online panel. The survey was conducted in December 2012. Respondents are representative of the German internet population with respect to state of residence, age, and gender. The working sample consists of 927 cases. 52% of respondents are male. The mean age is 47 (min 18, max 81). The share of respondents with a higher education entrance certificate – 52% – lies above the share in the German population – 27% (Destatis, 2015).

3.4. Analysis

We started the analysis with the initial analytical framework derived in Section 2 (compare Figure 1). Cronbach's alpha was included as a measure for the reliability of the exogenous score variables and thus allowed for error in the measurement of egoistic and altruistic values, control of nature and perceived state of nature (see Cronbach's alpha on the main diagonal in Table 1).

The analysis of the initial analytical framework yielded a comparative fit index (CFI) of 0.95, indicating a satisfying overall fit of the model (Acock, 2013, p. 23). The root mean squared error of approximation (RMSEA) was, however, relatively high at 0.102 indicating an insufficient fit (Browne & Cudeck, 1992). The likelihood ratio test was significant ($\chi^2(12)=128.60$; $p=0.00$).

To improve the model fit and make the model more efficient, we iteratively removed insignificant paths and tested additional paths. Additional paths were included based on modification indices and theoretical justifications. The likelihood ratio test of the final model was still significant ($\chi^2(22)=78.88$; $p=0.00$); this indicates that the model does not perfectly reproduce the covariance matrix. The likelihood ratio test can, however, be problematic for

complex models because it tests the entire model and can already reject the null hypothesis when only a part of the covariance matrix cannot be reproduced (Backhaus et al., 2011). Therefore, we evaluated the model using additional fit statistics. Both the CFI (=0.98) and the RMSEA (=0.045) indicate a close fit (Backhaus et al., 2011; Browne & Cudeck, 1992).

Table 1: Pearson's correlation coefficients of exogenous variables; main diagonal: Cronbach's α

	egoism	altruism	control over nature	state of nature	risk aversion	
egoism	0.80					
altruism	-0.06*	0.74				
control over nature	0.25***	-0.04	0.63			
state of nature	-0.02	0.21***	-0.12***	0.63		
risk aversion	-0.16***	0.00	-0.11***	0.01	-	
trust	0.21***	-0.04	0.20***	-0.01	-0.05	-

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 1 shows the correlations between these exogenous variables. Egoism and altruism clearly measure different concepts as they are not correlated (-.06*). Egoism is correlated with control over nature (.25***), while altruism is correlated with state of nature (.21***). Egoism is further correlated with risk aversion (-.16***) and trust in government (.21***). These relationships are mirrored in the covariance structure specified in the path model (compare Table 2): Trust and risk aversion were allowed to co-vary with egoism. Trust, risk aversion, and egoism were allowed to co-vary with control over nature while altruism was allowed to co-vary with state of nature. The covariances between the remaining exogenous variables were constrained to zero.

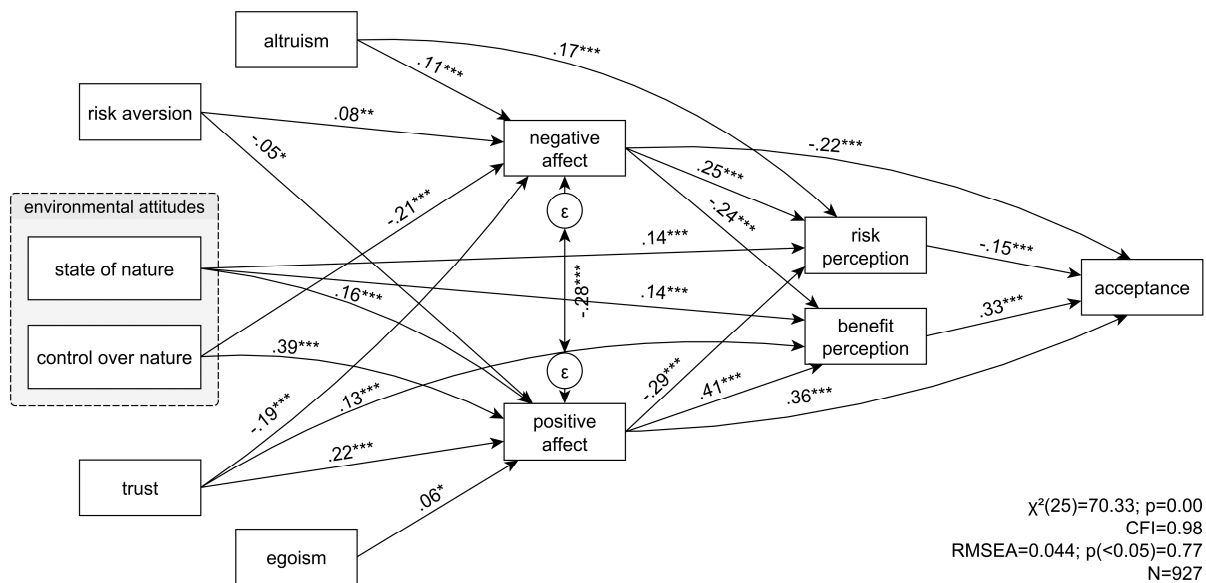
Table 2: Covariance between exogenous variables in path model

		covariance
trust	* egoism	0.24***
trust	* control over nature	0.26***
risk aversion	* egoism	-0.18***
risk aversion	* control over nature	-0.13***
egoism	* control over nature	0.34***
altruism	* state of nature	0.30***
control over nature	* state of nature	-0.18***

4 Results

The final results from structural equation modelling are displayed in Figure 2. Positive and negative affect, as well as the perception of risks and benefits have a direct effect on acceptance. Furthermore, they mediate the impact of a person’s psychological variables on the acceptance of SAI.

Figure 2: Path model explaining acceptance of stratospheric aerosol injection



Note: covariance structure see Table 2.

Some paths of the final model (Figure 2) deviate from the initial analytical model (Figure 1). Several paths turned out to be insignificant at the 10-percent level: (1) Risk aversion influences neither risk nor benefit perception. It influences only positive affect (-.05*) and negative affect (.08**). (2) Egoism has no impact on benefit perception and only weakly influences positive affect (.06*). (3) Environmental attitudes are split up into two categories. For beliefs about humans’ control over nature, we do not find the hypothesized influence on risk and benefit perception; they influence only positive and negative affect. Beliefs about the state of nature have no impact on negative affect but have an impact on risk and benefit perception and positive affect. An additional path was included between negative affect and benefit perception (-.24***). The errors of positive and negative affect are correlated (-.28***); while there is no relationship between the errors of risk and benefit perception.

Table 3: Standardized total effects on acceptance

	coefficient	standard error
egoism	0.037*	0.023
altruism	-0.080***	0.017
control over nature	0.333***	0.039
state of nature	0.153***	0.033
risk aversion	-0.045**	0.018
trust in government	0.185***	0.021
negative affect	-0.356***	0.026
positive affect	0.492***	0.025
risk perception	-0.174***	0.026
benefit perception	0.324***	0.024

Affect is the strongest driver in attitude formation (see Table 3). We find that affect influences both risk and benefit perception. While positive affect increases benefit and decreases risk perception, the reverse is true for negative affect (Figure 2). This result is broadly in line with the literature but contrasts the finding of Midden and Huijts (2009) who report no impact of negative affect on the perception of benefits. Affect has a larger influence in attitude formation than perceived risks and benefits. Moreover, positive affect is more influential in the evaluation of the technology than negative affect. This finding supports previous results of Huijts et al. (2014).

Both benefit perception and risk perception influence acceptance significantly. Furthermore, benefit perception is a stronger predictor of acceptance than risk perception. This finding is consistent with previous findings on attitude formation (De Groot et al., 2013; Siegrist et al., 2007; Terwel et al., 2009). Accounting for the affective pathway, Midden and Huijts (2009) previously found no effect of risk perception on acceptance. In our data, risk perception remains a direct antecedent of acceptance. Our data further show that benefit and risk perception have different roles in attitude formation, both as determinants and mediating factors. Hence, they should be included as distinct concepts in the analysis of technology acceptance.

Apart from direct cognitive or affective influences on acceptance, trust in government has a strong influence in our model. The data show that trust determines acceptance through direct influences on positive and negative affect. It also directly influences the perception of benefits but not the perception of risks. These findings confirm results of Midden and Huijts (2009) and Montijn-Dorgelo and Midden (2008). In contrast to our finding, data of Huijts et al. (2014) suggested that the influence of trust is not mediated by negative affect.

Altruistic and egoistic values determine a person's focus in evaluating risks and benefits. Our data show, for the first time, that their influence on risk and benefit perception is mediated by affect. Altruistic and egoistic values have different impacts. Altruistic values directly increase both negative affect and risk perception. By contrast, egoistic values directly increase only positive affect, and only weakly so. The direction of the total effect of values is in line with the literature. Also previously, altruistic values were shown to increase risk perception and decrease acceptance (De Groot et al., 2013; Slimak & Dietz, 2006; Whitfield et al., 2009) and egoistic values were shown either to have no effect (Slimak & Dietz, 2006; Whitfield et al., 2009) or to increase benefit perception and acceptance (Corner & Pidgeon, 2015; De Groot et al., 2013).

If technologies have both environmental benefits and environmental risks, the effect of environmental attitudes on the acceptance of these technologies is potentially ambiguous. Our model takes a more nuanced look at the effect of environmental attitudes by splitting up the NEP into two separate factors: Firstly, the perceived control over nature, which captures the belief in the human capacity to control and to rule over nature; Secondly, the perceived state of nature, which captures limits to growth, the fragility of nature, and the possibility of an eco-crisis. Beliefs about the control over nature are among the strongest determinants of acceptance, while the impact of beliefs about the state of nature is less pronounced. Furthermore, these factors affect acceptance differently. Control over nature reduces negative affect and enhances positive affect, but does not directly influence risk or benefit perception. Its effect is unambiguous. By contrast, beliefs about the state of nature have a more ambiguous impact. They intensify both risk and benefit perception, plausibly because SAI can be seen both as a cure and a threat to the environment.

In sum, we show that environmental attitudes enter attitude formation. They do so both via affect and via risk and benefit perception. Previous studies did not find a strong impact of environmental attitudes on risk and benefit perception of nuclear power (De Groot et al., 2013; Whitfield et al., 2009), but these did not take affective pathways into account. We also find that the impact of both NEP factors is large compared to the impact of altruistic and egoistic values. This contrasts findings for acceptance of nuclear power but mirrors findings for the perception of ecological risk (Slimak & Dietz, 2006).

