RESOURCES
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Eliciting Mental Models for Understanding Reasoning for and Against Solar Geoengineering Research

Dale S. Rothman, Payam Aminpour, Ilan Chabay, Jennifer Helgeson

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About the Authors

Dale S. Rothman is an associate professor in the College of Science at George Mason University. He is currently doing research in the use of scenario development and integrated modeling as applied to social-ecological systems. His recent work has focused on applying these to issues related to climate change economics and policy, including new technologies for greenhouse gas removal and solar radiation management.

Payam Aminpour is a postdoctoral fellow at Johns Hopkins University and the National Institute of Standards and Technology. Aminpour's research revolves around how to harness the collective intelligence of human crowds to address complex issues around social and environmental sustainability like climate change, overfishing, urbanization, and most recently COVID-19.

Ilan Chabay is an adjunct professor in the School of Sustainability, Arizona State University, chair of the External Research Evaluation Committee of the Research Institute for Humanity and Nature in Kyoto, Japan, and co-director of KLASICA, the Knowledge, Learning, and Societal Change Alliance, which is an open international research alliance founded by Ilan in 2008. KLASICA conducts transdisciplinary research at the community and regional scale to develop policy and practice-relevant knowledge of factors, including narratives, that positively or negatively influence collective behavior change to just, equitable cultures of sustainability.

Jennifer Helgeson is affiliated with the Virginia Polytechnic Institute and State University (Virginia Tech) School of Public & International Affairs. Her research interests focus on decision science, including survey assessments and economic analyses that consider behavioral aspects and approaches to dealing with environmental issues. Helgeson's research revolves around resilience to hazards (shocks and stressors) in the built and natural environments, with consideration for cost-effectiveness of community- scale climate mitigation and adaptation efforts.

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About RFF

Resources for the Future (RFF) is an independent, nonprofit research institution in Washington, DC. Its mission is to improve environmental, energy, and natural resource decisions through impartial economic research and policy engagement. RFF is committed to being the most widely trusted source of research insights and policy solutions leading to a healthy environment and a thriving economy.

Working papers are research materials circulated by their authors for purposes of information and discussion. They have not necessarily undergone formal peer review. The views expressed here are those of the individual authors and may differ from those of other RFF experts, its officers, or its directors.

About the Project

The Resources for the Future Solar Geoengineering research project applies tools from multiple social science research disciplines to better understand the risks, potential benefits, and societal implications of solar geoengineering as a possible approach to help reduce climate risk alongside aggressive and necessary mitigation and adaptation efforts. The project began in 2020 with a series of expert workshops convened under the SRM Trans-Atlantic Dialogue. These meetings resulted in a 2021 article in *Science* that lays out a set of key social science research questions associated with solar geoengineering research and potential deployment. The Project followed this with additional sponsored research, including a competitive solicitation designed to address research areas highlighted in the *Science* article. This paper is one of eight research papers resulting from that competition and supported by two author workshops. A key goal of the solicitation and the overall project is to engage with a broader set of researchers from around the globe, a growing number of interested stakeholders, and the public.

Sharing Our Work

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1. Introduction

Solar geoengineering (SG) is a potential approach to reducing global climate change impacts by counteracting radiative forcing change driven by increased atmospheric concentration of greenhouse gases (GHGs). This negative radiative forcing can be produced in many ways, such as painting roofs white, modifying cloud properties, or installing mirrors in space. Stratospheric aerosol injection (SAI), where small reflecting particles are injected into the stratosphere, may be the most feasible and globally effective approach (NASEM 2012). This is also why it draws the most attention and stronger disagreements. SAI (henceforth SG) is the focus of this study. There has been no formal global debate on this topic, with discussions confined to conference and workshop meetings with limited international and sectoral representation.

Most people would agree that SG should not be deployed in the near term. The technology has not reached the stage where it can be seriously considered, and many fundamental questions, both technical and social, remain unanswered (NASEM 2012). However, a debate has arisen about whether we should even use resources to research SG. In the present study, we explore the latter question by examining expert reasoning concerning SG research.

Looking at information as a commodity that reduces uncertainty, economists would suggest that the value of any information is nonnegative. As such, using an extension of the widely used dynamic integrated assessment model of climate and economy (DICE), Harding et. al (2022) estimate that the value of information about the effectiveness of SG is as large as that about equilibrium climate sensitivity (Harding 2022). They also show that over- and underconfidence about SG are equally harmful. NASEM (2012) calls for *cautious* exploration of SG, which is a recurring theme in discussions of SG research, rooted in concerns around its procedural aspects and consequences.

Opposition to SG research takes various forms. Some opponents suggest that SG is either not needed or unacceptable under any circumstance, so research is unnecessary (Biermann 2021). A related concern, referred to as the “slippery slope,” states that research itself increases the likelihood of SG deployment. This is due, in part, to potential technological and institutional lock-in, whereby unnecessary and unwarranted deployment may emerge from research. Similarly, they suggest that research conducted largely by the Global North would only preserve current inequalities in the world (Stephens 2020) and further concentrate power among elites (Stephens and Surprise 2021). Perhaps the most common argument against SG research is the possibility that even research alone would reduce efforts toward emissions abatement (Stephens et al. 2021).

