Climate experts’ views on geoengineering depend on their beliefs about climate change impacts

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Abstract

Climate change damages are expected to increase with global warming, which could be limited directly by solar geoengineering. Here we analyse the views of 723 negotiators and scientists involved in international climate policy who will have a significant influence on whether solar geoengineering will be deployed to counter climate change. We find that respondents who expect severe global climate change damages and who have little confidence in current mitigation efforts are more opposed to geoengineering than respondents who are less pessimistic about global damages and mitigation efforts. However, we also find that respondents are more supportive of geoengineering when they expect severe climate change damages in their home country than when they have more optimistic expectations for the home country. Thus, when respondents are more personally affected, their views are closer to what rational cost-benefit analyses predict.

With international climate policy being unable so far to stop and reverse the trend of rising global greenhouse gas emissions1, solar geoengineering is increasingly gaining attention. It is in particular discussed as a way to bridge the time until clean technologies are developed and implemented and to respond in case of a climate emergency2,3. Solar geoengineering, or solar radiation management, aims to cool the earth’s surface temperature to counter climate change by partially deflecting the incoming sunlight. The most prominent proposal is to inject aerosol particles into the lower stratosphere to increase deflection of sunlight. Other ideas involve cloud brightening, the deployment of space mirrors, or whitening of rooftops. Solar radiation management could have a rapid effect on temperature and it would be relatively cheap4–6. The main concern is about the risks and side effects, such as a chemical ozone loss at high latitudes7,8, changes in regional precipitation patterns9, or the...
consequences of abrupt determination\textsuperscript{10,11}. Sometimes geoengineering is defined more broadly to also include carbon dioxide removal technologies, such as ocean iron fertilization, biomass energy with carbon capture and storage, enhanced weathering, and direct-air capture with storage. However, these technologies are very different from solar radiation management. The costs of deploying these technologies are relatively high and the resulting effects on the climate are very slow, making these technologies unsuitable as an emergency response\textsuperscript{11–15} (see Supplementary Note 1 for more details).

Governments around the world have adopted a wait-and-see approach so far. None of the major economies has officially endorsed or rejected solar geoengineering as a strategy to fight climate change, yet most of them invest in research into geoengineering. The Convention on Biological Diversity has invited its 196 parties to abstain from deploying geoengineering that may affect biodiversity until there is an adequate scientific basis. The Paris Agreement on climate change does not mention solar geoengineering. A recent proposal by Switzerland and ten other countries that the UN Environment Programme prepares a comprehensive assessment of geoengineering, including rules on research and deployment, was rejected by the United Nations Environment Assembly\textsuperscript{16}.

Scientists have studied the potentials and limitations of solar geoengineering technologies\textsuperscript{17–19}. The latest reports by the Intergovernmental Panel on Climate Change include solar geoengineering\textsuperscript{11,20}, showing that it is becoming part of mainstream climate science. Social scientists have studied how the technologies are perceived by the public\textsuperscript{21–26}, activists\textsuperscript{27–29}, and media\textsuperscript{30}. This research consistently finds that public awareness and knowledge about solar geoengineering technologies are low\textsuperscript{25,31} and at least the initial support tends to be low\textsuperscript{32,33}. Research on geoengineering is more readily accepted than deployment\textsuperscript{25,31,32}. Assessments are very sensitive to the provided information\textsuperscript{34,35} and there is concern that geoengineering deflects efforts to reduce emissions, especially among policy makers, activists, and researchers in developing countries\textsuperscript{22,24,36}. Two large-scale surveys with citizens living in the UK and Germany find higher support of geoengineering among those who are concerned about climate change\textsuperscript{37,38}. Economic cost-benefit analyses show that solar geoengineering can be part of an optimal policy portfolio, especially if the expected temperature increase and the corresponding damages without solar geoengineering are high. Uncertainty about climate sensitivity – the increase in temperature from a doubling of CO\textsubscript{2} concentrations – increases the use of solar geoengineering. Severe side effects of solar geoengineering and uncertainty about those side effects limit its use, in some scenarios to a climate emergency only\textsuperscript{39–42}.