Our results also highlight the benefit of taking a differentiated look at the different facets of environmental attitudes; they confirm previous results that pointed toward nuanced effects of the NEP's different facets on technology acceptance (Merk et al., 2015; Sjöberg, 2003).

However, the relevance of beliefs about humans' capacity and right to rule over nature likely varies with the perceived scope of the technologies' interference with nature.

5 Conclusion

We proposed a technology acceptance framework that captures the interplay between values, attitudes, affect, risk and benefit perception, and the acceptance of new technologies. Using data from a large survey, we successfully tested the framework analyzing the determinants of the acceptance of stratospheric aerosol injection.

Our data provide evidence of both affective and cognitive pathways in attitude formation. Acceptance is directly influenced by positive and negative affect, as well as perceived risks and benefits. People are, however, more strongly guided by affect than by their perception of risks and benefits. Furthermore, affect is the most important mediator between psychological variables – such as trust, values, and attitudes – and acceptance. All variables influence acceptance partly through an altered affective evaluation. Only trust, altruism, and state of nature change the perceived effects of the technology not only via affect but also directly.

Our study adds to a growing literature about the importance of affect in guiding judgement (Finucane et al., 2000; Lerner et al., 2015; Loewenstein et al., 2001; Zajonc, 1980). In contrast to this literature, we not only show the relevance of affect, but also how affect is influenced by a person's characteristics. We show that it is in part shaped by a person's values, attitudes, trust, and risk aversion. Hence, affect, as automatic emotional reaction, seems to express a person's core values and attitudes applied to a specific situation. In this sense, it is essential to and supports rational action. Our result also speaks to literature that shows reductions in the quality of decisions when affective evaluations are impaired (Bechara et al., 1997; Damasio, 1994; Wilson et al., 1993; Wilson & Schooler, 1991).

In our survey, we provided neutrally framed, unbiased information. Only few respondents had heard about SAI before the survey and there has not yet been a broad public discourse about the topic. Hence, the effects we found are likely to be characteristic of attitude formation toward a topic of low familiarity. Once a technology becomes more mature, the relevance of the factors influencing perception might shift. This might, for example, be reflected in a reduced impact of the affective component. Future research should thus test our model with more familiar technologies to evaluate the stability of the pathways indicated by our study. Furthermore, future studies might include experimental variation or longitudinal data to further substantiate causality of the relationships.

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Chapter 2

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Appendix

Table A-1: Items measuring egoism and altruism from Schwarz et al. (2012), Cronbach's α

In the following we describe different people. Please state for each case how similar or dissimilar the described person is to you.	
Egoism ($\alpha=.80$)	dissimilar (1) - similar (4)
She wants people to do what she says.	
Being wealthy is important to her.	
It is important to her to be the one who tells the others what to do.	
It is important to her to be the most influential person in any group.	
Altruism ($\alpha=.74$)	dissimilar (1) - similar (4)
She thinks it is important that every person in the world have equal opportunities in life.	
She works to promote harmony and peace among diverse groups	
Protecting society's weak and vulnerable members is important to her.	
Caring for the well-being of people she is close to is important to her.	

Knowledge about aerosol injection does not reduce individual mitigation efforts

Christine Merk, Gert Pönitzsch & Katrin Rehdanz

Abstract

Stratospheric aerosol injection (SAI) is a climate engineering (CE) method that is reputed to be very effective in cooling the planet but is also thought to involve major risks and side effects. As a new option in the bid to counter climate change, it has attracted an increasing amount of research and the debate on its potential gained momentum after it was referred to in the 5th IPCC assessment report (IPCC 2013). One major objection to SAI and the research done on it is that it could undermine commitment to the mitigation of greenhouse gases. Policymakers, interest groups or individuals might wrongly perceive SAI as an easy fix for climate change and accordingly reduce their mitigation efforts. This is the first study to provide an empirical evaluation of this claim for individuals. In a large-scale framed field experiment with more than 650 participants, we provide evidence that people do not back-pedal on mitigation when they are told that the climate change problem could be partly addressed via SAI. Instead, we observe that people who have been informed about SAI mitigate more than people who have not. Our data suggest that the increase is driven by a perception of SAI as potential threat.

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1 Introduction

Concern that mitigation efforts might decrease once stratospheric sulfate injection (SAI) was discussed as an option in the fight against climate change is strong both in scientific debate (Lawrence & Crutzen 2013; Schneider 2001) and among lay persons (Corner & Pidgeon 2014; Ipsos MORI 2010; Mercer et al 2011; Merk et al 2015; Wibeck et al. 2015; Winickoff et al. 2015). In scientific debate, this concern is referred to as “risk compensation”, “moral hazard” or “mitigation obstruction” (Betz & Cacean 2012; Keith 2013; Morrow 2014). Lay persons participating in surveys or focus groups have found the risk-compensation argument convincing and fear that SAI might be used as an excuse to continue with carbon-intensive lifestyles (Corner & Pidgeon 2014; Ipsos MORI 2010; Mercer et al 2011; Merk et al 2015; Wibeck et al. 2015; Winickoff et al. 2015). The validity of this concern is underlined by many theoretical arguments (for an overview see Lin 2012; Morrow 2014). It is said, for example, that optimism bias and overconfidence can be expected to lead to the perception of SAI as a viable technological fix for climate change, an attitude that creates an illusion of control (Lin 2012). People also tend to readily accept arguments exonerating them from their responsibility for climate change and wrongly justifying a mitigation cutback (Morrow 2014).

2 Theory

Despite the prominence and persuasiveness of the risk-compensation argument, there has as yet been no rigorous assessment of whether people actually reduce mitigation. Prior studies have dealt only indirectly with risk compensation, discussing the perception of climate engineering (CE), of SAI or of the risk-compensation argument. Nonetheless, these studies provide helpful insights into people’s perceptions of mitigation and SAI, and a number of them cast doubt on the validity of the risk-compensation argument. Participants in group discussions have stated that mitigation should remain a priority (Bellamy et al. 2015; IAGP 2014; Ipsos MORI 2010). In a survey study, most respondents were against SAI being used as a way of continuing with carbon-intensive lifestyles (Mercer et al. 2011). Furthermore, in two focus groups participants were in favour of increasing mitigation efforts once they had learned about SAI (Shepherd 2009; Wibeck et al. 2015). These findings indicate no decrease in the perceived importance of mitigation as a result of knowledge about SAI and accordingly question the validity of the risk-compensation argument. What it is that actually drives such behaviour has so far remained a matter for speculation.

There are three reasons why knowledge of SAI might not lead to risk compensation and might indeed even cause an increase in mitigation. First, risk compensation can only occur if its basic assumption is

fulfilled, i.e. SAI is perceived as an effective method against climate change (Corner & Pidgeon 2014; Hedlund 2000; Lin 2012). This assumption has not yet been tested empirically. Second, information on SAI might function as a clarion call; when they learn that such massive interventions as SAI are under consideration, people might take the threat of climate change more seriously and thus mitigate more (Reynolds 2015). One survey experiment found that subjects who were informed about CE were slightly more concerned about climate change than subjects in the control group (Kahan et al. 2015). Third, an increase in mitigation could also be caused by the perception of SAI as a threat. Research on acceptance shows that individuals respond very negatively to the idea of SAI and support for it is low (Borick & Rabe 2012; Macnaghten & Szerszynski 2013; Merk et al. 2015; Wright et al. 2014). As a policy option against climate change, mitigation is preferred over CE (Pidgeon et al. 2012; US GAO 2011; Wibeck et al. 2015). Accordingly, people may mitigate more, so as to prevent the deployment of SAI.

3 Method

We conduct a framed-field experiment to find out whether people actually compensate a potential risk reduction from SAI and mitigate less. As mitigation behaviour we observe how many voluntary carbon offsets (VCO) subjects buy during the experiment.

The experiment consisted of three treatment groups that subjects were randomly assigned to: BASE (N=243), SAI (N=211) and AUG (N=204). The treatments contain different blocks of information. All subjects received information about the effect of greenhouse gases on the climate and on currently observed climate change. This information was based on the official German translation of the main findings of the IPCC's 5th assessment report (BMUB 2014). In addition, mitigation and adaptation were referred to as two ways of dealing with climate change (see Appendix for information material).

Subjects in BASE received no further information. Subjects in SAI were additionally informed about the injection of aerosols into the stratosphere as a third way of dealing with climate change alongside mitigation and adaptation. The basic principles of SAI were set out along with the risks and benefits involved according to current scientific knowledge (e.g., Crutzen 2006; Rickels et al. 2011; Robock 2008). Subjects in AUG were provided the information from BASE augmented with additional information on expected future climate changes (IPCC 2014). The AUG treatment ensures that any differences in behaviour between BASE and SAI will be due to the qualitative effect of the information on SAI and not to changes in the amount of information or in the time spent reading about climate change.

After having received the information, all subjects were told about the possibility of supporting climate mitigation projects by purchasing VCOs (similar to Löschel et al. 2013 and Diederich & Goeschl 2014; See Appendix for experimental script). Subjects could use their endowment of €10 to purchase offsets, each mitigating 50 kg CO₂; this means that we do not merely rely on statements of intent but evaluate actual decisions. The offsets were offered at a reduced price of €1, amounting to a subsidy of €0.15 per offset paid by the researchers. The subsidy incentivised subjects to make any planned purchases of offsets during the experiment instead of postponing them until later. This made it possible for us to observe any changes in planned behaviour concerning the purchase of VCOs. Before the purchase, subjects had to correctly answer four questions designed to check whether they had understood the choice situation and its consequences. Subjects who failed to answer the control questions correctly in fewer than four attempts were not allowed to continue with the survey. Any endowment remaining after the purchase was credited to the subjects' accounts with the online panel. After the experiment, subjects were sent a link to a confirmation of purchase for the offsets.

The survey and the experiment consisted of six parts: (1) information blocks according to treatment, (2) questions on climate change perception, (3) information on, and purchase of, VCOs, (4) questions on purchasing motives and on perception of the information text, (5) questions on attitudes towards climate change, mitigation and SAI research, (6) socio-demographic questions. The sequence of items within the blocks of questions was randomised to avoid order effects. The variables used in the analysis are listed in the supplementary material. Principal component analysis was used to combine items assessing the perception of climate change risks into one factor.

