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GOVERNING EMERGING CLIMATE INTERVENTION TECHNOLOGIES: ENGAGEMENT AND JUSTICE IN THE CASE OF SOLAR GEOENGINEERING

A dissertation submitted in partial satisfaction
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

POLITICS

by

Zachary Dove

June 2025

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Abstract

Governing Emerging Climate Intervention Technologies: Engagement and Justice in the Case of Solar Geoengineering

by

Zachary Dove

Attention has turned towards different forms of climate intervention as potential response options to complement - not replace - mitigation. This dissertation focuses on solar geoengineering as one case of an emerging climate intervention technology. Solar geoengineering as a is a set of proposed technologies that would aim to limit climate impacts by reflecting incoming sunlight back into space, thereby cooling the planet. The risks, uncertainties, and challenges associated with solar geoengineering necessitate governance of its research and engagement with publics and other interested groups around the world in discussion, research, and decision-making. This dissertation focuses on engagement as one form of governance that has thus far been overlooked in analysis of climate intervention governance.

A dominant perspective in the global governance literature views attempts to broaden engagement as a legitimation practice. And yet, this dissertation shows that under certain conditions, engagement can take on a variety of forms and be practiced in more varied ways than expected. Engagement can be both a means of legitimation and a tool that empowers actors to substantively shape research and decision-making. This dissertation aims to can advance our understanding of how engagement is used to

govern climate intervention research and the conditions under which it legitimates actors and their interests or empowers specific actors to challenge, constrain, enable, produce, or otherwise shape research. It also aims to better understand the justice implications of using engagement as a form of governance.

Using interviews, document analysis, and review research methods, the dissertation pursues these aims across three interrelated forms of engagement that are used to govern research of climate intervention technologies: invited engagement, perspectives research, and capacity building programs. All three forms of engagement can be employed by an authoritative actor to govern, a phenomenon the dissertation labels governance by engagement. Governance by engagement refers to authoritative efforts to initiate engagement practices in order to influence or steer a target audience's behavior or otherwise shape research or decision-making towards public goals. The concept applies broadly, as engagement is commonly practiced across a range public policy domains.

Overall, this dissertation leverages original empirical analysis, theoretical insights, and novel conceptual and analytical tools to show that engagement practices should be understood and studied as a potential form of governance, which focuses attention on how engagement can shape political outcomes by producing governance effects. It can do so by normalizing research; by broadening the actors and values, perspectives, and knowledge involved in discussion, research, and decision-making; and by generating novel actors with particular identities and capacities.

These insights are crucial as engagement plays a central and often taken-for-granted role in efforts to govern emerging technologies, as engagement is a double-edged sword: it can both contribute to and undermine our ability to govern in just and effective ways. The dissertation can inform how decision-makers, researchers, and practitioners use engagement to govern research into climate intervention technologies, emerging technologies, and other pressing issues.

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- Dove, Zachary, Sikina Jinnah, and Shuchi Talati. 2024. "Building Capacity to Govern Emerging Climate Intervention Technologies." *Elementa: Science of the Anthropocene* 12 (1): 00124. https://doi.org/10.1525/elementa.2023.00124.

Sikina Jinnah and Shuchi Talati directed and supervised the research which forms the basis for the dissertation. Sikina Jinnah funded the research. Arien Hernandez conducted research assistance under the supervision of Zachary Dove and Sikina Jinnah. All co-authors approve the inclusion of this work in the dissertation. Zachary Dove led the conceptualization, research design, data collection, data analysis, and writing for all three chapters of this dissertation.

Introduction

This dissertation explores how engagement with publics and other interested groups contributes to the governance of research on emerging climate intervention technologies and what implications this can have for justice.[1] This introduction first briefly establishes the background and context of the study. It then establishes the main problem that motivates the dissertation's aims and research questions. An overview of the dissertation is then provided, outlining the argument and briefly identifying the contributions of each of the dissertation's three chapters. This is followed by a synthetic discussion of four central themes that are found throughout the dissertation chapters. It then outlines a future research agenda to build on the dissertation's contributions. Finally, it closes by discussing broader implications and distills recommendations for policy-makers, research funders, engagement practitioners, and researchers.