In this paper, we investigate how experts involved in the diplomatic and scientific efforts relating to climate change assess solar geoengineering. Our analysis is based on data from a worldwide survey (see Methods and Supplementary Methods) with 723 respondents from more than 150 countries. Participants were recruited from the two main institutions that the international community has established to address climate change: the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC). The views of this group of experts have not been studied before, even though they arguably have a bigger influence on the role that solar geoengineering will play to address climate change than previously studied groups. Using a standardized online
questionnaire, we asked the experts about their views on three aspects of geoengineering: how important it is to include geoengineering in the climate negotiations, if more investment should be directed to research and development (R&D) on geoengineering technologies, and if geoengineering technologies should be deployed in the event of an approaching climate emergency that could not be avoided by means of conventional mitigation techniques. We also elicited a number of other attitudinal and personal characteristics that potentially affect the views on geoengineering, including expectations about the effectiveness of current mitigation efforts and climate change impacts. We thereby distinguish between expectations about global climate change impacts, representing the perceived severity of climate change for humankind in general, and expectations about impacts in the respondents’ home country, representing more personal consequences of climate change. The difference between the global perspective and the home country perspective has been ignored so far and it turns out to be very important for the assessment of geoengineering.

Respondents’ expectations about climate change impacts

Figure 1 shows that respondents’ expectations about climate change impacts in their home country and the estimations of the impacts in that country according to a recent study by Burke, Hsiang, and Miguel (BHM) are positively correlated (Pearson correlation test, \( r = 0.33, P < 0.01, N = 634 \)). Respondents from countries for which high damages are predicted tend to expect higher damages (lower left in the graph) while respondents from countries for which low damages or gains are predicted tend to expect lower damages (upper right in the graph). The correlation is stronger if we disregard the seven respondents who expect positive consequences of climate change (\( r = 0.36, P < 0.01, N = 627 \)). Using a different measure of countries’ vulnerability to climate change, namely the ND-Gain Index for the year 2015, we also get a significant positive correlation between respondents’ expectations for their home countries and the index value for that country (\( r = 0.39, P < 0.01, N = 623 \)).

We also estimate an ordered probit model with respondents’ expectations as the dependent variable and the BHM forecast of the impacts as the main explanatory variable. The regression results are shown in the Supplementary Table 1. They show that the BHM estimations have a significantly positive effect on respondents’ expectations (2-sided test \( P > |z|, P < 0.01 \)), confirming that respondents’ expectations correspond with recent projections, albeit not perfectly. Separate analyses for the IPCC sample and the UNFCCC sample to compare the BHM estimations and respondents’ expectations show similar results (see Supplementary Table 1).

Respondents’ views on geoengineering

Respondents are almost evenly divided in their views on geoengineering. Forty-two percent consider it important to include the issue of geoengineering in the international climate negotiations, 53% do not consider this as important, and 5% don’t know (\( N = 719 \)). Fifty percent of participants think that more investments should be directed to R&D in geoengineering technologies while 43% do not agree with this, and 7% don’t know (\( N = 711 \)). Finally, 52% support large-scale deployment of geoengineering in the event of an approaching climate emergency, 30% do not support such a response, and 18% don’t know...
(N = 705). Assessments of the three aspects are positively correlated (the correlation coefficients range between 0.42 and 0.60, all P < 0.01). A correlation table and further descriptive statistics are provided in Supplementary Table 2.

In order to compare respondents’ views on geoengineering with their views on conventional mitigation, they were also asked about the importance of negotiating emission reduction targets (global and sectoral), land use change, adaptation, and technology transfer. The results (see Figure 2) show that the climate experts, similar to other populations\textsuperscript{26,29,31}, prefer conventional mitigation and adaptation over geoengineering. The distribution of answers for geoengineering shows significantly lower support than the distribution of answers for all other issues (Pearson $\chi^2$ test (4), all P < 0.01, see Supplementary Table 3).

A comparison of the views of our sample with recently elicited opinions of the US population indicates that the climate experts are more skeptical about geoengineering. While the survey by Mahajan, Tingley, and Wagner\textsuperscript{25} finds that 81% of their respondents support research into solar geoengineering, only half of our respondents support more investment into geoengineering research. Sixty-seven percent of the surveyed US population support the use of solar geoengineering while only half of our respondents support its use even when limited to an emergency response.

Our main regressions are based on binary probit models. To this end, we define a binary variable “supportive,” which is set to one if an individual provided a more supportive assessment of geoengineering and zero otherwise (see Methods). Respondents who chose the “I don’t know” option are not included in the regression analysis below. We opted for this more conservative approach because the respondents who chose the “I don’t know” option cannot be unambiguously assigned to a positive or negative assessment of geoengineering. Including these respondents as not supportive of geoengineering yields similar results (see Supplementary Table 4). Individual controls such as age, gender, training, and employer organization are included in all regressions but are not shown in the tables below to save space. Respondents’ expectations about global climate change impacts, their expectations about current and future mitigation efforts, and CO$_2$ per capita in the respondents’ home country are included as explanatory variables. To account for region-specific climate change impacts we include either respondents’ expectations about climate change impacts in their home country or the BHM estimation of the impacts in that country. Because of correlations between current GDP per capita and future climate change impacts, we show regression results with and without current GDP per capita. Supplementary Table 2 provides further information on the definitions and the summary statistics of all included variables and Supplementary Table 5 provides the complete regression tables with all controls and model statistics.