The experiment was administered online. Recruitment was performed from the German internet population using an online panel. Participants were sampled using quotas for the characteristics gender, age and state (Land) of residence.

The final sample consists of 658 cases. 1,262 subjects completed the experiment. Subjects were excluded from the analysis based on the following criteria: (1) giving identical responses in three or more blocks of questions; (2) taking less than 12 minutes to complete the experiment; (3) answering 'don't know' to at least one of the main explanatory variables used in the analysis. Of the 1,262 subjects in the experiment, 19 were excluded because of the first criterion. The second criterion led to the exclusion of 375 subjects, and 210 subjects were excluded based on the third criterion. The number of exclusions based on the second criterion – the minimum completion time – is high. This is probably due to the substantial remuneration, which subjects only received when they completed the experiment.

The exclusion is justified as there is strong evidence that subjects who finished in less than 12 minutes did not carefully read the information provided.

The average age of subjects in the final sample was 49 (18 to 86 years). 46 percent of the subjects were female. 51 percent of the subjects had a high level of education, whereas 49 percent of the subjects had completed only lower secondary education or had no school leavers' certificate. The fieldwork was conducted within a period of four weeks in March and April 2015.

4 Results

A first look at the summary statistics reveals no significant difference in average VCO purchases between treatments (Wilcoxon rank-sum tests, $p > 0.105$). On average, subjects buy 4 offsets in the BASE treatment (95% confidence interval (CI) [3.51, 4.49]), 4.59 offsets in the SAI treatment (95% CI [4.06, 5.13]), and 4.22 offsets in the AUG treatment (95% CI [3.70, 4.74]).

To control for the influence of other factors on the mitigation decision, we run a Tobit regression (Table 1). When we include the controls, we find that learning about the SAI option increases offset purchases significantly ($p = 0.011$). By contrast, merely reading a longer text on the effects of climate change in the AUG treatment does not influence offset purchases over and against the BASE treatment ($p = 0.913$). Accordingly, it is the information content of the SAI treatment that drives the observed increase in offset purchases and not the additional quantity of general information on climate change (Wald test, $p = 0.020$).

As control variables we include the perception of climate change risks and mitigation, the influence of the study's experimental purchase mechanism, the perceived effectiveness of offsets, and socio-demographic variables. This ensures that these factors do not drive the results or obscure the treatment effect.

The following control variables influence the purchase decisions significantly; The direction of their effect is as expected. Subjects who feel morally obliged to help mitigate climate change buy more offsets (cf. Table 1; $p < 0.001$). Subjects who believe that offsets are an effective way of mitigating climate change also purchase more offsets ($p < 0.001$). Subjects who would rather buy offsets directly purchase fewer of them than those who prefer buying through us ($p < 0.001$). Finally, a high level of education increases VCO purchases ($p < 0.001$).

The treatment effect of SAI information on offset purchases is substantial compared to other factors. On average, subjects buy 0.8 VCOs more when they have been informed about SAI. Compared to other factors, this effect is similar to an increase in perceived VCO effectiveness of half a standard deviation or to an increase of one standard deviation in the perceived moral obligation to mitigate.

Table 1: Tobit regression explaining the amount of purchased VCOs

Dependent variable:	Average	Standard
amount of purchased VCOs	Marginal Effect (AME)	Error
<i>Treatment group</i>		
SAI	0.774 **	(0.305)
AUG	0.033	(0.307)
<i>Climate change</i>		
(1) Perception of impacts	0.029	(0.128)
(2) Daily mitigation	0.016	(0.145)
(3) Moral obligation to mitigate	0.782 ***	(0.148)
<i>Experiment characteristics</i>		
(4) VCO effectiveness	1.145 ***	(0.134)
(5) Indirect purchase of VCOs	1.061 ***	(0.136)
(6) Payment via panel points	0.088	(0.140)
<i>Socio-demographic variables</i>		
Female	0.115	(0.261)
Age	0.016 *	(0.008)
Higher education	1.012 ***	(0.259)
pseudo R ²	0.0953	
N	658	

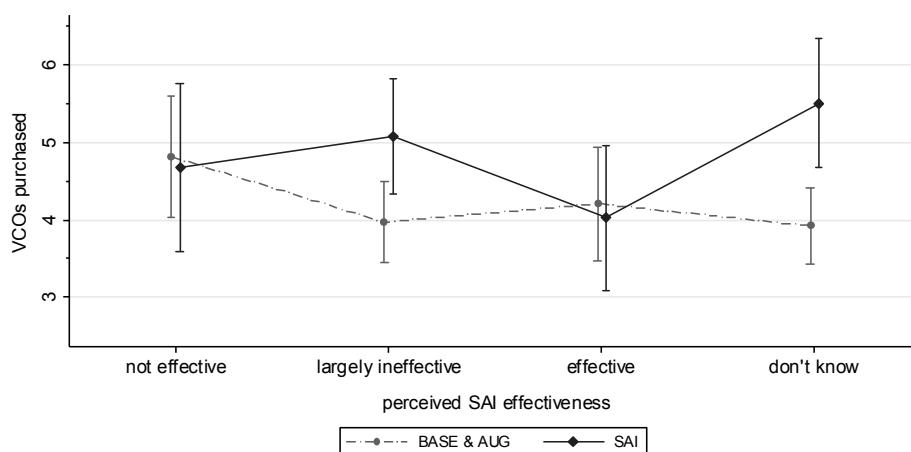
Note: SAI, AUG, female and higher education are dummy variables; all others except awareness of climate change impacts are standardised. (1) factor of the variables perception of climate change impacts 'today'/'in 25 years' for people in 'my environment including myself'/'in industrialized countries'/'in developing countries' (2) 'In your daily life, how often do you try to cut down on greenhouse gas emissions?'; (3) 'I feel morally obliged to help mitigate climate change.' (4) Perceived effectiveness of voluntary carbon offsets; Influence on purchase decision of: (5) 'The IfW is handling the purchase, not me.' and (6) 'My remaining endowment can only be cashed in via the online panel.' For full description of variables, see Appendix Table A-1. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

In the final step of the analysis, we test the potential reasons for the absence of risk compensation and for the observed increase in purchases. To this end, we look at the three potential reasons we identified before and how they interact with the SAI information treatment. This reveals whether subjects in the SAI treatment buy more VCOs generally or only under certain conditions. Since behaviour in BASE and AUG is not significantly different, we pool the data from these treatments in the following analyses.

First, risk-compensation arguments require that SAI be perceived as an effective measure against climate change risks. Figure 1 plots the effect of the SAI treatment on offset purchases for different levels of perceived SAI effectiveness. As expected, subjects who perceive SAI to be ineffective do not

change their mitigation behaviour after learning about SAI compared to those in BASE ($p=0.826$). Contrary to what risk-compensation arguments suggest, subjects who think SAI is effective do not reduce their mitigation ($p=0.765$). An increase in offset purchases is observed for those who think SAI is largely ineffective ($p=0.018$) or who feel unable to assess SAI's effectiveness ($p=0.001$).

Figure 1: Effect of SAI treatment depending on perceived effectiveness of SAI



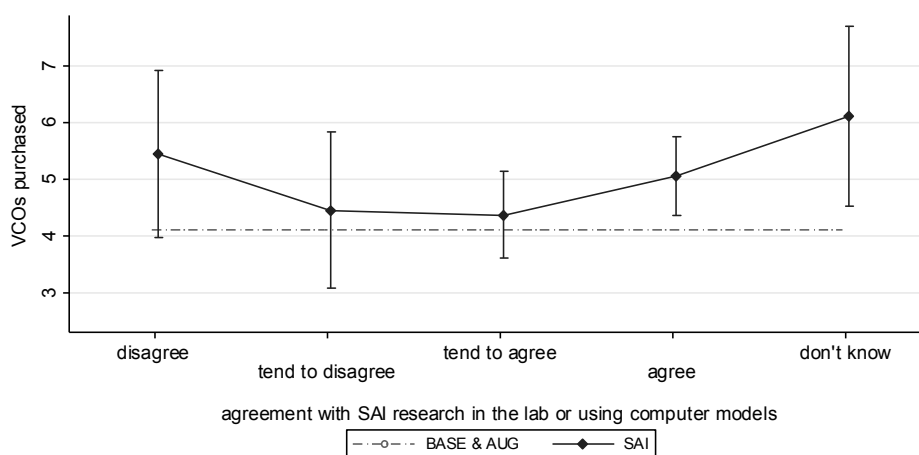
Note: Predicted margins from a Tobit regression including the control variables of the regression presented in Table 1 additionally including interaction effects between SAI and perceived effectiveness of SAI (see Appendix Table A-2 for full results)

Second, information on SAI may increase the perceived threat of climate change. After learning about SAI, subjects in the SAI treatment expect more negative impacts from climate change on average (mean: 0.09, 95% CI [-0.04, 0.22]) than subjects in the BASE or AUG treatment (mean: -0.04, 95% CI [-0.14, 0.05], Wilcoxon rank-sum test $p=0.096$). When asked directly, 42 percent in the SAI treatment are more alarmed about climate change after learning about SAI, while only 3 percent are less alarmed. 55 percent state no changes in their perception of climate change. This variable's interaction effect with the treatment shows that those who are more alarmed buy more VCOs (average marginal effect (AME) =0.67, $p=0.083$; results see Appendix Table A-3). However, subjects who are just as alarmed about climate change as they were before learning about SAI also buy significantly more VCOs (AME=0.81, $p=0.017$). This indicates that though SAI slightly increases awareness of climate change risks, this increased awareness does not drive the increase in VCO purchases.

Third, the increase in purchases might be caused by the perception of SAI as a threat and thus by a lack of acceptance of the technology. Subjects in the SAI treatment were asked about the acceptability of SAI research in the lab. This item is a strong indicator of acceptance because lab research is still a long way from deployment; not accepting lab research implies strong opposition to SAI. On average, subjects

who disagree with the conduct of lab research and those who 'don't know' buy more offsets ($p=0.082$ and $p=0.015$, respectively) than subjects in the BASE and the AUG treatment (Figure 2). Interestingly, subjects in the SAI treatment who have no objection to SAI lab research also buy more offsets on average ($p=0.015$).

Figure 2: Effect of SAI depending on attitude towards SAI research.



Note: Predicted margins from a Tobit regression including the control variables of the regression presented in Table 1 additionally including interaction effects between SAI and the acceptance of SAI research in the lab (see Appendix Table A-4 for full results).