[1] Although the term "stakeholder" is commonly used in the literature, following NASEM guidelines the dissertation does not use the term "stakeholder" in our study unless quoting or citing the work of others (NASEM 2023). Instead it uses the term "interested groups".

Background and Context

According to scientists and assessment bodies, we are now unlikely to meet to the internationally negotiated goal of limiting global warming to 1.5 degrees Celsius above pre-industrial temperatures by relying on mitigation alone, which aims to avoid climate change by cutting emissions of climate warming greenhouse gasses (IPCC 2022; Hansen et al. 2023; UNEP 2024). There is a substantial gap between current climate mitigation efforts and the ambitious efforts that scientific assessments say are necessary to avoid dangerous climate change (IPCC 2022; UNEP 2024). It is in this context that attention has turned towards different forms of climate intervention as potential response options to complement - not replace - mitigation and adaptation. Climate intervention is a broad term used to refer to multiple sets of emerging technologies that enable deliberate human intervention into the climate system to limit or reverse climate risks (The Royal Society 2009; National Research Councils 2015).

Emerging climate intervention technologies currently appear capable of reducing climate risks in ways that mitigation and adaptation cannot, but each are also imperfect options on their own and may also introduce novel and potentially severe physical, ecological, and social risks (NASEM 2019; NASEM 2021; NASEM 2022; NASEM 2024). Carbon dioxide removal (CDR) technologies aim to remove the important greenhouse gas carbon dioxide from the atmosphere through technological or biological means. Solar geoengineering (SG) (also called solar radiation management or modification) is a set of proposed technologies that would aim to limit climate impacts by reflecting incoming sunlight back into space, thereby quickly

cooling the planet.[2] SG technologies are currently speculative and their technical feasibility and social and ecological impacts remain highly uncertain (NASEM 2021).[3] Scientists propose that SG could be used to temporarily reduce climate risks if warming surpasses temperature targets, buying time for mitigation and CDR to bring greenhouse gas concentrations down to safer levels (MacMartin et al. 2018; Irvine et al. 2019).

Critically, there is consensus that emerging climate intervention technologies, and SG in particular, cannot replace mitigation and adaptation and should only be deployed, if at all, alongside rapidly accelerated efforts to slash greenhouse gas emissions, adapt to climate impacts, and remove carbon dioxide from the atmosphere (NASEM 2021; UNEP 2023). There is however broad concern that research and discussion of climate intervention technologies will detract from mitigation efforts (e.g. Mclaren 2016) or generate momentum towards deployment (Tang 2023). High-level assessments of climate intervention technologies recommend further interdisciplinary research to address the social, legal, and ethical issues associated with SG and have also advanced calls for broad engagement with publics and other interested groups (e.g. NASEM 2021; The Royal Society 2009; UNEP 2023; NASEM 2022).

This dissertation focuses on SG as a case of an emerging climate intervention technology because it appears capable of rapidly altering the global climate system,

[2] Solar geoengineering is also referred to as solar radiation management or modification (SRM). Climate intervention technologies are also sometimes referred to as climate engineering.

[3] The most prominent proposals to implement solar geoengineering include injecting reflective aerosols (or small particles) into the stratosphere, called stratospheric aerosol injection, and injecting sea salt aerosols into low-lying marine clouds to increase their reflectivity, called marine cloud brightening (Irvine et al. 2016; NASEM 2021).

sparking loud calls for broad and inclusive engagement with publics, other interested groups, and Indigenous communities around the world (e.g., NASEM 2021; Carr et al. 2013; Fritz et al. 2024; Busch et al. 2025; Nicholson et al. 2018; Jinnah et al. 2018). Here engagement is used to refer to participatory practices in which individuals or groups are invited to participate in structured activities focused on learning about, discussing, researching, or making decisions about an issue. Many consider engagement "essential for assessing the desirability and feasibility of emerging climate-intervention technologies" (e.g., Fritz et al. 2024, p. 2).