The main regression results are shown in Tables 1-3. We show separate regressions for each survey item because the three questions that we use for the assessment of geoengineering are quite different in content and have also been studied separately in the previous literature. Table 1 shows if respondents’ opinions on whether geoengineering should be included in the international climate negotiations are influenced by the explanatory variables. Respondents who expect severe global climate change damages are less likely to support the inclusion of...
geoengineering in the climate negotiations than respondents with less pessimistic expectations (P < 0.01 in all specifications). Likewise, respondents who have pessimistic expectations about the effectiveness of the current pledge approach are less likely to support the inclusion than respondents with more optimistic expectations (P < 0.05 in two specifications). If GDP per capita in the home country is not included, we find that respondents from countries that are predicted to suffer high climate change damages are more likely to support the inclusion of geoengineering in the negotiations (P < 0.01). In line with this, respondents who expect high climate change damages in their home country are more likely to support the inclusion (P < 0.05). The significance of these two differences disappears if GDP per capita is included. The dominant effect in this case is that respondents from richer countries are less likely to support the inclusion than respondents from poorer countries. Finally, respondents who prefer a broad approach of the climate negotiations support the inclusion of geoengineering more than respondents who prefer a narrow approach (P < 0.01 in all specifications).

Table 2 shows regression results on respondents’ support for more investment directed to R&D on geoengineering technologies. Respondents who expect severe global climate change damages are less likely to support more investment in geoengineering technologies than respondents with less pessimistic expectations (P < 0.05 or P < 0.01). Similarly, respondents who are pessimistic about the current pledge approach are less likely to support more investment than more optimistic respondents (P < 0.01). Considering regional climate change impacts, we find that both measures of vulnerability, the BHM estimations of future climate change impacts and respondents’ own expectations about their home country, increase the support for more geoengineering investments significantly (P < 0.01). This is independent of whether GDP per capita is included or not. As before, a higher GDP per capita decreases the support for geoengineering (P < 0.01).

Table 3 shows regression results on respondents’ support of large-scale deployment of geoengineering in case of an approaching climate emergency. Negative expectations about global climate change impacts tend to reduce the support of geoengineering as before, though the difference is not significant at the 1% or 5% level. Optimism about the current pledge approach does not have a significant effect. Respondents who are optimistic that countries will reduce their emissions even in the absence of a global agreement are more likely to support deployment of geoengineering than more pessimistic respondents (P < 0.05 in two specifications). Respondents from countries for which severe climate change damages are predicted are more likely to support deployment of geoengineering. The same is true when we consider respondents’ expectations about their home country (P < 0.05 in two specifications).

These results show that respondents who expect severe global damages of climate change and respondents who are skeptical about the mitigation efforts are more opposed to geoengineering than more optimistic respondents. By contrast, severe climate change damages in the home country, either predicted by the BHM study or by respondents themselves, increase support for geoengineering. The difference between global and home country perspectives is illustrated in Figure 3. Robustness analyses show that our main results hold if we use a combined index of the three dependent variables (Supplementary
Table 6), if an ordered probit model is used instead of a binary model (Supplementary Table 7), for alternative measures of climate change impacts (Supplementary Table 8), and if we run separate estimations for the UNFCCC and IPCC samples (Supplementary Table 9).

A possible reason for the difference between the global and home country perspective is that respondents extrapolate, consciously or unconsciously, from generally difficult governance at the global level and easier governance at the national level. In this case, we would expect the difference between the global and home country perspective to be particularly large when respondents are asked about the deployment of geoengineering because this is when governance matters the most. However, as shown in Figure 3, the difference is smaller for deployment than for the other two issues. We would also expect that the difference between the global and home country perspective would be particularly large for respondents from countries with effective governance systems. However, additional regression analyses that include the governance effectiveness index provided by the World Bank do not show any evidence that an effective governance system in respondents’ home country increases the difference between the global and home country perspective (see Supplementary Figure 1). Extrapolation from global and national governance therefore is unlikely to be a driver of these results.

The regression results also show how other personal characteristics of the respondents influence their views on geoengineering (see Supplementary Table 5). A robust finding is that respondents from the IPCC sample are more opposed to geoengineering than respondents from the UNFCCC sample. Respondents with a degree in natural science are more likely to oppose geoengineering than respondents with other backgrounds (mostly economics or business administration, engineering, political science, or law). Interestingly, this is not only true for deployment of geoengineering but also for research on it and the inclusion of geoengineering in the climate negotiations. A possible explanation for this is that individuals who are more engaged in the difficulties of reducing emissions are more open to geoengineering than individuals who focus more on the physical impacts of climate change. Another possible explanation is that IPCC and natural scientists are more skeptical about the effectiveness of geoengineering or more concerned about the potential risks. While intuitive, our data do not allow us to investigate these possibilities further.