5 Conclusion and discussion

To sum up, we find no evidence for risk compensation at an individual level as a reaction to information on SAI. Furthermore, we find no reduction in mitigation for those who perceive SAI as an effective method against climate change, even though they should be the ones most likely to reduce mitigation. Instead, our results empirically support the intuition that subjects who have been informed about SAI will mitigate more (Shepherd 2009; Betz & Caecan 2012; IASS 2014; Wibeck et al. 2015).

We examine two potential explanations for an increase in the mitigation levels. We find that though for many subjects information on SAI increases concern about climate change, this increased concern does not drive the increase in VCO purchases. Essentially, we find that subjects who perceive the deployment of SAI as an actual threat increase mitigation to prevent a level of climate change that would make the deployment of SAI more likely. This is reflected in the increase in mitigation by individuals who are uncertain about SAI effectiveness, who think it is largely ineffective, who reject SAI research or who are uncertain about SAI research. Correspondingly, those who think that SAI would not be effective at all do

not buy more VCOs because they do not think the deployment of SAI is at all likely. Future research should examine this argument more closely.

In addition, subjects who agree with SAI research increase mitigation as well, even though they do not reject the idea out of hand. This is in line with previous findings: On the one hand, the acceptance of SAI research does not automatically imply the acceptance of deployment (Pidgeon et al. 2013). SAI is perceived ambiguously as an emergency measure whose deployment should be prevented (Merk et al. 2015). People may thus increase mitigation because the deployment of SAI could be prevented if mitigation levels were higher. On the other hand, people think that just one method alone will not be enough to solve climate change and any progress on CE should be conditional on reaching mitigation targets (Ipsos MORI 2010; Winickoff et al. 2015).

Our findings suggest that research on SAI and public engagement with it is not likely to undermine current mitigation efforts by individuals. Our results, however, depend on the information we provided our subjects with and people may react differently to other framings. With this limitation in mind, our results show that the occurrence of risk compensation remains an open question and the debate about it is far from being settled. In addition, our results do not affect the argument that other actors like policymakers or interest groups might reduce mitigation efforts because of SAI. This should be addressed by future research.

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Appendix

Table A-1: Survey items used in the analysis

<i>Questions and items</i>	<i>response scale</i>
Dependent variable	
How many CO ₂ offsets would you like to buy?	0 – 10
Attitude towards mitigation	
In your daily life, how often do you try to cut down on greenhouse gas emission?	never (0); rarely (1); from time to time (2); often (3); always (4)
I feel morally obliged to help mitigate climate change.	strongly disagree (0) - strongly agree (5)
Determinants of the purchase decision	
(How did the following aspects influence your choice in buying CO ₂ offsets?)	
The IfW is handling the purchase, not me.	negatively influenced purchase amount (-2)-
My remaining endowment can only be cashed in via the online panel.	positively influenced purchase amount (2)
Effectiveness of measures against climate change	
(How do you evaluate the effectiveness of the following measures against climate change?)	
Release of sulfate particles in higher regions of the atmosphere	very ineffective (0) - very effective (3)
Effectiveness of individual mitigation options	
(How do you evaluate the effectiveness of the different options with which you can do something about climate change?)	
Purchase of voluntary carbon offsets	very ineffective (0) - very effective (3)
Perception of climate change impacts	
(How do you evaluate climate change? Do you think the following demographic groups will be positively or negatively affected by climate change today / in 25 years?) Questions combined into one factor by principal component analysis.	
People in my environment, including myself (today/in 25 years)	
People in industrialized countries (today/in 25 years)	strongly negatively affected (-3) – strongly positively affected (3)
People in developing countries (today/in 25 years)	
Effect of SAI information on perception of climate change	
(The idea of sulfate particles being released into higher regions of the atmosphere to counter climate change affects my feelings about climate change. I now find it ...)	
... a lot more threatening; ... more threatening; ... as threatening or not threatening as before;	
... less threatening; ... no longer threatening.	
Research on SAI	
(Do you agree or disagree with the following kinds of research being conducted within the next 25 years?)	
Research on efficiency and side effects of releasing sulfate particles via computer models in the laboratory, without releasing any particles in the atmosphere.	strongly disagree (0) - strongly agree (5)
Socio-demographics (from panel database)	
Age	years
Gender	male (0); female (1)
Highest academic qualifications obtained	no degree or secondary education certificate (0); university entrance certificate or university degree (1)

Table A-2: Tobit regression including interaction terms between SAI and SAI effectiveness for Figure 1

Dependent variable: purchase of VCOs		Average Marginal Effect	Standard Error
<i>Treatment Group</i>			
SAI	(at SAI effectiveness = 1)	-0.146	(0.663)
	(at SAI effectiveness = 2)	1.095**	(0.459)
	(at SAI effectiveness = 3)	-0.181	(0.608)
	(at SAI effectiveness = 4)	1.572***	(0.489)
<i>Perceived SAI effectiveness</i>			
	SAI effectiveness = 2	-0.842*	(0.477)
	SAI effectiveness = 3	-0.601	(0.558)
	SAI effectiveness = 4	-0.891*	(0.471)
<i>Climate Change</i>			
	(1) Awareness of impacts	0.004	(0.127)
	(2) Daily mitigation	-0.007	(0.142)
	(3) Moral obligation to mitigate	0.644***	(0.119)
<i>Experiment characteristics</i>			
	(4) VCO effectiveness	1.378***	(0.161)
	(5) Indirect purchase of VCOs	1.044***	(0.135)
	(6) Payment via panel points	0.141	(0.177)
<i>Socio-demographic variables</i>			
	Female	0.049	(0.261)
	Age	0.014*	(0.008)
	Higher education	0.982***	(0.257)
pseudo R ²		0.099	
N		658	

Note: SAI is a dummy variable indicating the SAI treatment. SAI effectiveness is a categorical variable indicating perceived SAI effectiveness (1 = not effective, 2 = largely ineffective, 3 = effective, 4 = don't know).

Female and higher education are dummy variables; all others except awareness of climate change impacts are standardised. (1) factor of the variables perception of climate change impacts 'today'/in 25' years for people in 'my environment including myself'/in industrialized countries'/in developing countries' (2) 'In your daily life, how often do you try to cut down on greenhouse gas emission?'; (3) 'I feel morally obliged to help mitigate climate change.' (4) Perceived effectiveness of voluntary carbon offsets; influence on purchase decision of: (5) 'The IfW is handling the purchase, not me.' and (6) 'My remaining endowment can only be cashed in via the online panel.' For complete description of variables, see Appendix Table A-1.

* p < 0.10, ** p < 0.05, *** p < 0.01

Table A-3: Tobit regression including interaction terms between SAI and change in perception of climate change caused by learning about SAI

Dependent variable:	Average Marginal Effect	Standard Error
<i>Treatment Group</i>		
SAI (at Higher CC threat = 1)	0.671*	(0.387)
(at Higher CC threat = 0)	0.812**	(0.341)
(at Higher CC threat = -1)	1.028	(1.218)
<i>Climate Change</i>		
(1) Awareness of impacts	0.032	(0.128)
(2) Daily mitigation	0.019	(0.143)
(3) Moral obligation to mitigate	0.633***	(0.120)
<i>Experiment characteristics</i>		
(4) VCO effectiveness	1.338***	(0.157)
(5) Indirect purchase of VCOs	1.053***	(0.136)
(6) Payment via panel points	0.116	(0.177)
<i>Socio-demographic variables</i>		
Female	0.114	(0.261)
Age	0.016*	(0.008)
Higher education	1.016***	(0.259)
pseudo R ²	0.095	
N	658	

Note: Higher CC threat is a categorical variable indicating an alteration in perception of climate change caused by learning about SAI (1 = more threatening, 0 = as threatening or not threatening as before, -1 = less threatening); the variable was only elicited in the SAI treatment and is thus also an indication of the SAI treatment.

Female and higher education are dummy variables; all others except awareness of climate change impacts are standardised. (1) factor of the variables perception of climate change impacts 'today'/in 25 years' for people in 'my environment including myself'/in industrialized countries'/in developing countries' (2) 'In your daily life, how often do you try to cut down on greenhouse gas emission?'; (3) 'I feel morally obliged to help mitigate climate change.' (4) Perceived effectiveness of voluntary carbon offsets; influence on purchase decision of: (5) 'The IfW is handling the purchase, not me.' and (6) 'My remaining endowment can only be cashed in via the online panel.' For complete description of variables, see Appendix TableA-1.

* p < 0.10, ** p < 0.05, *** p < 0.01

Table A-4: Tobit regression including interaction term between SAI and acceptance of SAI research in the lab for Figure 2

Dependent variable: purchase of VCOs	Average Marginal Effect	Standard Error
<i>Treatment Group</i>		
SAI (at SAI research = 1)	1.327 [*]	(0.762)
(at SAI research = 2)	0.339	(0.717)
(at SAI research = 3)	0.248	(0.421)
(at SAI research = 4)	0.940 ^{**}	(0.388)
(at SAI research = 5)	1.998 ^{**}	(0.819)
<i>Climate Change</i>		
(1) Awareness of impacts	0.025	(0.127)
(2) Daily mitigation	0.017	(0.142)
(3) Moral obligation to mitigate	0.623 ^{***}	(0.119)
<i>Experiment characteristics</i>		
(4) VCO effectiveness	1.339 ^{***}	(0.157)
(5) Indirect purchase of VCOs	1.040 ^{***}	(0.136)
(6) Payment via panel points	0.115	(0.176)
<i>Socio-demographic variables</i>		
Female	0.126	(0.260)
Age	0.016 [*]	(0.008)
Higher education	0.993 ^{***}	(0.259)
pseudo R ²	0.097	
N	658	

Note: SAI research is a categorical variable indicating agreement with SAI research in the lab or using computer models (1 = disagree, 2 = tend to disagree, 3 = tend to agree, 4 = agree, 5 = don't know); the variable was only elicited in the SAI treatment and is thus also an indication of the SAI treatment. Female and higher education are dummy variables; all others except awareness of climate change impacts are standardised. (1) factor of the variables perception of climate change impacts 'today'/'in 25 years' for people in 'my environment including myself'/'in industrialized countries'/'in developing countries' (2) 'In your daily life, how often do you try to cut down on greenhouse gas emission?'; (3) 'I feel morally obliged to help mitigate climate change.' (4) Perceived effectiveness of voluntary carbon offsets; influence on purchase decision of: (5) 'The IfW is handling the purchase, not me.' and (6) 'My remaining endowment can only be cashed in via the online panel.' For complete description of variables, see Appendix Table A-1.