SG is controversial for many reasons, not least stemming from its potential to either ameliorate or reinforce climate-related injustices, originating in the disparity between countries and communities that are responsible for causing climate change and those that are disproportionately vulnerable to climate impacts (Svoboda et al. 2018; Hourdequin 2019; Gardiner 2011; Schöngart et al. 2025). These climate vulnerable communities and countries have the most at stake in decisions about whether and how SG research and deployment moves ahead (Hourdequin 2019; Rahman et al. 2018). In this context, calls for geoengineering justice highlight the need to meaningfully engage diverse, vulnerable communities and countries in SG discussion, research, and governance (Hourdequin 2019; Preston and Carr 2018). This dissertation's understanding of just and inclusive governance is informed by these perspectives, which underscore the importance of basic respect for and consideration of diverse perspectives, values, and worldviews in SG research and governance (Hourdequin 2019).

The risks, uncertainties, and challenges associated with emerging climate intervention technologies have also sparked widespread consensus on the need to govern their research and development. Governance "at whatever level of social organization it may take place, refers to conducting the public's business—to the constellation of authoritative rules, institutions, and practices by means of which any collectivity manages its affairs." (Ruggie 2004; p. 504). Governance is needed to, for example, manage risks-risk tradeoffs between producing knowledge about SG and enabling its future use; transparently evaluate risks, burdens, and benefits; ensure that mitigation and adaptation remain priorities; prevent international conflict stemming from research or use; increase trust and legitimacy; and enable broad and inclusive engagement and deliberation (e.g., NASEM 2021; Jinnah 2018; Parson and Ernst 2013; Chhetri et al. 2018). The literature on SG governance identifies a wide range of currently existing or potential forms governance may take, including, for example, rules and regulations, voluntary codes of conduct, international cooperation, authoritative assessments, disclosure mechanisms, and crucially, engagement processes such as public engagement and multi-stakeholder dialogue (e.g., Reynolds 2019; Morrow 2017; Chhetri et al. 2018; Parson and Keith 2024; Nicholson et al. 2018; Gupta and Möller 2019). Using SG as a case, this dissertation focuses on engagement as one potential form of governance that has thus far been overlooked in analyses of climate intervention governance.

The Problem

Engagement with publics and other interested groups is frequently demanded at high-levels and often placed front and center in proposals for SG research governance frameworks and arrangements (NASEM 2021; UNEP 2023; Brent et al. 2024; Jinnah et al. 2020; Chapter 1). Some propose engagement is a tool for democratizing or improving assessment and governance by empowering diverse and knowledgeable actors to 'open up' or shape decision-making (e.g. Stilgoe et al. 2013; Fritz et al. 2024; Bellamy et al. 2016). However, a dominant perspective in the global governance literature views attempts to broaden participation and engagement fundamentally as a legitimation practice (e.g., Tallberg et al. 2018), or a practice that aims to enhance an audience's beliefs that an exercise of authority is appropriate (Tallberg and Zürn 2019). Indeed, there are many cases of engagement across diverse issue areas in which engagement is used instrumentally to generate support for predetermined decisions, or in which it in effect reinforces existing concentrations of power and patterns of exclusion (e.g., van Boven et al. 2025; Cooke and Kothari 2001). From this view, we would expect that engagement practices in the climate intervention issue area amount to little more than attempts to enhance an audience's beliefs in the legitimacy of political or scientific authorities, who use engagement instrumentally to secure their own interests related to advancing specific directions of political decision-making, scientific research, or technology development.

However, my dissertation research challenges this view by showing that under certain conditions, engagement can take on a variety of forms. The dissertation shows that engagement can be both a means of legitimation and a tool that empowers actors

to substantively shape research or decision-making. In the cases of engagement in the climate intervention issue area that are studied here, legitimation is present, but it is not the overriding motivation driving engagement, and the effects produced in these cases extend beyond what we would expect if engagement were no more than a legitimation practice. This demands an explanation that is both empirically grounded and theoretically informed.

Many empirical studies of engagement have contributed to a rich literature on SG engagement (e.g., Fritz et al. 2024; Baum et al. 2024; Buck 2018; Corner et al. 2012; Bellamy and Lezaun 2017; Burns et al. 2016; Chapter 2). This literature however focuses on analyzing the results of engagement based on what participant perspectives of SG. There are few attempts to understand how the practice of engagement may itself function as a form of governance or generate a variety of governance effects (but see Mettiäinen et al. 2022; Buck 2018; Bellamy and Lezaun 2017; Nelson et al. 2021; Stilgoe et al. 2013b). Attempts to characterize the existing state of SG governance have similarly overlooked the role of engagement (Horton and Koremenos 2020; Talberg et al. 2018). This is a problem for two reasons. First, engagement can take different forms, and we know little about the conditions under which it does so. However, the form of engagement that is employed carries significant sociological implications for governance, as well as normative implications for justice. Second, the lack of empirical analysis of the motivations, models, outcomes, and governance effects of engagement in the climate intervention issue area leaves us with a limited understanding of how engagement matters. This is further impeded by a lack of conceptual and analytical