**Discussion**

Solar geoengineering could be used to limit temperature increase that is responsible for a large part of expected climate change damages. Cost-benefit analyses show that the incentives to deploy geoengineering become stronger with higher CO₂ emissions and expected climate change damages. Many people, however, reject this argument on moral grounds. The Australian philosopher Clive Hamilton, for instance, writes: “merely by choosing to engineer the climate instead of cutting emissions we succumb to moral failure.” From this perspective, geoengineering is not a legitimate solution to address climate change but rather another risky experiment with unforeseeable and potentially irreversible consequences. Higher climate change damages do not justify deployment of geoengineering; on the contrary, they warn against further experimentation with the planet and stress the moral obligation of curbing emissions. Our results suggest that
geoengineering represents a moral dilemma for the surveyed climate experts. At the global level, we find that respondents indeed oppose geoengineering more strongly the more they are concerned about severe climate change damages and continued rise of global emissions. However, at a more personal level, they are more open to geoengineering the more they are concerned about high damages of climate change in their home country. This latter view is what we would expect from rational cost-benefit analysis in which geoengineering generally is considered as legitimate solution as long as the risks and side effects are not too high.

Solar geoengineering poses different challenges for governance than conventional climate change mitigation. Many questions of geoengineering governance have not been answered yet. Who should decide whether, under which conditions, and to what extend geoengineering should be deployed? Which side effects are acceptable and which are not? Our research shows that the opinions about the deployment of geoengineering are positively correlated with the opinions about research on geoengineering technologies and the integration of the issue in the UNFCCC process. Thus individuals who oppose the deployment of geoengineering also tend to oppose research on it and putting the topic on the agenda. This is not necessarily to be expected. For example, if the experts opposed the use of geoengineering because of the potential side effects and uncertainty, they should support more investment in research. If the experts opposed geoengineering because of the involved governance challenges, they should be in favor of including the issue in the UNFCCC process. Bringing geoengineering into the UNFCCC process would allow them to be actively involved in the implementation of common rules and constraints. The tendency of the experts to be concerned, or not concerned, about all three aspects – deployment of geoengineering, research and development, and including the topic in the negotiations – indicates that for many experts geoengineering is indeed a moral issue. The implication for all policy makers, scientists, and other actors who wish to shape the debate about geoengineering is that moral concerns beyond costs and benefits must be addressed. All the same, our study suggests that the climate experts’ support for geoengineering will increase over time, as more regions are adversely affected and more experts observe or expect damages in their home country.

Methods

Sample

Invitations to take part in the survey were sent out via email in the run-up to the twenty-first Conference of Parties (COP 21) in Paris. The contacts were taken from two sources. First, for the UNFCCC sample, invitations were sent to individuals listed as party member in at least one of the COPs since COP 16 in 2010. The email addresses were taken from previous studies or searched in the Internet. The UNFCCC provides participation lists that distinguish between “parties” and “observer organizations.” Since our interest is on negotiators, and not observers, we only invited people who were listed at least once as party. Individuals who attended the COPs only as observer (and never as party) were not included. Second, for the IPCC sample, invitations were sent to individuals listed as authors or reviewers of the Fifth Assessment Report. The list is available on the IPCC website and the email addresses were obtained through Internet searches. In the regression analyses, we always control for...
whether an individual is from the UNFCCC sample or the IPCC sample. Regressions analyses for each sample separately are provided in Supplementary Table 9.

Separated by source we reached out to 8763 individuals from the UNFCCC lists and 900 individuals from the IPCC list. A total of 723 individuals from 153 countries took part in the survey (509 from the UNFCCC lists and 214 from the IPCC list). The number of observations in the regression analyses is lower because some respondents did not answer all questions included as control variables and we left out all respondents who chose the “I don’t know” option when assessing geoengineering. The response rate of 7% (6% UNFCCC and 24% IPCC) is not high but comparable to previous studies using similar samples. It should also be noted that the response rate of 7% is a very conservative estimation as it refers to all emails that were sent out and did not immediately bounce back. We do not know, and have no way to find out, how many of these emails went to the spam folder, arrived at inactive email accounts, or were never opened for other reasons. If we related the number of respondents to the number of people who were invited and verifiably opened the link to the survey, the response rate would be 63% (59% UNFCCC and 77% IPCC).