* p < 0.10, ** p < 0.05, *** p < 0.01

Information treatment

Please read the following text carefully:

Causes of climate change

Since 1900, the average global surface temperature has risen by about 0.9°C. It is extremely likely that this has been caused by increased emissions of greenhouse gases such as carbon dioxide (CO₂). Greenhouse gases are, for example, released when coal, oil and gas are burnt. If the current trend continues and nothing is done about climate change, the average global surface temperature will have risen by about another 3.9°C by the end of the century.

Visible evidence of climate change

Changes in climate can already be observed. It has been getting warmer. Massive glacier loss is evident almost everywhere. Arctic sea-ice and the snow cover of the northern hemisphere have also decreased.

The oceans have grown warmer and the sea level has risen. Furthermore, the oceans have absorbed about two-thirds of the greenhouse gases emitted and acidification of the seas is on the rise.

Since about 1950, changes in many extreme weather and climate events have been observed. Among other things, there are fewer very cold days and more very hot days. There has also been an increase in the number of extreme precipitation events in some regions.

All of these changes have an effect on plants, animals and humans. The more greenhouse gases we emit, the bigger the future changes will be.

[new Screen]

To stop or reduce climate change and its effects, various measures can be adopted either individually or in combination with each other. These include:

Climate protection via reduction of greenhouse gas emissions

Greenhouse gas emissions can be reduced by switching to renewable energies or by a change in consumer behaviour. Switching to renewable energies (e.g. wind or solar energy) costs money, requires grid expansion and involves interference with landscapes and Nature. Changes in consumer behaviour include flying less frequently, switching from the car to public transport/bikes or lowering room temperatures.

[new Screen]

Adaptation to climate change

Examples of adaptation to climate change are building higher dikes, resettling people or cultivating more stress-resistant crops. Adaptation measures also involve costs. Resettling means that a lot of people will lose their livelihood and their social environment. Some animals and plants are either completely or largely unable to adapt, especially when environmental changes happen very suddenly.

[new Screen]

only for SAI treatment

Manipulation of global surface temperature

Currently there is increasing discussion about a measure for manipulating surface temperature directly. When sulfate particles are released into higher regions of the atmosphere, they reflect some of the sunlight back out into space before it warms the Earth.

This measure could slow down global warming much faster than cutting back greenhouse gas emissions. To achieve that goal, the particle layer would have to be renewed constantly until the share of greenhouse gases in the atmosphere dropped again. Ocean acidification cannot be prevented by this measure.

Little research has been done on the effects and side effects of this measure. Injecting sulfate particles could have negative effects on various ecosystems, the ozone layer and the health of animals and people. Furthermore, political conflicts might arise over deployment itself and the extent of deployment. It is unclear whether additional negative effects would occur during deployment. Research can provide new information about effects and side effects, without necessarily coming to any definite conclusions.

only for AUG treatment

Future climate development

Researchers throughout the world are trying to work out how the climate will change in future. The following points are largely uncontested:

Global mean surface temperature will continue to rise. Heat waves will occur more frequently. In addition, hot days will become hotter and more frequent, while cold days will be warmer and less frequent. However, occasional extremely cold winters will continue to occur. In many regions, the number of extreme precipitation events will increase, as will the occurrence of longer and more severe droughts. The differences between arid and humid regions will increase. The differences between dry and wet seasons will also increase (with some regional exceptions).

In future, the Arctic sea-ice cover will shrink and lose volume and the spring snow cover in the northern hemisphere will decrease. Glacier volume will continue to decrease and the ocean will get progressively warmer. Extremest ocean warming is projected for subtropical regions in the northern hemisphere and for tropical regions. The sea level will continue to rise, though not uniformly across regions.

[new Screen]

for all treatment groups

Purchasing CO₂ certificates against climate change

Another way of cutting down greenhouse gas emissions is to buy CO₂ certificates. The trade revenues finance projects to combat climate change like the construction of renewable energy systems or projects to improve energy efficiency.

In this questionnaire you have the opportunity to contribute to the fight against climate change and to buy CO₂ certificates. To do so, you can use the 10 euros you were given for taking part in this survey. Any money you do not use to buy certificates will be added to your YouGov account approximately 4 weeks after completing the survey.

The certificates meet the so-called gold standard. In other words, you can rest assured that carefully selected and certified projects will be financed by the certificates and that CO₂ reduction is actually happening. Every one of these certificates reduces greenhouse gas emission by 50 kg CO₂.

[new Screen]

How much is 50 kg CO₂?

A car emits approximately 50 kg CO₂ during a drive from Hamburg to Berlin. Average per capita emission in Germany is 11,400 kg CO₂ every year. On a global scale, average emission per head of population amounts to approximately 5,100 kg CO₂ every year.

How much does one CO₂ certificate cost?

Usually, one certificate costs 1.15 euros. If you buy certificates during this survey, the Kiel Institute for the World Economy (IfW) will shoulder 15 cents of the cost of every certificate. As a participant in this survey you only need to pay 1 euro to mitigate the emission of 50 kg CO₂.

[new Screen]

How does the purchase work?

After completing the survey, the IfW will buy the requested amount of CO₂ certificates for every participant. The IfW will publish the overall amount of requested certificates on its website, so you can make sure that the certificates have actually been purchased. You will also find a confirmation of the buying process on the website. The corresponding link will be sent to you by email via YouGov. Your personal information will, of course, remain anonymous and will not be published.

[new Screen]

Control questions

Before you make your decision, please answer the following 4 questions to ensure that you have understood what is at stake.

Remember: Every participant has a credit of 10 euros, and one certificate for 50 kg CO₂ costs 1 euro.

Assume that one of the participants wants to buy 6 CO₂ certificates. *[Participants are excluded from the survey after three incorrect attempts to answer]*

How many CO₂ certificates will be bought on his behalf? _____ certificates

What amount of CO₂ emissions will be avoided? _____ kg

How much is he paying for this purchase? _____ Euros

How much money is left after the purchase? _____ Euros

[new Screen]

Your purchase decision

In this survey, one certificate for 50 kg CO₂ costs 1 euro. Your credit is 10 euros.

How many CO₂ certificates would you like to buy? Please enter your decision here.

_____ Y _____ certificates

[new Screen]

Your purchase decision is equivalent to the avoidance of $Y \cdot 50$ kg CO₂ and $10 - Y$ Euros remain in your account.

The impact of social information on individuals' climate change mitigation

Christine Merk

Abstract

This paper examines the effect of information about peers' behavior on individuals' climate change mitigation. In a framed field experiment subjects had the opportunity to buy voluntary carbon offsets. After having been informed about the amount bought by another randomly chosen subject, they could reconsider their initial decision. The main results are that free-riders do not react to social information. By contrast, subjects who have already bought offsets react to social information. Good examples tend to motivate an increase in purchases and bad examples have the reverse effect. However, the effect of good examples on subjects' probability to increase the purchase is stronger than the effect of bad examples on the probability to decrease purchases. At the same time, however, the marginal change caused by bad examples is larger than the change caused by good examples. The results suggest that subjects buy offsets to create or maintain a positive self-image from doing what they feel is morally right; they change their behavior when social information affects their self-image. Subjects who do not derive a positive self-image from mitigation tend to free-ride.

1 Introduction

There is an increasing interest in the effect of peer information on pro-social behavior as it might be a very (cost) effective way to increase contributions to public goods (Allcott et al., 2012; Behavioural Insights Team, 2011; Goldstein et al., 2008). It has been researched both in the lab and in the field. In the lab, most work is done in the context of voluntary contribution games (Engel et al., 2014; Güth et al., 2007; Moxnes et al., 2003), and in the field, research focusses on the contexts of energy or water conservation (Behavioural Insights Team, 2011; Allcott, 2011; Ayres et al., 2013; Costa et al., 2013; Dolan et al., 2015), and charitable giving (Croson et al., 2008, 2013; Frey & Meyer 2004). The present study looks at the effects of social information on individuals' changes in climate change mitigation, i.e. their purchases of voluntary carbon offsets.

People take social information as examples for how to act in a specific context; they infer the social norm from observation. In voluntary contribution games in the lab, first-movers', i.e. leaders', contributions influence followers' behavior significantly (Güth et al., 2007; Moxnes & van der Heijden, 2003). But followers do not match leader contributions; they cooperate conditionally and stay below the leaders' example (Güth et al., 2007; Fischbacher et al., 2001; Keser et al., 2000). Conditional cooperation is both reactive to others' behavior and forward looking to future interactions; it has a strong strategic component. When there is no leader, people first act upon their home-grown beliefs about what is appropriate and update these beliefs as they observe and interact with peers (Fischbacher et al., 2010).

But also when there are no or negligible strategic incentives, social information gives cues about the social norms in the respective contexts; it sets the tone for or against cooperation when subjects are only informed about how other subjects behaved in a similar context without interaction between the observer and the observed (Engel et al., 2014). Evidence from the domain of charitable giving shows that observing good examples or high contribution rates increases donations, while bad examples or low contribution rates decrease donations (Croson & Shang, 2008, 2013; Frey & Meier, 2004). However, social information does not affect free-riders, they continue to donate nothing (Frey & Meier, 2004). The observed behavior seems not to be connected to a social norm which is relevant in their social context.

Observing peers also influences people because they receive feedback about their own behavior relative to others'; they seem to care whether they are behaving 'better' or 'worse' than others. Households reduce their electricity or water consumption when they learn that their neighbors use less than they do (Allcott, 2011; Bhanot, 2015; Dolan & Metcalfe, 2015).

Social norms motivate behavior because following the norm creates a positive social image and a good reputation while transgressions create stigma (Bénabou et al., 2006). But even when households are anonymous, they seem to dislike knowing that they are wasteful. Thus, people also follow social norms when their behavior is not publicly observed because individuals derive utility from a positive self-image, i.e. warm glow, or disutility from guilt (Andreoni, 1990; Bénabou & Tirole, 2006; Charness et al., 2006; Kahneman et al., 1992; Kraft-Todd et al., 2015).

The downside of social information is its negative impact on pro-social behavior when bad examples are observed. Households with a low consumption level use more water after having learned about their relative status (Bhanot, 2015). For charitable there is evidence that the decrease in donations caused by bad examples is larger than the increase caused by good examples as the increase lowers private payoffs while the decrease raises payoffs (Croson & Shang, 2008). However, the downward effect disappears when people are assured about the norm for example with a smiley for 'good' behavior or information about how to save energy (Allcott, 2011; Cialdini et al., 1990; Schultz et al., 2007).