In the context of the ongoing climate crisis, proponents of SG research urge governments to evaluate all action options, including SG (Give Research into Solar

Geoengineering a Chance 2021). They do share several of opponents' concerns. Rather than forgoing research, however, they encourage capacity building in developing countries and argue for a responsible international program (Keith 2017). Others suggest that the research program should include safeguards to prevent unwarranted deployment, including explicit conditions under which deployment is justifiable (Jamieson 1996). As for deterring emissions abatement, the counterargument states that SG research may change the perception of how serious climate risks are, triggering an increase in emissions abatement. In addition, proponents suggest that even if emissions deterrence occurred, it would be characterized by increased overall welfare. Finally, proponents argue that a better understanding of not only the technical but also social, political, and economic aspects of SG may improve decisionmaking if, and when, deployment is ever considered. Suppressing SG research may not prevent future deployment but rather make it less informed and more dangerous (Parson 2021).

Both sides have some points of agreement, such as the importance of an international governance mechanism that is just and inclusive. However, expectations differ significantly. While many proponents believe international governance would emerge from multilateral agreements and informal scientific cooperation, many opponents argue that democratic and fair governance of SG is unattainable (NASEM 2012). Finally, not all opponents argue for an unconditional moratorium on research. Instead, they propose a set of conditions that must be satisfied. For example, Biermann and Möller (2019) suggest that developing countries should lead the discourse on SG research. Jamieson (1996) calls on the United Nations to govern SG research that otherwise may be militarized or securitized.

In a nutshell, both opponents and proponents share many concerns; however, they arise from different base assumptions and reasoning. In addition, both are typically driven by the principle of precaution, but their interpretations and conclusions diverge. This warrants an in-depth study of the underlying reasoning about SG research.

Another important caveat regarding the debate is the difference between in-lab and small-scale field SG research. By "in-lab research," following Parson and Keith (2013), we mean computer simulations, chemistry experiments in controlled laboratories, and social and political science research. By "small-scale field research," we mean activities with trivial and only local environmental impact that is smaller than common commercial activities. Thus, the debate is not just between opponents and proponents of SG research, but between three groups: (a) those who support both types of research, (b) those who support only in-lab research under current circumstances, and (c) those who oppose both types.

In the present paper, we extend the existing analyses of the arguments for and against SG research by having 10 experts complete a questionnaire, which is used to create a fuzzy cognitive map (FCM)[1] of their thinking related to this topic. This is followed by an online interview, in which the initial maps are presented, discussed, refined, and "verified." Our contributions are twofold. First, ours is the first study to employ fuzzy cognitive mapping to analyze attitudes toward SG research. Second, we explicitly distinguish and systematically compare attitudes toward in-lab and small-scale field research. Discussions concerning SG do not always consider these separately. In some cases, arguments are put forward for/against both in-lab and small-scale field research, although not stated so explicitly.

The remainder of the paper is organized as follows. The following section details our methodology. Section 3 presents (preliminary) results accompanied by a discussion.

2. Materials and Methods

We employed a mixed-method approach. We started with a literature review, creating a corpus of material from the peer-reviewed and gray literature (Section 2.1). Next, we conducted a content and textual analysis to identify key system components and their interactions ("concepts" and "causal edges," respectively, in the terminology of fuzzy cognitive mapping) to create a prototype conceptual model. At this point, only the direction of causality was included in the causal edges; neither the sign or strength was specified. This conceptual model was used to design a structured survey instrument in the form of a series of questions related to each system component and its related causal edges. The model and accompanying survey were refined in a pilot phase where they were tested on, and discussed with, three experts in the field.

In parallel, we identified a pool of potential participants in the study and created a subsample (Section 2.2). The participants were asked to complete the survey. Their responses were used to specify the sign and strength of the causal edges, thereby constructing individual FCMs. They were also able to suggest additional concepts and causal edges.

After we constructed these individual FCMs, each participant was invited to participate in a private, online interview to review, validate, and, if desired, modify the map. At the beginning of each interview, we presented our objective, explained the process and methodology, and reminded participants that as part of reviewing/validating a personalized map, they should feel free to add and delete any concepts and add, delete, and alter the strength/direction of any edges. This was done, in part, by discussing any inconsistencies between their maps and their answers to specific questions on the overall direct and indirect effects of SG research. We used these final maps for our analysis, in which we compared and contrast maps between the participants.

[1] See Appendix C for more on fuzzy cognitive mapping.

We measure the overall merits/risks of research in terms of its ultimate net consequences for global society in the medium (around 2050) and longer (around 2100) terms. We explicitly assume that those who support (oppose) research believe that society would derive a net benefit (net loss) when accounting for both potential positive and negative consequences. Because the views in opposition and support may be conditional on developments in SG and climate conditions, we stress that our results are in the context of the current state of affairs.

2.1. Literature Review

We conducted an extensive search of publications in the Thomas Reuters Web of Science looking for the keywords "solar geoengineering" research, "solar radiation management" research, "geoengineering research," and "climate intervention" research in the title and abstract. The only filter we implemented was to exclude books due to the associated complexity of content analysis, but we included book chapters. After manually excluding non-SAI studies, we found 256 publications that fall into one of the following categories:

- Focus on or devote substantial attention to the argument(s) for/against SG research,
- Focus on SG research governance,
- Arguments are stated as part of literature review or discussion,
- Public opinion survey, and
- Arguments for/against SG research not mentioned or mentioned without significant elaboration.