Because of the low response rate, we conducted two different non-response analyses for the UNFCCC sample. First, we compared the regional distribution between individuals who completed the survey (respondents) and individuals who were contacted but did not complete the survey (non-respondents). Of the UNFCCC participants who completed the survey, 26% were from Europe, 24% from Africa, 20% from Asia, 13% from North America, 12% from South America, and 5% from Australia/Oceania. The respective frequencies for the contacted persons who did not complete the survey were 22%, 27%, 24%, 10%, 13%, 4%. These proportions are based on delegation country and not nationalities, as delegation country is the only available information for non-respondents. The comparison of the regional distribution between respondents and non-respondents shows that the distributions do not significantly differ from each other (Pearson $\chi^2$ test ($\chi^2$ test ($5) = 2.95, P > 0.1)$. We also find that the distribution of the respondents is very similar to the regional distribution of the participants in recent COPs. Of the parties to COPs 16-20, on average, 21% were from Europe, 27% from Africa, 25% from Asia, 9% from North America, 13% from South America, and 4% from Australia/Oceania. Second, we compared the answers of respondents and individuals who started the survey but did not finish it (dropouts). We could only do these comparisons for questions that were answered by sufficiently many dropouts, which mainly were in the first part of the survey. Depending on the questions, the number of dropouts that could be used for comparison ranged between 48 and 91. Depending on the type of question, we used Fisher’s Exact tests or T-tests. We found that for 19 out of 21 questions the answers were not significantly different between respondents and dropouts ($P > 0.1$). These comparisons thus do not point to a selection bias in the data but of course we cannot completely rule this possibility out.

As our main interest in this paper is on the assessment of geoengineering, it is more important that the respondents do not have biased opinions about geoengineering rather than that they are overall representative of the population. In other words, the assessment of geoengineering by the respondents should not systematically differ from the assessment by non-respondents. Before we provide evidence on this, note that the invitation to take part in
the survey did not mention geoengineering and the survey did not start with the questions about geoengineering. Of all people who started the survey and dropped out at some point, 93% dropped out before they could see the first question about geoengineering. In order to compare the opinions about geoengineering between our respondents and others, we use the survey data collected by Kesternich, Löschel, and Ziegler (KLZ)\(^{49,53}\). The KLZ survey was conducted in 2012 with officially listed participants in COP 16 (Cancún) and COP 17 (Durban). This sample is particularly useful for comparison because the survey included 24 items that we also included in our questionnaire (10 socio-demographic characteristics, 14 items on expected global and regional climate change consequences, countries’ willingness to reduce emissions without global agreement, and the importance of including emission reduction targets, technology transfer, adaptation, land-use change, and geoengineering in climate negotiations). While the KLZ survey included one item on geoengineering, their main interest was on burden sharing rules and the design of minimum participation thresholds in climate treaties (the resulting publications do not mention geoengineering). Because of the overlap in questions, we excluded the respondents in the KLZ survey in our survey (by not inviting them) which makes them a good reference group. The comparison of the KLZ sample and our sample shows some small differences which can be explained by changes over time and the fact that we drew our sample from more COPs. Our sample is more balanced with relatively more women and more respondents from South America and North America. Our sample is slightly more pessimistic about climate change damages in the future and, at the same time, slightly more optimistic about emission reductions in the US, Europe, and China. Most importantly, opinions about the importance of including geoengineering in the climate negotiations do not significantly differ between the two samples. The average answer to this question is almost the same (2.47 for KLZ versus 2.45 for our sample) and the same is true for the standard deviation (1.01 versus 1.02). The P-value is far from any conventional significance levels (P = 0.77).

**Questionnaire and empirical approach**

The survey was conducted online and comprised several parts. All survey questions used in this research can be found in the Supplementary Methods. Definitions and summary statistics of the dependent and explanatory variables can be found in the Supplementary Table 2.

After obtaining the respondents’ consent to participate, the first part assessed the consequences of climate change for future living conditions and the importance of various measures to combat climate change. The second part was about the effectiveness of current and future climate change mitigation efforts. The third part of the survey contained questions about the participants' personal background, such as gender, age, nationality, the field in which they have obtained their highest degree of training, and the type of organization for which they work. The questions about geoengineering were included in the first part of the survey. Participants were asked about the importance of including geoengineering in international climate negotiations, the need to direct more investment to research and development on geoengineering technologies, and deployment of geoengineering in the event of an approaching climate emergency. All three assessments were elicited by means of a Likert-type scale with four possible answer categories that ranked respondents’ support.
from low to high, with one additional “I don’t know” option. We did not provide a
description or definition of geoengineering, so as to not bias the answers, but explicitly
mentioned solar radiation management.