In this paper, I analyze the effect of social information on individual climate change mitigation, i.e. contributions to the global public good climate protection. In a framed field experiment, subjects first indicated how many voluntary carbon offsets they wanted to buy, then they learned how many offsets another randomly selected participant bought and they could reconsider their initial purchase decision. There was no interaction between subjects and contributing as well as free-riding was anonymous.

The study extends past research by disentangling the effects of good and bad examples on (1) free-riding, (2) the propensity to change behavior, and (3) the extent of change in behavior. To the best of my knowledge, it is furthermore the first study to test the impact of relative peer information on contributions to climate protection. Previous studies on peer effects on voluntary carbon offsetting either analyze stated behavior (Araghi et al., 2014; Bolsen et al., 2014) or look at the impact of mean information (Löschel et al., 2013).

The data show that social information does not motivate free-riders to buy offsets. The effect on cooperators is twofold – good examples raise the probability to increase the purchase more than bad examples raise the probability to decrease the purchase. Especially, subjects with high beliefs about peers increase the amount of offsets when their initial purchase was low. But while good examples increase the probability to change more strongly, bad examples have a larger marginal effect on the change in the purchase decision.

The remainder of the paper is structured as follows: Section 2 explains the study's design and procedures. Section 3 presents the results and Section 4 discusses the results and concludes.

2 Design and procedures

The study analyzes subjects' reaction to social information in a within-subjects-design by comparing the amount of purchased voluntary carbon offsets before and after learning about a peer's behavior. This is a strong test of the effect of social information because to change the decision, inertia and resistance to change have to be overcome. Furthermore, the design allows analyzing the effect of subjects' contribution in relation to the social reference.

The design was as follows: Subjects received an endowment of 10 Euro which they could either use during the experiment to buy voluntary carbon offsets or keep for themselves. To create common baseline knowledge, subjects had to read a text about climate change, its effects, and about the possibility to support climate protection by buying voluntary carbon offsets (see Merk et al., 2016).

The experimental sequence proceeded in four steps (Figure 1).¹ At *purchase decision 1*, subjects stated how many offsets they wanted to buy. They were offered offsets for 50 kg CO₂ at a discount price of 1 Euro. The regular price is 1.15 Euro. The rebate of 15 cents reduces subjects' incentives to postpone the purchase and use the money to buy offsets after the experiment. With their endowment, subjects could buy between 0 and 10 offsets.²

Subjects were then asked about their *beliefs about peers*. They had to guess the average number of offsets bought by all subjects during the experiment. Correct beliefs – within a margin of +/-0.5 offsets – were rewarded with a payment of 20 cents.

In the third step, subjects received *social information*. For this, they had to choose one of 6 figures which represented subjects from the pre-test phase to learn how many offsets this other subject had bought. The possible values for the social information ranged between 0 and 10 offsets; the values occurred randomly and were uniformly distributed across all possible values.

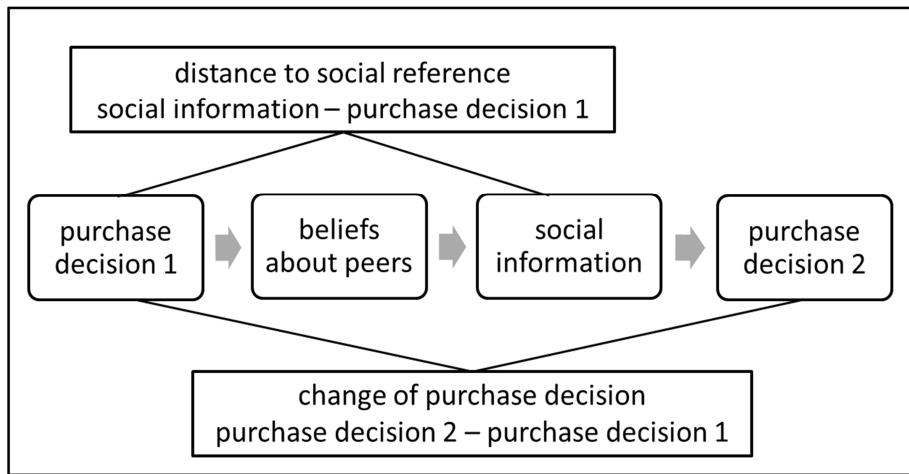
At *purchase decision 2*, subjects had to state again how many offsets they wanted to buy. Subjects were not informed about the experimental sequence in advance and were not able to

¹ See experimental script in the Appendix.

² Subjects had to answer 4 questions to check whether they had understood the purchasing procedure. Three failed attempts to answer the questions correctly lead to the early termination of the experiment (N=103).

return to the previous steps. After the *purchase decision 2*, subjects answered questions about their attitudes towards mitigation and mitigation options, and socio-demographics.

Figure 1: Experimental sequence and definition of variables



After the survey, the amount of offsets from *purchase decision 2* was bought for every subject. Any remaining endowment and payment for correct beliefs was credited to their account with the online panel. The confirmation of the purchase was posted online and subjects were informed about the purchase and received a link to the confirmation about 4 weeks after the experiment.

The experiment was conducted online in spring 2015. Subjects were sampled from an online panel and are representative of the German internet population with respect to their gender, age, and state of residence (Bundesland). The final sample after data cleaning consists of 548 subjects.³ Subjects' age ranges between 18 and 86 years with mean age of 48 years. Overall, 43% are female. Furthermore, 50% of subjects have a higher education entrance certificate (see Table A-1 in the appendix for descriptive statistics for all variables in the analysis).

3 Results

Subjects' decisions and the impact of social information are analyzed in three steps: (1) the decision to buy offsets during the experiment, i.e. cooperate, or to free-ride instead, (2) the decision to increase or decrease the initial purchase decision, and (3) the change in the

³ Subjects who completed the experiment in 11 minutes or less are excluded because they were probably not able to read the text and the instructions carefully and participate in the experiment attentively in less time. Furthermore, subjects who answered 'don't know' to the questions about the perceived effectiveness of voluntary carbon offsets and the feeling of a moral obligation to mitigate are excluded from the analysis. The initial sample consisted of 866 subjects.

purchase decision (*purchase decision 2 – purchase decision 1*). The sample at step (2) and (3) is conditional on the previous step(s): at (2) free-riders are excluded and at (3) those who do not change their decision. As people's preferences for pro-social behavior are heterogeneous the step-wise analysis helps to identify effects for subgroups which would remain hidden in aggregate analysis.

The focal independent variable in step (1) is *social information*; in step (2) and (3), it is the difference between *social information* and *purchase decision 1 (distance to social reference)*. For this variable, negative values indicate a bad example [-10;-1] and positive values [1;10] indicate a good example. The different form of the variable in step (1) is necessary because the *distance to the social reference* is by definition equal to or larger than zero for free-riders.

(1) Decision to buy offsets

Free-riders predominantly decide not to buy offsets at the first occasion and receiving *social information* seems not to make them reconsider. 28% of subjects (N=151) are free-riders who do not buy at either of the two occasions, while 72% of subjects (N=397) buy offsets.⁴ The means and the distributions of the variable *social information* are equal in the two groups (t-test: $p=.964$; Kolmogorov-Smirnov test $p=1.000$). Only 22 subjects (4%) buy offsets at the second occasion after they did not want any at the first occasion. Furthermore, the coefficient of *social information* in the logistic regression for the decision to buy offsets is not significant (Table 1).

Higher *beliefs about peers* are positively associated with the propensity to buy offsets ($\beta=.333^{***}$, Table 1). Both, free-riders and cooperators assume that their peers buy offsets but on average cooperators' beliefs are higher than free-riders' (5.748 vs. 4.12; one-sided t-test $p<.000$). In addition, the overall distribution of *beliefs about peers* is significantly different between groups (Kolmogorov-Smirnov test for the equality of distributions: $p<.000$).

In fact, subjects' decision to buy offsets is strongly influenced by whether they feel morally obliged to help mitigate climate change in general and their perception of the effectiveness of voluntary carbon offsets for climate change mitigation (Table 1).⁵ For example, a typical subject is 25 percentage points more likely to buy offsets when he feels morally obliged

⁴ Compared to similar experiments, the share of subjects who buy offsets is very high. In Gallier et al.'s (2014) study, 43% make at least one purchase and in Diederich and Goeschl's (2014) study about 16% buy offsets instead of taking a cash amount.

⁵ The independent variables perceived effectiveness and feeling of moral obligation to mitigate are coded as dummy variables. The answer categories 'very ineffective'/'ineffective' and 'strongly disagree'/'disagree'/'somewhat disagree' are grouped together and equal 0, while 'effective'/'very effective' and 'somewhat agree'/'agree'/'strongly agree' equal 1.

compared to someone otherwise similar who does not feel morally obliged.⁶ For the perceived *offset effectiveness*, the marginal effect on the probability is 38 percentage points. Accordingly, 78% of buyers feel morally obliged to mitigate compared to 43% of free-riders. 93% of buyers think offsets are effective, while only 56% of free-riders do. Overall, only 6% do not buy offsets even though they think offsets are effective and they feel morally obliged to mitigate. These two factors are strongly conditional for making a purchase.

Result 1: Social information does not influence the decision to free-ride. This decision is strongly influenced by the perceived effectiveness of offsets and a feeling of moral obligation to mitigate climate change.

Table 1: Logistic regression for the decision to buy offsets; standard errors in parentheses⁷

	buy
social information	0.004 (0.037)
beliefs about peers	0.333*** (0.059)
offset effectiveness†	1.990*** (0.288)
moral obligation to mitigate†	1.255*** (0.280)
female†	-0.284 (0.233)
high level of education†	0.384 (0.240)
age	-0.004 (0.008)
constant	-2.224*** (0.583)
N	548
pseudo R ²	0.247

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; † dummy variable

⁶ Male, high level of education; Variables fixed at the mean: age, social information, beliefs about peers; moral obligation=0 or effectiveness=0.

⁷ Note: Unlike in the subsequent regressions, *social information* is included as the actual value instead of the relative *distance to the social reference*. When the *distance to the social reference* is included instead, the coefficient is significant (-.294***); this is, however, caused by design rather than an actual effect. For the group of free-riders, the distance is by definition larger than 0 and ranges only from 0 to 10 (mean: 5.046), while it ranges from -10 to 10 for buyers (mean: -.632).