To balance our analysis management and outcome quality, we chose to proceed with publications from the first category, yielding 59 publications for deeper content analysis. We referred to the broader set of publications when creating the participant pool (Section 2.2).

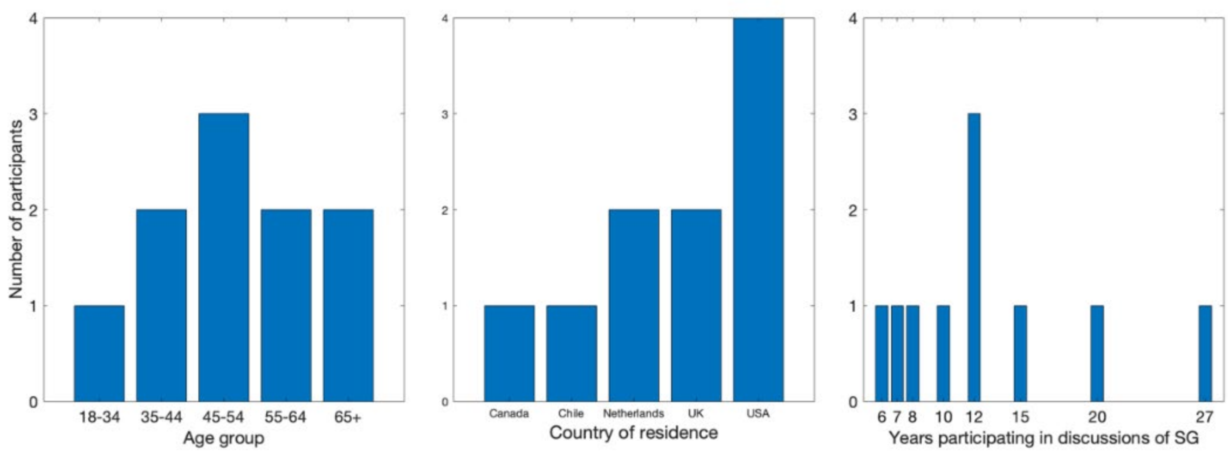
As part of the content analysis, we derived concepts and relationships from publications and narrowed this down to the set of concepts and statements to be presented to participants by categorizing them into themes. We ended up with 22 concepts and 61 relationships, detailed in Appendices A and B, respectively. To provide greater clarity and form a shared vocabulary, we specified definitions for the concepts (see Appendix A). A document with these definitions was provided to the participants before the survey, and the survey tool was equipped with a pop-up information window that showed the concept definition when it was pointed to by the participant as they completed the survey.

2.2. Participant Selection

Our pool of participants included scholars from academia, government, and NGOs, who are familiar with SG to an extent that they are able to form what we considered to be a knowledgeable opinion. We constructed the potential pool from the authors of publications in the first three categories from the literature review. To ensure that we include those opponents who have not published on the topic but expressed their opposition in some other form, we included the initiators and first signatories of the Call for an International Non-Use Agreement on Solar Geoengineering (NASEM 2012). After excluding participants of the workshop organized by RFF, where the initial project outline and the results were presented, we arrived at just over 250 scholars.

Our final sample (those who both completed the questionnaire and had a follow-up interview) included 10 scholars, representing those who have expressed arguments for and against SG research. While we strived to create a geographical-, discipline- and gender-diverse sample, we caution against generalizing our results to represent the full breadth of scholars' opinions.

Figure 1. Participants' Background Information



Note: Information includes number of participants across age groups, countries of residence, and the number of years participating in discussions of solar geoengineering.

Six participants identified as male and four as female. Their expertise spans physical sciences, social sciences, arts and humanities, life sciences and biomedicine, and technology, with seven employed in academia, two in nonprofit, and one in a government organization. Eight have coauthored more than two publications (peer reviewed or gray literature) on SG, and two coauthored one or two publications. Figure 1 illustrates additional background data.

2.3. The Survey

2.3.1. Survey Design

The majority of the questions aimed at identifying the sign and strength of those 61 relationships identified in the literature review (Section 2.1). These questions had the same general structure, in which we asked the participant how an increase in one concept would directly influence a second concept. The responses used the following 7-point Likert scale or an option to indicate "I don't know":

strongly decrease—decrease—somewhat decrease—no effect—somewhat increase—increase —strongly increase

Questions were categorized into blocks. For the first blocks, each had a single concept as the target. That is, each block evaluated how other concepts directly affect the target. The end of each block included an open-ended question inviting the participant to add more factors:

"*Please indicate other factors, if any, that you believe have significant direct impact on CONCEPT NAME.*"

To elicit participants' overall impression of in-lab research and small-scale field SG research, we introduced three additional blocks. The first asked whether a participant supports or opposes research under current circumstances (and how strongly), followed by an inquiry into conditions under which they might change their mind. The scale was as follows:

Strongly support—Support—Somewhat support—Neither support nor oppose—Somewhat oppose—Oppose—Strongly oppose

The second block asked for a view on the ultimate net societal impacts of the two types of research. In a best-case scenario, this would match the outcome of the individual FCM. As noted, these responses played a key role in the follow-up interview.