Respondents’ assessments of geoengineering were used as dependent variables in the
regression analyses. In the binary probit models the dependent variables are constructed as a
dummy that takes the value one if the respondent chose one of the two more supportive
answer categories and zero otherwise. We also estimated an ordered probit model to test the
robustness of the results with respect to the regression model. The results of the ordered
probit model are generally very close to the binary probit results (see Supplementary Table
7).

Three types of information were included as explanatory variables: specific information
about the respondents and their home country, expectations about the effectiveness of
current and future climate change mitigation efforts, and expectations about climate change
impacts. Estimations of regional climate change impacts were taken from a recent study by
Burke, Hsiang, and Miguel (BHM). This study estimates region-specific changes in GDP per
capita due to temperature increase from unmitigated climate change compared to a
counterfactual without climate change. Using two scenarios from the IPCC (the business-
as-usual Representative Concentration Pathway (RCP) 8.5 and the Share Socioeconomic
Pathway (SSP) 5, which assumes fast economic growth and high energy demand), the study
provides comparisons of regional GDP per capita with and without climate change in 2100.
We use this percentage difference in GDP per capita, separated as either loss or gain, as
explanatory variables in our regression analyses to take vulnerability of respondents’ home
country into account.

Home country refers to a person’s citizenship for the IPCC sample. For the UNFCCC
sample, we can take either a person’s citizenship as home country or the country he or she
represents in the negotiations. We decided to show regressions based on delegation country
in the main paper and regressions based on citizenship in the Supplementary Table 10. As
most negotiators represent their own country in the negotiations (93% of negotiators in our
data), the results are very similar. We also provide additional regression analyses where
regional vulnerability is measured by the 2015 ND-GAIN Index (see Supplementary Table
8). This index is compiled by the Notre Dame Global Adaptation Initiative and combines
different measures of vulnerability to climate change with measures of adaptive capacity.
Using this index, instead of the estimations by the BHM study, yields very similar results.
We also tested the suitability of more recent and fine-grained climate change data provided
by Ricke, Drouet, Caldeira, Tavoni (RDCT). This study provides country-specific
estimates of the social cost of carbon discounted from the year 2200. The correlations
between the BHM estimates and the RDCT estimates are relatively weak which can be
attributed to the existing differences between the two data sets. There is no significant
correlation between the RDCT estimates and the expectations of our respondents (r = 0.03, P
= 0.51, N = 636). The reason for this arguably is that the question we used to elicit
expectations (“How would you assess the consequences of climate change on future living
conditions up to 2100 in your home country?”) is closer to the BHM estimates than the
RDCT estimates. The more fine-grained results of the RDCT study apparently do not outweigh this difference.

The regressions furthermore include CO$_2$ emissions per capita in the home country to account for countries’ dependence on fossil fuels and GDP per capita in the home country to account for adaptive capacity. Again, for the UNFCCC sample, we can take either the country a person represents in the negotiations (shown in the main paper) or his/her citizenship (see Supplementary Table 10), both of which yield similar results.

All other variables used in the regressions were elicited in the survey. Respondents’ subjective expectations about climate change impacts were elicited by asking them to estimate the consequences of climate change on future living conditions up to 2100 both globally and for their home country. The assessments were elicited by means of a Likert-type scale with four answer categories ranging from “very negative” to “positive” and an “I don’t know” option. “Expect severe global damages” is constructed as dummy variable that takes the value one if the respondent expects very negative consequences of climate change on future global living conditions up to 2100 and zero otherwise. “Expect severe home country damages” is constructed in precisely the same way with the only difference that respondents are asked to assess the consequences for the home country. Despite the similarity, the regressions show that the two variables affect respondents’ assessment of geoengineering very differently. Including an interaction term of respondents’ global expectations and their home country expectations in the regressions yields very similar results and the interaction term is never significant. This implies that the positive effect of home country expectations does not depend on respondents’ global expectations, and vice versa.

To account for respondents’ expectations about current and future climate change mitigation efforts, we constructed two different variables. First, participants were asked to indicate on a four-point Likert-type scale to which degree they think that certain countries or groups of countries would reduce emissions relative to business as usual independent of an international climate agreement. The list of countries included the major emitters China, US, and the EU. The answers were averaged for each respondent and form the variable “Optimistic about GHG reductions” (Cronbach’s $\alpha = 0.71$). Second, participants were asked about their expectations about the pledges made in the context of the Paris Agreement. Specifically, they were asked how confident they are that (a) the current Intended Nationally Determined Contributions (INDCs) in aggregate are consistent with the 2°C target, (b) countries will submit more ambitious INDCs in the future, and (c) future INDCs in aggregate are consistent with the 2°C target. Answers were elicited on a four-point Likert-type scale. The variable “Optimistic about INDCs” was constructed by taking the respondent’s average level of confidence stated in these three questions ($\alpha = 0.78$). For the question whether geoengineering should be included in the international climate negotiations, we additionally included the explanatory variable “Negotiation scope,” which was constructed by taking the respondents’ average level of support regarding the inclusion of different issues in the climate negotiations. For each of the following issues we asked the respondents to state on a four-point Likert-type scale how important it is to include the issue in the climate negotiations: (a) quantitative reduction targets for global GHG emissions, (b)
quantitative reduction targets for sectoral GHG emissions, (c) R&D and technology transfer, (d) land-use change and reforestation, and (e) adaptation measures. Combining the average support for each issue, the index yields a high value if a respondent supports a broad negotiation approach, i.e. the inclusion of many issues in the negotiations, and a low value if a respondent supports a narrow approach, i.e. the inclusion of only a few issues in the negotiations ($\alpha = 0.67$).