(2) Decision to increase or decrease the first purchase decision

The *distance to the social reference* influences both the probability to change and the direction of the change in the purchase decision. Among all those who buy offsets, the majority does not change the initial decision after receiving social information; they state the same amount as before (70%; N=276). Subjects who see good examples are more likely to change than subjects who see bad examples (41% vs. 25%; one-sided t-test $p < .000$). The probability to change is lowest when the first decision and the reference value coincide (10%). When subjects change their decision, good examples predominantly lead to an increase (91%; N=62) and bad examples to a decrease (88%; N=44).

Good examples with higher values have a stronger effect on the probability to change than bad examples with the same absolute value. This is confirmed by results from multinomial logistic regression for the decision to increase or decrease the purchase compared to not changing the initial decision (Table 2). The comparison of the effects of the *distances to the social reference* of -5 and +5 illustrates this difference well. While the probability to decrease is 21% for the bad example of -5, the probability to increase is 46% for the corresponding good example of +5 (Wald-test for *distance to social reference*: $-\beta_{decrease} = \beta_{increase}$: $p < .000$).⁸

In addition, the effect of the *distance to the social reference* on the probability to increase (decrease) is stronger, when the *beliefs about peers* are high. Especially subjects who see good examples and believe their peers buy many offsets are more likely to increase their purchase compared to subjects with low beliefs about their peers. Figure 2 shows the predicted probabilities to increase (decrease) along the *distance to the social reference* for very low (=0) and very high (=10) *beliefs about peers*. Though less pronounced this difference also exists for bad examples: subjects with high *beliefs about peers* are more likely to react to bad examples and decrease their purchase.

In stark contrast to the decision to free-ride, the decision to increase or decrease the purchase is not at all influenced by the perceived *offset effectiveness* or a feeling of a *moral obligation to mitigate*. Among the sociodemographic variables only a *high level of education* has a significant effect – it decreases the likelihood to change the decision. Overall, the inclusion of control variables in model (2) shows that the effects of the *distance to the social reference* and the *beliefs about peers* are robust to the inclusion of the control variables (Table 2).

⁸ Based on model (1) in Table 2 for *beliefs about peers* at the mean.

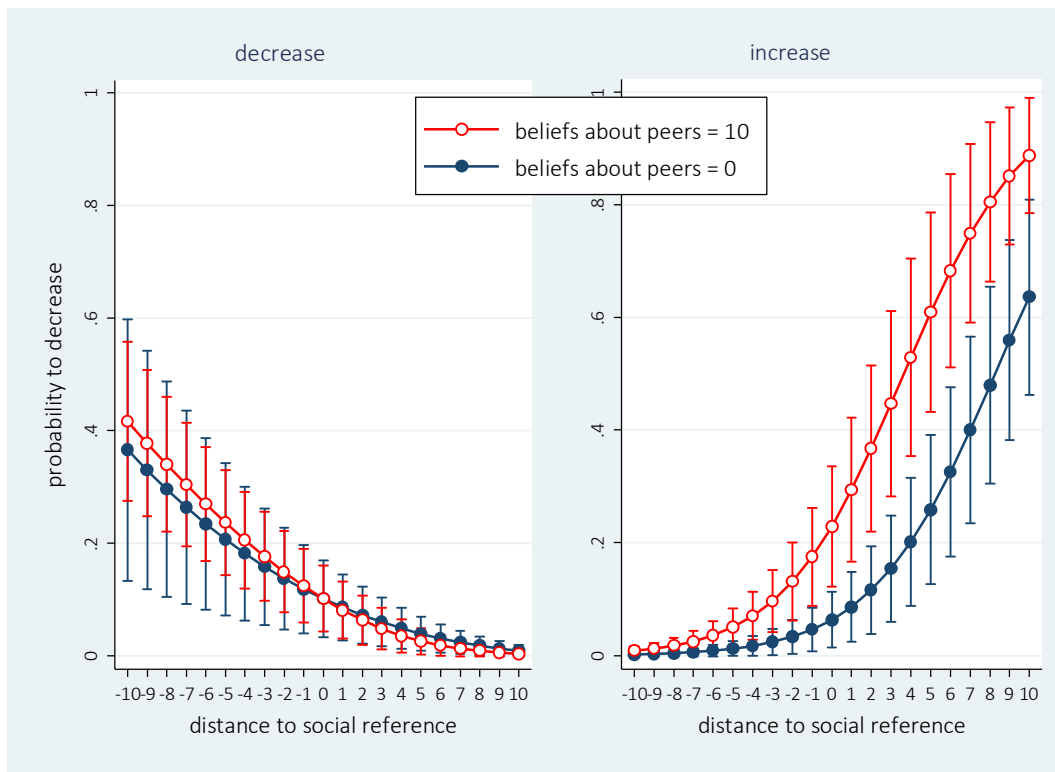
Result 2: Good examples increase the probability to buy more offsets more strongly compared to bad examples increasing the probability to buy less offsets. The effect increases in the absolute distance to the social reference. Furthermore, the effect on the probability to change is stronger when the beliefs about peers are high.

Table 2: Multinomial logistic regression for the decision to decrease or increase the amount of offsets at purchase decision 2; base category: no change; standard errors in parentheses

	(1)		(2)	
	decrease	increase	decrease	increase
distance to social reference	-0.140*** (0.040)	0.383*** (0.052)	-0.160*** (0.042)	0.387*** (0.053)
beliefs about peers	0.136* (0.077)	0.169** (0.080)	0.139* (0.080)	0.141* (0.084)
moral obligation to mitigate†			-0.329 (0.607)	-0.528 (0.480)
offset effectiveness†			-0.272 (0.338)	-0.128 (0.345)
female†			-0.356 (0.333)	0.049 (0.328)
high level of education†			-0.822** (0.339)	-0.679** (0.343)
age			-0.011 (0.010)	0.005 (0.010)
constant	-2.879*** (0.507)	-2.953*** (0.535)	-1.447* (0.859)	-2.227*** (0.836)
N	397		397	
pseudo R ²	0.188		0.209	
AIC	542.388		548.91	
BIC	566.291		612.653	

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; † dummy variable

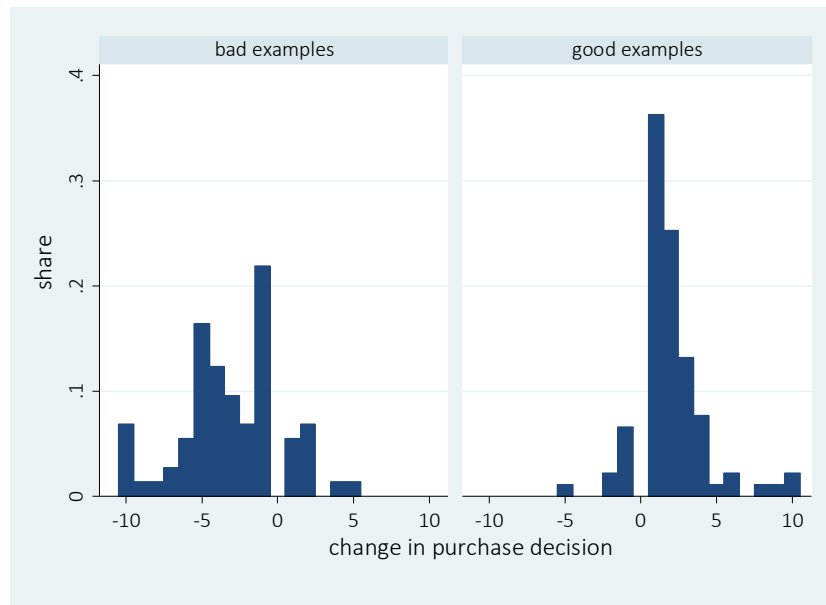
Figure 2: Predicted probability to decrease or increase the amount of offsets for different distances to the social reference and beliefs about peers, 95% confidence intervals; based on regression (1) in Table 2



(3) Decision about how much to change the purchase decision

While good examples increase the probability to change more, bad examples cause more actual change; they lead on average to a stronger adjustment than good examples. Purchases are mostly only increased by one or two offsets while decreases tend to be higher (Figure 3). Most subjects (87%; $N=105$) do not imitate the example they see but adjust (marginally) towards the reference. Only 13% of subjects match the social reference with their second decision. Few go higher (lower) than the good (bad) example (8 cases each). For bad examples, the average change is -3.2 ($N=50$) while those who see good examples change on average by 2.06 offsets ($N=68$; two-sided t-test for difference between absolute values: $p=0.028$). This difference in the change is not driven by an absolute difference of the examples between groups: Good and bad examples are on average similar in magnitude (4.59 vs. -4.94 ; two-sided t-test for absolute values: $p=.49$).

Figure 3: Distribution of changes in the purchase decision for good and bad examples (N=121)



Regression analysis confirms that the effect of the *distance to the social reference* on the *change in purchase decision* is asymmetric: the marginal effect of bad examples on the change is about twice the marginal effect of good examples. When a bad example worsens by 1 this leads to a decrease of .711 offsets, while an increase of a good example by 1 leads to an increase of .365 offsets (Table 3; Wald test $p=.033$). Figure 4 shows the difference in the slopes of the linear prediction and the actual observations. The break is modelled via a regression discontinuity design. The variable *good example* indicates the regime switch – 0 indicating a bad example, 1 a good example; it is interacted with the variable *distance to social reference*. Cases where *purchase decision 1* is equal to the *social information* are excluded from the analysis.⁹

Beliefs about peers do not influence the amount of change. The control variables *age* and *high level of education* increase the amount of change.

On aggregate, the asymmetric and opposing effects of good and bad examples on the probability to increase (decrease) and the amount of change cancel out. Among those who buy offsets, the mean amount of offsets at the first and the second occasion is the same (5.665 vs. 5.622; two-sided t-test $p=.682$).

⁹ As the data is restricted to the range [-10; 10], it was checked whether a Tobit regression should be used instead of OLS. The estimated standard error of the Tobit regression and the RMSE of the OLS as well as the coefficients in the model are very similar; this indicates the use of OLS (Stata Manual 2329f.). Furthermore, only 3 of overall 118 observations are left-censored and 2 are right-censored.