The third block included questions that offer insights on desirability and necessity of SG as perceived by respondents. We inquired about participants' perception of the technical and economic feasibility of keeping temperature below 1.5°C and 2°C (without overshoot) using mitigation and carbon dioxide removal (CDR) only.

A final block requested basic demographic information. A subset of responses was used in the analysis, but no identifying information is included here or elsewhere.

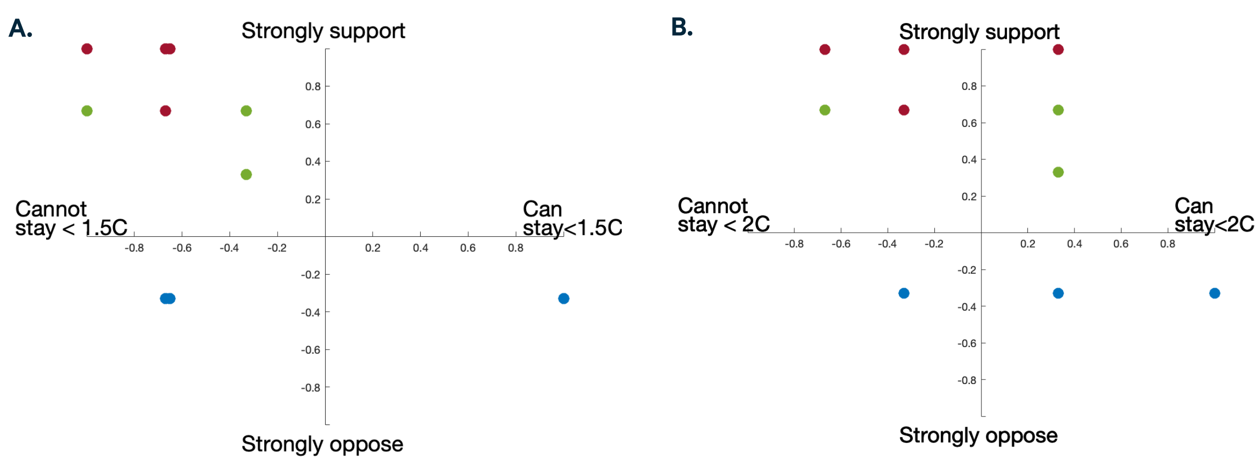
3. Results

Arguments over SG research often start with the fundamental disagreement as to whether it may be needed in the future. Proponents often cite the presumed inability of the world to stay below 1.5°C or 2°C without overshoot using mitigation and negative emissions technologies alone. We were curious about a correlation between attitude toward SG research and perception of the feasibility of keeping temperature below 1.5°C, or at least 2°C, without SG. Does this differ between in-lab and small-scale field SG research?

To see the results for our group of participants, we plotted the technical and economic feasibility of staying below 1.5°C (Figures 2a and 3a) or 2°C (Figures 2b and 3b) as perceived by each participant against their attitude toward in-lab research (Figure 2) and small-scale field research (Figure 3). Here, the markers color-code is used to distinguish 3 groups of participants:

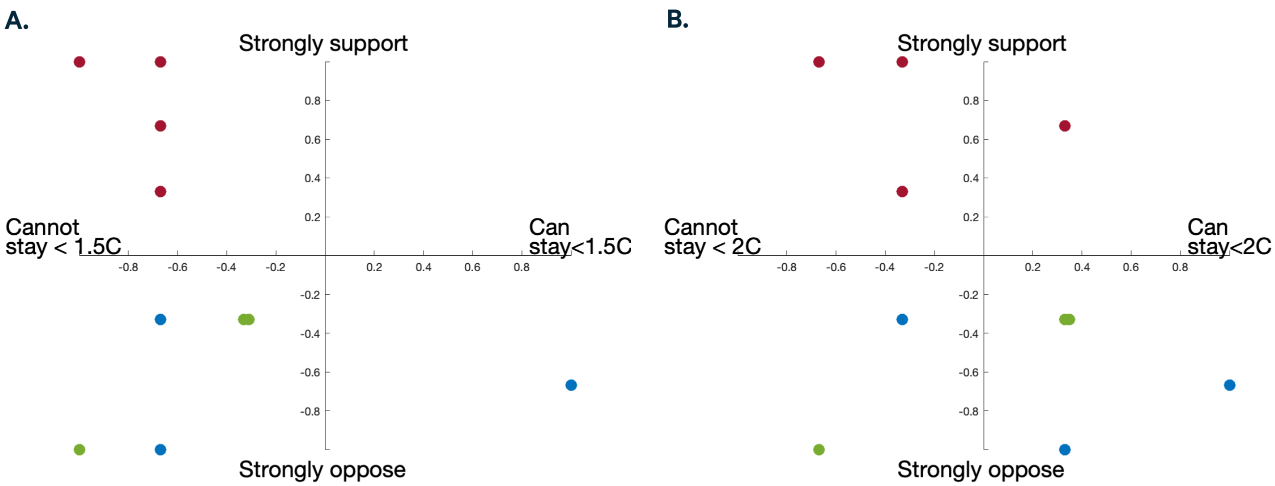
- In red: those who **support both types** of research,
- In green: those **who support only in-lab** research under current circumstances and do not support small-scale field research, and
- In blue: those who **oppose both types** of research.