In all estimations, we control for respondents’ gender, age, training, employer organization, and if the respondent belongs to the IPCC sample or the UNFCCC sample.

**Supplementary Material**

Refer to Web version on PubMed Central for supplementary material.

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Figure 1. Scientific estimates and respondents’ expectations about climate change impacts in the home country

The box plot shows the distribution of the BHM estimations of changes in GDP per capita in 2100 in percent due to climate change in respondents’ home country separated by respondents’ own expectations of climate change impacts in 2100 for their home country. The boxes border the 25th and 75th percentiles of the estimated change in GDP, with the median depicted as a line within the box. The vertical lines extending from the boxes include all data points within 1.5 times the interquartile range of the nearer quartile. The dashed red line divides the BHM estimations in gains and losses from climate change. The number of observations for expected “positive” consequences for the home country is very low (N = 7). The number of observations for the other categories are (from left to right) N = 190, N = 342, and N = 95.
Figure 2. Comparison of geoengineering with conventional mitigation and adaptation
Bars indicate the categorical percentages for each answer to the question “How important do you think it is to include the following issues in current international climate change negotiations?” for six issues.
Figure 3. Predicted probability of supporting geoengineering depending on respondents’ beliefs about climate change impacts

The probability of supporting geoengineering predicted by the binary probit models shown in Tables 1-3. The green lines (rectangular markers) show the difference between respondents who expect very negative global consequences of climate change and other respondents. The purple lines (circular markers) show the difference between respondents who expect very negative consequences of climate change for their home country and other respondents. The vertical lines show the 95% confidence interval. Number of observations (from left to right): N = 447, N = 432, N = 385.
### Table 1

Results of binary probit regression testing support for including geoengineering in international climate negotiations

|                                | (1)     | (2)     | (3)     | (4)     |
|--------------------------------|---------|---------|---------|---------|
| **Supportive**                 | 0.19*** | 0.11    | 0.11    | 0.06    |
| Percentage loss in GDP in 2100 | (2.72)  | (1.35)  | (2.12)  | (1.25)  |
| Percentage gain in GDP in 2100 | -0.03   | -0.02   | -0.05***| -0.02   |
| Expect severe home country damages (d) | 0.11** | 0.06    | (2.12)  | (1.25)  |
| GDP per capita                  | -0.03*  | -0.05***| (-1.90) | (-3.55) |
| Expect severe global damages (d) | -0.11***| -0.11***| -0.16***| -0.14***|
| CO₂ per capita                  | 1.56    | 8.88    | -2.16   | 10.92*  |
| Optimistic about GHG reductions | -0.02   | -0.02   | -0.03   | -0.02   |
| Optimistic about INDCs          | 0.07**  | 0.07*   | 0.08**  | 0.06*   |
| Negotiation scope               | 0.32*** | 0.31*** | 0.33*** | 0.30*** |
| IPCC (d)                        | -0.09   | -0.07   | -0.07   | -0.05   |
| Controls included               | Yes     | Yes     | Yes     | Yes     |
| Observations                    | 492     | 491     | 447     | 446     |

The numbers show binary probit estimations of average marginal effects (discrete effects for dummy variables) and z-values in parentheses. The models are estimated with maximum likelihood, using heteroscedasticity robust standard errors. The stochastic component in the models is assumed to be normally distributed. The dependent variable is a dummy, taking the value 1 if an individual response is categorized as supportive of geoengineering and 0 otherwise. Level of significance: * P < 0.10, ** P < 0.05, *** P < 0.01. (d) indicates dummy variables. Variables included as controls but not shown: gender, age, training, and employer organization.
### Table 2
Results of binary probit regression testing support for more investment in R&D on geoengineering technologies