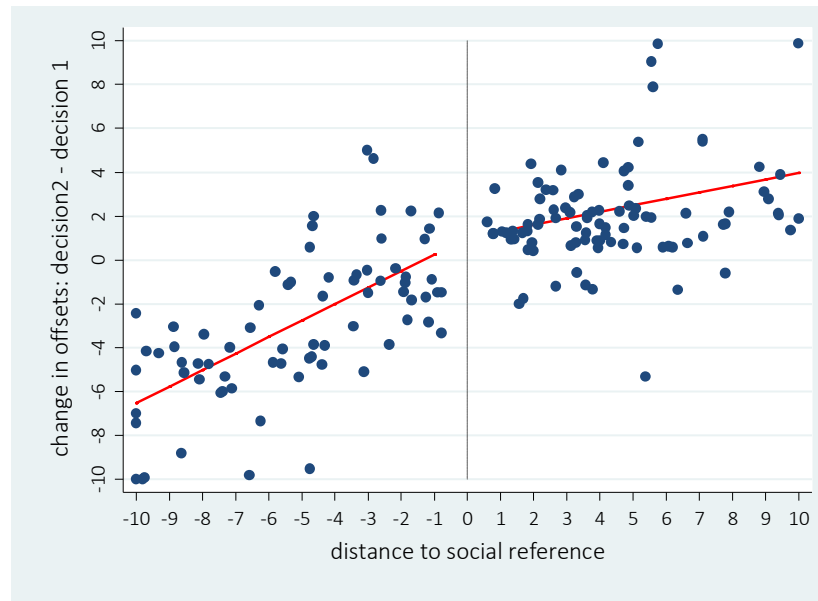
Result 3: Bad examples decrease offset purchases more strongly than good examples increase them.

Table 3: Linear regression for the change in the purchase decision

	change in purchase decision
bad example * distance to social reference	0.711*** (0.085)
good example * distance to social reference	0.365*** (0.097)
beliefs about peers	-0.038 (0.103)
offset effectiveness†	0.116 (0.466)
moral obligation to mitigate†	-0.031 (0.657)
female†	-0.008 (0.462)
high level of education†	0.809* (0.458)
age	0.034** (0.014)
constant	-1.404 (1.123)
N	118
adj. R ²	0.632

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; † dummy variable

Figure 4: Linear prediction of the marginal impact of distance to social reference on the change in the purchase decision based on the OLS regression in Table 3 (N=118) and observations¹⁰



4 Discussion and conclusion

This study analyses the effect of social information on individuals' decision to buy voluntary carbon offsets. It disentangles the effect of social information on the decisions (1) to free-ride or to cooperate, i.e. buy offsets, (2) to decrease or increase the amount of purchased offsets, and (3) the decision about how much to change the amount of offsets. It is the first study which looks at the effects at the different decision steps; it is also the first study to analyze the effect of social information in the context of climate change mitigation with revealed preferences.

The three main results are that first, free-riders do not react to social information. This is in line with previous findings from Frey and Meyer (2004) on charitable giving. A sense of moral obligation to mitigate and a perceived effectiveness of carbon offsets are strong facilitators of contributions. Especially the impact of a sense of moral obligation suggests that subjects who buy offsets (cooperators) gain positive self-image from mitigating climate change.

Second, unlike free-riders, subjects who buy offsets react to social information: the better an example, i.e. the higher subjects' distance to the social reference, the more likely they are to increase the purchase decision. Bad examples have the opposite effect: higher absolute values raise the probability to decrease the purchase decision. The effect is, however, less pronounced than the effect of good examples.

¹⁰ See Table A-2 for the results of a robustness check without multivariate outliers.

The reaction to good examples implies that maintaining a positive self-image is an important motivation to change the decision. When subjects receive the feedback from the environment that they are a 'worse' contributor than a peer, they increase their purchase to be 'better' again. Furthermore, an increase is especially likely when the initial purchase decision was low and both the beliefs about peers and the distance to the social reference are high. Subjects seem to catch themselves at violating their own high standards and feel especially guilty. This indicates that they try to resolve the cognitive dissonance (Akerlof et al., 1982) and restore their self-image of being someone who does the 'right' thing by increasing their purchase.

The, in comparison, smaller effect of bad examples on the probability to change indicates that many subjects value the positive self-image they derive from mitigation more highly than the potential gain in private payoff they could realize by adjusting downward towards the bad example. They might even feel an endowment effect because of a strong link between the purchase and the self-image (Dommer et al., 2013) which could explain their reluctance to decrease the purchase.

The third result is that subjects decrease their purchase more strongly when they see bad examples compared to the increase when they see good examples. This is in line with previous findings from the context of charitable contributions to local public goods (Croson & Shang, 2008). The intuitive explanation is that increasing the purchase lowers subjects' private payoffs and is thus more costly, while decreasing the purchase leads to higher private payoffs. Subjects are, however, reluctant to buy less than the bad example; this is not in line with an adjustment below the example which conditional cooperation would predict (Keser & van Winden, 2000). This implies that subjects who react to bad examples try to remain 'better' contributors than their peer and maximize their payoff at the same time.

For climate policy, this study identifies pitfalls and opportunities of informing about peers for increasing cooperation among those who are already willing to mitigate: it is important to provide realistic examples which are bad examples to as few as possible. Furthermore, the study shows that it can already suffice to observe only one other peer to change behavior. But the results also show that a substantial share of people is not affected by social information, i.e. social norms. Future research should thus look at ways to extend the reach of the social norm for contributing to climate protection to also motivate free-riders to contribute.

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Chapter 4

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Appendix

Experimental script

Information text on climate change and voluntary carbon offsets see Merk et al. (2016).

Your purchase decision

In this survey, one certificate for 50 kg CO₂ costs 1 Euro. Your credit is 10 Euro.

How many CO₂ certificates would you like to buy? Please enter your decision here.

_____Y_____ certificates

[new Screen]

Your purchase decision avoids $Y*50$ kg CO₂ and your remaining credit is $10-Y$ Euro.

[new Screen]

Now, we would like to know what you think about the other participants and their purchase decisions.

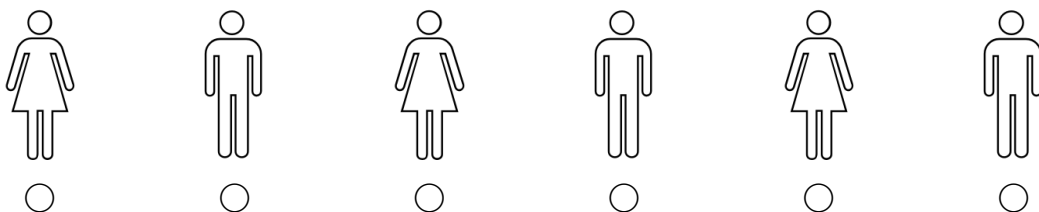
What do you think is the average number of certificates purchased by all participants?

If your estimate differs from the actual average by less than ± 0.5 you will receive an additional credit of 20 cents to your YouGov account.

_____ average number of certificates

[new Screen]

Here you can see 6 participants. You now have the opportunity to learn how many certificates one of these participants bought. Please choose one of the figures.



[new Screen]

The person you chose bought A certificates and avoided $A*50$ kg CO₂.

[A is a random number between 0 and 10]

You now have the opportunity to make your purchase decision again. Only this decision will be relevant and only this amount of certificates will be bought for you and any remaining endowment from this decision will be credited to your account with YouGov after this survey.

How many CO₂ certificates would you like to buy? Please enter your decision here.

_____ P _____ certificates

[new Screen]

With your decision you avoid $P \cdot 50$ kg CO₂ and your remaining credit is $10 - P$ Euro.

Table A-1: Summary statistics by groups in the regression models

	buy		change		amount of change	
	mean	sd	mean	sd	mean	sd
offsets, 1st decision	4.104	3.844	5.665	3.397	4.780	3.647
offsets, 2nd decision	4.073	3.642	5.622	3.097	4.610	2.559
beliefs about peers	5.299	2.243	5.748	2.149	5.884	2.379
social information	5.036	3.094	5.033	3.103	5.331	2.944
distance to social reference	0.932	5.029	-0.632	4.736	0.551	5.452
change of purchase decision	-0.031	1.768	-0.043	2.078	-0.169	3.790
offset effectiveness	45%		57%		54%	
moral obligation to mitigate	85%		91%		87%	
female	43%		44%		43%	
high level of education	50%		49%		41%	
age	48.50	15.627	48.72	16.033	48.35	16.669
N	548		397		118	

Analysis without multivariate outliers**Table A-2:** Linear regression for amount of change with and without multivariate outliers

	amount of change	
	all cases	without multivariate outliers
bad example * distance to social reference	0.711*** (0.085)	0.667*** (0.059)
good example * distance to social reference	0.365*** (0.097)	0.281*** (0.071)
beliefs about peers	-0.038 (0.103)	0.059 (0.077)
offset effectiveness†	0.116 (0.466)	-0.268 (0.327)
moral obligation to mitigate†	-0.031 (0.657)	-0.181 (0.476)
female†	-0.008 (0.462)	0.330 (0.320)
high level of education†	0.809* (0.458)	-0.095 (0.323)
age	0.034** (0.014)	0.023** (0.010)
constant	-1.404 (1.123)	-0.913 (0.837)
N	118	108
adj. R ²	0.632	0.736
AIC	539.848	407.292
BIC	564.784	431.431

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; † dummy variable

Multivariate outliers were determined via the influence statistic Cook's D. As critical value $4/N$ was used (Kohler et al., 2012, p. 282). Excluding 10 influential cases slightly decreases the coefficients of the focal independent variable *distance to the social reference* and its interaction with *good example*; the coefficients are, however, not significantly different between the regression with the full sample and the sample without outliers ($p=0.492$; $p=0.676$). The share of explained variance increases by 10 percentage points in the model without outliers. The outliers are subjects who did either not change in the expected direction or whose change exceeded their distance to the social reference.

Erklärung zum selbständigen Verfassen der Arbeit

Ich erkläre hiermit, dass ich meine Doktorarbeit „Essays on individuals’ responses to climate change and technologies to counteract climate change“ selbstständig und ohne fremde Hilfe angefertigt habe und dass ich als Koautor maßgeblich zu den weiteren Fachartikeln beigetragen habe. Alle von anderen Autoren wörtlich übernommenen Stellen, wie auch die sich an die Gedanken anderer Autoren eng anlehnenden Ausführungen der aufgeführten Beiträge wurden besonders gekennzeichnet und die Quellen nach den mir angegebenen Richtlinien zitiert.

29. März 2016

Datum

Unterschrift