Figure 2. Attitude Toward In-Lab Solar Geoengineering



Note: Plotted against the interviewee's perception of the technical and economic feasibility of keeping global temperature below 1.5°C (A) or 2°C (B) above preindustrial levels without overshoot using mitigation (including carbon dioxide removal) alone.

Figure 3. Attitude Toward Small-Scale Solar Geoengineering Field Research



Note: Plotted against the interviewee's perception of the technical and economic feasibility of keeping global temperature below 1.5°C (A) or 2°C (B) above preindustrial levels without overshoot using mitigation (including carbon dioxide removal) alone.

Figure 2 indicates that stronger support for in-lab research is generally negatively correlated with the perceived feasibility of staying below 1.5°C or 2°C without overshoot using mitigation and CDR alone. Figure 3 shows more opposition to small-scale field research, irrespective of the perceived feasibility of meeting a 1.5°C or 2°C using mitigation and CDR alone. In both cases, some participants oppose in-lab research even though they believe it is infeasible to stay below 1.5°C or 2°C, pointing to additional reasons for their opposition. We return to this in the detailed analysis that follows.

We do a more detailed exploration of the reasoning for and against each type of research by referring to the individual FCMs and interview discussions. We structure this analysis around the three scenarios presented at the interviews: (a) an increase in in-lab SG research, (b) an increase in small-scale field SG research, and (c) deployment without research. To visualize the individual FCMs and run scenarios, we used the online software MentalModeler (**https://www.mentalmodeler.com**).

In-Lab SG Research. Out of 10 participants, seven expressed support for in-lab research, and three were opposed. For all 10, the results of this scenario were consistent with their surveyed attitude toward in-lab SG research. That is, for those who support (oppose) in-lab research SG, the FCM based on the map yields a decrease (an increase) in the net societal risk associated with climate change and interventions when in-lab SG research is increased.

One proponent compared restriction on in-lab research to restriction of free speech. Two opponents would support moderate in-lab research but not large investments, as they see it as a distraction from more urgent climate research. One opponent stressed that they would support in-lab research if it were to take into account the much more complex sociopolitical environments in which SG might be used, going beyond highlighting effects on biogeophysical variables to also explore effects on political variables. They also emphasized that the researchers must make it clear that this research is highly speculative and should be seen as producing not “truth” or “fact” but rather results from an informed thought experiment.

Small-Scale Field SG Research. Out of 10 participants, four support and six oppose small-scale field research. For all participants, the results of this scenario were once again consistent with their surveyed attitude toward small-scale field SG research after suitable modifications in the follow-up interviews.

An important nuance is that a few opponents argue that small-scale research is actually necessary to improve our understanding of SG but certain conditions should be met before small-scale research can proceed. These include international governance of research with multilateral and international funding. Lacking such governance, the research may appear disruptive and counterproductive in that it would strengthen opposition. One proponent challenged calls for “democratic and inclusive international governance,” which has been widely used by both sides of the argument, without a clear and systematic specification of what qualifies. They believe that if we find that SG can reduce risks and is safe and effective but wait for democratic and effective governance, it will never be deployed. They suggest that the demand for democratic global governance builds on a status quo bias and is not necessarily in the best interest of global society. Another proponent believes that small-scale research should be treated as other forms of potentially dangerous research (i.e., through an environmental impacts assessment). One opponent believes that it would not substantially improve understanding but rather establish overconfidence in SG and thus reduce the judiciousness in deployment decisionmaking.

Deployment Without Research. The majority of both opponents and proponents agreed that deployment without research would improve understanding of efficacy and risks but ultimately increase the net risk to society due to the associated political risk and, potentially, negative climate impacts. Only one participant suggested a net reduction in the societal risk following deployment without research, citing reduced climate risks. That is, the reduction in direct climate impacts would still exceed any associated negative climate effects and/or societal reactions.

4. Reflections

SG has only begun to receive significant attention in the climate change policy debate in the past few years. It is a contentious topic, even as any potential implementation at scale is unlikely for at least a decade. While this might seem to afford time to research not only the technological and scientific but also the social, political, and ethical aspects, some argue that even pursuing research is inappropriate.

We summarize our effort to get a better understanding of the debate surrounding SG research using fuzzy cognitive mapping and modeling to clarify the underlying mental models of a small number of proponents and opponents. The results highlight the importance of the need to distinguish between in-lab and field research and the fundamental role played by research governance. Complete consensus is not to be expected, but the present, more nuanced, approach to understanding the differences of opinion can point to areas of compromise.

Please note, this draft is a work in progress. A more complete version is being prepared for peer review. If interested, please contact the research team for questions and availability of the detailed mental maps analysis.

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A. Appendices

A.1. Appendix A: Concepts and Definitions

Please note that throughout the study, when we say "solar geoengineering" (SG), we are referring specifically to stratospheric aerosol injection.

SG research: funding for and actual research into various aspects. We separate this into two categories:

- In-lab research: computer simulations, chemistry experiments in controlled laboratories, social and political science research; and
- Small-scale field research: activities with trivial environmental impact, smaller than common commercial activities—for example, average ΔRF ~10^{-6} Wm^{-2} or lower.

SG deployment: at various levels and under different strategies but with the intent to alter the climate.