|                           | (1) Supportive | (2) Supportive | (3) Supportive | (4) Supportive |
|---------------------------|----------------|----------------|----------------|----------------|
| Percentage loss in GDP in 2100 | 0.36***        | 0.23***        |                |                |
|                           | (5.50)         | (2.85)         |                |                |
| Percentage gain in GDP in 2100 | -0.00          | 0.01           |                |                |
|                           | (-0.15)        | (0.33)         |                |                |
| Expect severe home country damages (d) | 0.25***        |                | 0.18***        |                |
|                           | (5.05)         |                | (3.53)         |                |
| GDP per capita            | -0.05***       |                | -0.07***       |                |
|                           | (-2.99)        |                | (-4.90)        |                |
| Expect severe global damages (d) | -0.09**        | -0.09**        | -0.19***       | -0.17***       |
|                           | (-2.25)        | (-2.18)        | (-4.17)        | (-3.82)        |
| CO₂ per capita            | 1.21           | 11.75***       | -2.11          | 15.71***       |
|                           | (0.30)         | (2.16)         | (-0.50)        | (2.73)         |
| Optimistic about GHG reductions | 0.05           | 0.05           | 0.06           | 0.08*          |
|                           | (1.33)         | (1.44)         | (1.49)         | (1.95)         |
| Optimistic about INDCs    | 0.13***        | 0.12***        | 0.16***        | 0.13***        |
|                           | (3.64)         | (3.35)         | (4.02)         | (3.46)         |
| IPCC (d)                  | -0.21***       | -0.19***       | -0.22***       | -0.18***       |
|                           | (-3.61)        | (-3.24)        | (-3.60)        | (-3.04)        |
| Controls included         | Yes            | Yes            | Yes            | Yes            |
| Observations              | 477            | 476            | 432            | 431            |

The numbers show binary probit estimations of average marginal effects (discrete effects for dummy variables) and z-values in parentheses. The models are estimated with maximum likelihood, using heteroscedasticity robust standard errors. The stochastic component in the models is assumed to be normally distributed. The dependent variable is a dummy, taking the value 1 if an individual response is categorized as supportive of geoengineering and 0 otherwise. Level of significance: * P < 0.10, ** P < 0.05, *** P < 0.01. (d) indicates dummy variables. Variables included as controls but not shown: gender, age, training, and employer organization.
Table 3
Results of binary probit regressions testing support for large-scale deployment of geoengineering in case of a climate emergency

|                             | (1)          | (2)          | (3)          | (4)          |
|-----------------------------|--------------|--------------|--------------|--------------|
|                             | Supportive   | Supportive   | Supportive   | Supportive   |
| Percentage loss in GDP in 2100 | 0.19 ***     | 0.18 *       |              |              |
|                             | (2.55)       | (1.89)       |              |              |
| Percentage gain in GDP in 2100 | 0.04         | 0.04         |              |              |
|                             | (1.23)       | (1.28)       |              |              |
| Expect severe home country damages (d) |             | 0.11 ***     | 0.10 *       |              |
|                             |              | (2.06)       | (1.65)       |              |
| GDP per capita              | -0.01        | -0.01        |              |              |
|                             | (-0.37)      | (-0.74)      |              |              |
| Expect severe global damages (d) | -0.04        | -0.04        | -0.09 *      | -0.09 *      |
|                             | (-0.86)      | (-0.91)      | (-1.83)      | (-1.76)      |
| CO₂ per capita              | -2.15        | -0.53        | -3.58        | -0.69        |
|                             | (-0.49)      | (-0.09)      | (-0.83)      | (-0.12)      |
| Optimistic about GHG reductions | 0.08 *       | 0.08 *       | 0.09 **      | 0.09 **      |
|                             | (1.91)       | (1.89)       | (2.07)       | (2.07)       |
| Optimistic about INDCs      | 0.04         | 0.04         | 0.07         | 0.06         |
|                             | (0.90)       | (0.86)       | (1.50)       | (1.37)       |
| IPCC (d)                    | -0.18 ***    | -0.18 ***    | -0.19 ***    | -0.19 ***    |
|                             | (-2.81)      | (-2.74)      | (-2.84)      | (-2.72)      |
| Controls included           | Yes          | Yes          | Yes          | Yes          |
| Observations                | 426          | 425          | 385          | 384          |

The numbers show binary probit estimations of average marginal effects (discrete effects for dummy variables) and z-values in parentheses. The models are estimated with maximum likelihood, using heteroscedasticity robust standard errors. The stochastic component in the models is assumed to be normally distributed. The dependent variable is a dummy, taking the value 1 if an individual response is categorized as supportive of geoengineering and 0 otherwise. Level of significance: * P < 0.10, ** P < 0.05, *** P < 0.01. (d) indicates dummy variables. Variables included as controls but not shown: gender, age, training, and employer organization.