We distinguish two pathways in which SG deployment has biogeophysical effects:

- Intended: **global temperature change and its associated biogeophysical effects**: the global mean surface temperature relative to preindustrial levels; implies nothing about regional distribution or changes in other climatic variables, with an implicit assumption that biogeophysical effects are positively correlated with global temperature; and.
- Unintended: via **biogeophysical side effects**: including a slowing of the recovery of stratospheric ozone, increased levels of acid precipitation, and dramatic changes in regional precipitation patterns.

Constituency for SG deployment: community of researchers and/or institutions that will promote implementation, irrespective of efficacy or need.

Corporate (fossil-fuel) interest/participation in SG research: the extent to which (fossil-fuel) corporations are involved in funding/conducting SG research.

Democratic and inclusive governance of SG deployment: the degree to which the governance of SG deployment decisionmaking is democratic and globally inclusive, which presumes an option to choose nondeployment.

Effective governance of SG research: the degree to which SG research is managed/coordinated effectively at both the international and domestic levels.

Judiciousness in decisionmaking about SG deployment: the care with which any global decision is undertaken, including how well it is targeted to maximize net benefits and addresses issues of potential unilateral or premature deployment, including establishing a moratorium on deployment.

Legitimacy of SG as a policy option: the degree to which SG is generally accepted as a viable policy option alongside mitigation, GHG removal, and adaptation.

Militarization/securitization of SG research: the degree to which military and security interests drive SG research.

Mitigation: the overall level of actual emissions reductions (includes CDR).

Negative societal effects of biogeophysical impacts of climate change and SG deployment: first- and higher-order impacts, such as changes in water availability, crop production, disease propagation, food security, migration, including both the absolute magnitude and distribution of effects, and political and equity consequences.

Public concern about climate change: the level of concern expressed by the public on the issue of climate change and its potential effects.

Public participation in the SG debate: the de facto level of public participation, at both the domestic and international levels, in the debates over SG.

Understanding of SG efficacy and risks: the certainty with which both the potential benefits and risks of SG deployment under alternative deployment strategies are understood.

A.2. Appendix B: The Survey Questions

Block 1: **How do the following factors impact the risk of negative societal effects in 2050 and in 2100.**

Q1.1 Increasing global temperature change and associated biogeophysical effects in 2050 would __________ the risk of negative societal effects in 2050.

Q1.2 Increasing global temperature change and associated biogeophysical effects in 2100 would __________ the risk of negative societal effects in 2100.

Q1.3 Increasing biogeophysical side effects of SG in 2050 would __________ the risk of negative societal effects in 2050.

Q1.4 Increasing biogeophysical side effects of SG in 2100 would __________ the risk of negative societal effects in 2100.

Q1.5 Please indicate other factors, if any, that you believe have a significant direct impact on the risk of negative societal effects of climate change and SG deployment (if any) in 2050. For each of these please indicate the direction and strength.

Q1.6 Please indicate other factors, if any, that you believe have a significant direct impact on the risk of negative societal effects of climate change and SG deployment (if any) in 2100. For each of these please indicate the direction and strength.

Block 2: How do the following factors impact the biogeophysical side-effects of SG?

Q2.1 Increasing the amount of SG deployment would __________ the biogeophysical side effects of SG.

Q2.2 Increasing the judiciousness in decision-making about SG deployment would __________ the biogeophysical side effects of SG.

Q2.3 Please indicate other factors, if any, that you believe have significant direct impact on the biogeophysical side effects of SG. For each of these please indicate the direction and strength.

Block 3: How do the following factors impact the judiciousness in decision-making about SG deployment?

Q3.1 Increasing public participation in the SG debate would __________ the judiciousness in decision-making about SG deployment.

Q3.2 Increasing the understanding of SG efficacy and risks would __________ judiciousness in decision-making about SG deployment.

Q3.3 Increasing democratic, inclusive and fair governance of SG deployment would __________ the judiciousness in decision-making about SG deployment.

Q3.4 Increasing the effectiveness of governance of SG research would __________ the judiciousness in decision-making about SG deployment.

Q3.5 Increasing corporate (fossil-fuel) interest/participation in SG research would __________ the judiciousness in decision-making about SG deployment.

Q3.6 Militarization/securitization of research would __________ the judiciousness in decision-making about SG deployment.

Q3.7. Please indicate other factors, if any, that you believe have significant direct impact on the judiciousness in decision-making about SG deployment.

Block 4: How do the following factors impact understanding of SG efficacy and risks?

Q4.1 Increasing the amount of in-lab SG research would __________ the understanding of SG efficacy and risks.

Q4.2 Increasing the amount of small-scale field SG research would __________ the understanding of SG efficacy and risks.

Q4.3 SG deployment (independent of deployment strategy and judiciousness) would __________ understanding of SG efficacy and risks.

Q4.4. Please indicate other factors, if any, that you believe have significant direct impact on understanding of SG efficacy and risks.

Block 5: How do the following factors impact the likelihood of establishment of democratic, inclusive and fair governance of SG deployment?

Q5.1 Increasing the amount of in-lab SG research would __________ the likelihood of establishing democratic, inclusive and fair governance of SG deployment.

Q5.2 Increasing the amount of small-scale field SG research would __________ the likelihood of establishing democratic, inclusive and fair governance of SG deployment.

Q5.3 Increasing public participation in the SG debate would __________ the likelihood of establishing democratic, inclusive and fair governance of SG deployment.

Q5.4 Increasing the involvement of corporations (fossil-fuel) in SG research would __________ the likelihood of establishing democratic, inclusive and fair governance of SG deployment.

Q5.5Increasing the effectiveness of governance of SG research would __________ the likelihood of establishing democratic, inclusive and fair governance of SG deployment.

Q5.6 Please indicate other factors, if any, that you believe have significant direct impact on the likelihood of establishing democratic, inclusive and fair governance of SG deployment. For each of these please indicate the direction and strength.

Block 6: How do the following factors impact the establishment of effective governance of SG research?

Q6.1 Increasing public participation in the SG debate would __________ the effective governance of SG research.

Q6.2 Increasing the understanding of SG efficacy and risks would __________ the effective governance of SG research.

Q6.3 Please indicate other factors, if any, that you believe have significant direct impact on the effectiveness of governance of SG research. For each of these please indicate the direction and strength.

Block 7: How do the following factors impact the likelihood of SG deployment?

Q7.1 Increasing the amount of in-lab SG research (independent of research findings) would __________ the likelihood of SG deployment.

Q7.2 Increasing the amount of small-scale field SG research (independent of research findings) would __________ the likelihood of SG deployment.

Q7.3 Increasing strength of the constituency for SG deployment would __________ the likelihood of SG deployment.

Q7.4 Increasing legitimization of SG as a policy option would __________ the likelihood of SG deployment.

Q7.5 Please indicate other factors, if any, that you believe have significant direct impact on the likelihood of SG deployment. For each of these please indicate the direction and strength.

Block 8: How do the following factors impact the strength of the constituency for SG deployment

Q8.1 Increasing the amount of in-lab SG research would __________ the strength of the constituency for SG deployment.

Q8.2 Increasing the amount of small-scale field SG research would __________ the strength of the constituency for SG deployment.

Q8.3 Increasing the effectiveness of governance of SG research would __________ the strength of the constituency for SG deployment.

Q8.4 Please indicate other factors, if any, that you believe have significant direct impact on the strength of the constituency for SG deployment. For each of these please indicate the direction and strength.

Block 9: How do the following factors impact global temperature change and associated biogeophysical effects in 2050 and 2100?

Q9.1 Increasing the level of mitigation would __________ the global temperature change and associated biogeophysical effects in 2050.

Q9.2 Increasing the amount of SG deployment would __________ the global temperature change and associated biogeophysical effects in 2050.

Q9.3 Increasing the amount of SG deployment would __________ the global temperature change and associated biogeophysical effects in 2100.

Q9.4 Increasing the level of mitigation would __________ the global temperature change and associated biogeophysical effects in 2100.

Q9.5. Please indicate other factors, if any, that you believe have a significant direct impact on global temperature change and associated biogeophysical effects in 2050.

Q9.6. Please indicate other factors, if any, that you believe have a significant direct impact on global temperature change and associated biogeophysical effects in 2100.

Block 10: How do the following factors impact legitimization of SG as a policy option?

Q10.1 Increasing the amount of in-lab SG research would __________ the legitimacy of SG as a policy option.

Q10.2 Increasing the amount of small-scale field SG research would __________ the legitimacy of SG as a policy option.

Q10.3. Please indicate other factors, if any, that you believe have significant direct impact on legitimization of SG as a policy option. For each of these please indicate the direction and strength.

Block 11: How do the following factors impact the level of mitigation?

Q11.1 Increasing the amount of in-lab SG research would __________ the level of mitigation.

Q11.2 Increasing the amount of small-scale field SG research would __________ the level of mitigation.

Q11.3 SG deployment would __________ the level of mitigation.

Q11.4 Increasing public participation in the SG debate would __________ the level of mitigation.

Q11.5 Increasing public concern about climate change would __________ the level of mitigation.

Q11.6 Legitimizing SG as a policy option would __________ the level of mitigation.

Q11.7 Democratic and inclusive governance of SG deployment would __________ the level of mitigation.

Q11.8 Please indicate other factors, if any, that you believe have significant direct impact on the level of mitigation.

Block 12: How do the following factors impact the public concern about climate change.

Q12.1 Increasing public participation in the SG debate would __________ the public concern about climate change.

Q12.2. Increasing the amount of in-lab SG research would __________ the public concern about climate change.

Q12.3. Increasing the amount of small-scale SG research would __________ the public concern about climate change. For each of these please indicate the direction and strength.

Q12.4. Please indicate other factors, if any, that you believe have significant direct impact on public concern about climate change.

Block 13: How do the following factors impact militarization/ securitization of research.

Q13.1 Increasing the effectiveness of governance of SG research would __________ the possibility of militarization/securitization of SG research.

Q13.2. Please indicate other factors, if any, that you believe have significant direct impact on militarization/securitization of SG research. For each of these please indicate the direction and strength.

Block 14: Up to this point, we have asked you to think of the impacts in terms of direct effects.

For the following questions, please think about overall net impact on the risk of negative societal effects associated with climate in 2050 and in 2100, considering both direct and indirect effects.

Q 14.1. The net effect of increasing in-lab SG research would be __________ the risk of direct and indirect negative societal effects of climate change, including side effects of climate change interventions (if any) in 2050.

Q 14.2. The net effect of increasing in-lab SG research would be __________ the risk of direct and indirect negative societal effects of climate change and SG deployment (if any) in 2100.

Q 14.3. The net effect of increasing the amount of small-scale field SG research would be __________ the risk of direct and indirect negative societal effects of climate change and SG deployment, if any, in 2050.

Q 14.4. The net effect of increasing the amount of small-scale field SG research would be __________ the risk of direct and indirect negative societal effects of climate change and SG deployment, if any, in 2100.

Block 15: Please let us know to what extent you agree or disagree with the following statements.

(Answer options: Strongly disagree - Strongly agree).

Q15.1 Climate change poses unacceptable and unequally distributed risks to the well-being and stability of human societies.

Q15.2 It is technically and economically feasible to keep global temperature below 1.5°C above pre-industrial levels without overshoot using mitigation (including Carbon Dioxide Removal) alone.

Q15.3 It is technically and economically feasible to keep global temperature below 2°C above pre-industrial levels without overshoot using mitigation (including Carbon Dioxide Removal) alone.

Q15.4 SG deployment at any level would lead to unacceptable biogeophysical side effects.

Block 16 Please indicate your attitude towards in-lab and small-scale field SG research.

(Answer options: Strongly support - Strongly oppose)

Q16.1 How would you describe your overall attitude towards in-lab research into SG?

Q16.2 In case you oppose in-lab research into SG, please indicate conditions, if any, under which you would support it?

Q16.3 How would you describe your overall attitude towards small-scale field research into SG?

Q16.4 In case you oppose small-scale field research into SG, please indicate conditions, if any, under which you would support it?

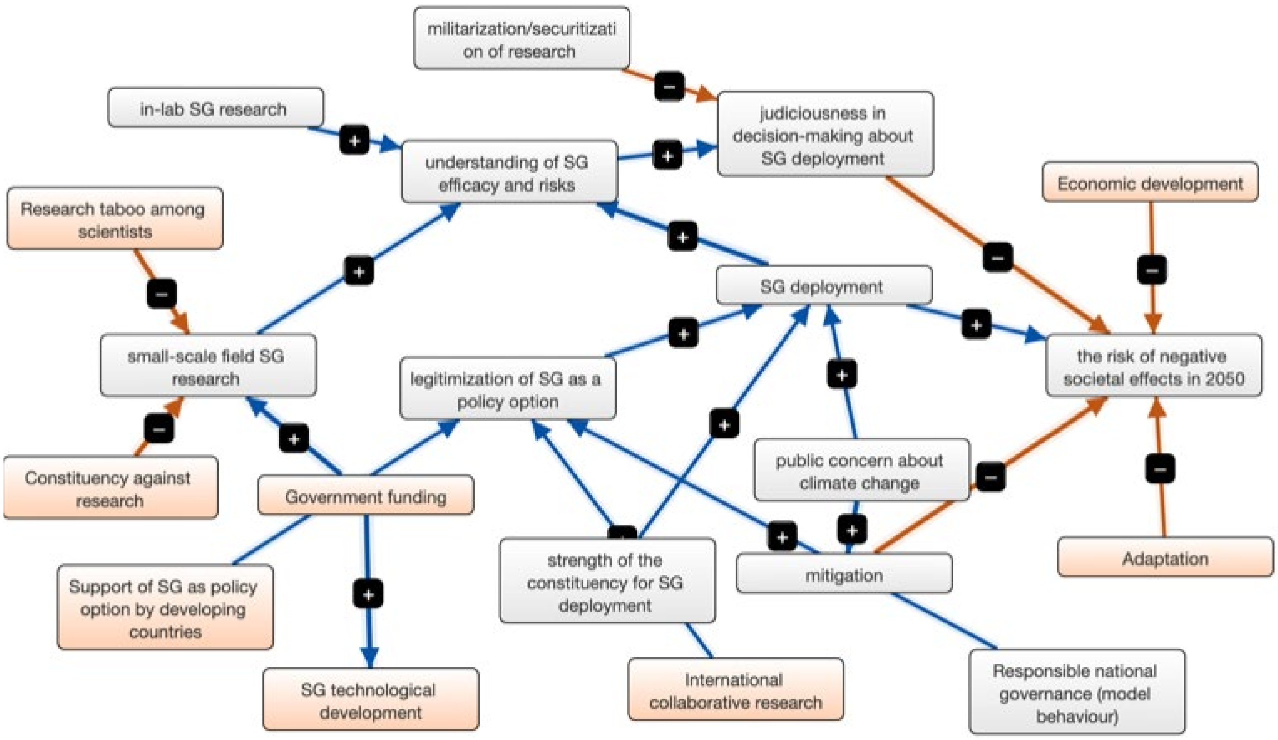
A.3. Appendix C: Fuzzy Cognitive Map (FCM)

As an example, here we present one participant's FCM. The participant added the concepts highlighted.

An FCM is a set of **nodes** (concepts) connected by **links** (relationships) that are

- **Causal**: implies a causal relationship between nodes
- **Directed**: indicates the direction of influence, from the source node to the destination node
- **Signed**: indicates the polarity, positive or negative, of the influence
    - in blue: positive
    - in orange: negative
- **Weighted**: indicates the strength of the influence; a wider the line implies stronger influence

Figure A1. Sample participant's fuzzy cognitive map visualized using the Mental Modeler software



Note: Numerical values for the weights are not shown in diagram.