tools that can advance our understanding of how engagement is used to govern climate intervention research and the conditions under which it primarily legitimates actors and their interests or empowers specific actors to challenge, constrain, enable, produce, or otherwise shape research.

Research Questions and Aims

This dissertation aims to advance our theoretical understanding of 1) how engagement governs climate intervention research and 2) the relationship between engagement, governance, and justice. Ultimately, the dissertation aims to generate a conceptual framework that can help scholars understand how engagement governs a range of empirical issue areas. It also aims to enable cross-case comparative research that explains why different models of engagement are deployed. The dissertation does so by generating new empirical insights into prominent cases of engagement in the issue area, and by developing novel conceptual and analytical tools that help us better understand broadly the relationship between engagement, governance, and justice across many issue areas.

The dissertation is broadly motivated by two research questions:

1. How can different forms of engagement govern research into climate intervention technologies?
2. What are the justice implications of using engagement as a form of governance?

Overview of Dissertation

This dissertation pursues the above research questions across three chapters that make up the body of the dissertation. Using SG as a case, the three chapters study this issue across three interrelated and overlapping forms of engagement practices that the dissertation argues are used to govern research on climate intervention technologies: invited engagement (chapter 1), perspectives research (chapter 1 and 2), and capacity building programs (chapters 1 and 3). Briefly, invited engagement refers to the use of structured activities that engage invited participants in tasks related to discussing, researching, or making decisions about an issue. Perspectives research refers to empirical research that uses engagement to produce knowledge about what or how groups of people think about a particular issue (chapter 2). Capacity building refers to programmatic processes that engage participants in activities to develop the knowledge, skills, and abilities necessary to perform tasks or accomplish goals (Khan et al. 2018; chapter 3).

All three forms of engagement can be employed by an authoritative actor to govern, a phenomenon my dissertation terms governance by engagement (GbE). GBE refers to authoritative efforts to initiate engagement practices in order to influence or steer a target audience's behavior or otherwise shape research or decision-making towards public goals.

This dissertation employs multiple methods to explore how engagement practices govern climate intervention research, including semi-structured key

informant interviews, document analysis, and review research methods.[4] Chapter 1 uses semi-structured interviews and document analysis within a qualitative case-based research design; chapter 2 uses document analysis to conduct review research, which generates novel knowledge from previously published research (Kunisch et al. 2023); and chapter 3 is intended as a practice bridge between the capacity building literature and the SG issue area.

Overall, this dissertation leverages original empirical analysis, theoretical insights, and a novel conceptual framework to argue that engagement practices should be understood – and studied - as a potential form of governance, which focuses attention on how engagement itself can under certain conditions shape political outcomes by producing governance effects.

Centrally, the dissertation builds on the literatures on transnational climate governance, global governance, and public engagement in science and technology to generate a novel conceptual framework for GbE that allows us to better understand how different forms of engagement are used to govern. The conceptual framework specifies that GbE occurs when engagement activities are initiated by authoritative actors, such as public research funding agencies and prominent scientific organizations, in response to a perceived governance challenge and aimed at achieving public goals. Under certain conditions, engagement activities can generate potentially significant governance effects on target audiences, decision-making processes, and broader research and

[4] This study received human subjects research approval from the UC Santa Cruz Institutional Review Board as study #HS-FY2024-73.

governance directions. It can do so by normalizing and legitimating research and actors; by broadening the actors and values, perspectives, and knowledge involved in discussion, research, and decision-making; and by generating novel actors and communities with particular identities and capacities. The target audiences primarily include those actors who are being governed, or whose behavior is steered, influenced, or otherwise shaped or constrained. In the context of near-term governance of climate interventions, the target audiences typically include scientists that want to conduct research or develop a technology. However, this dissertation shows a broader set of actors can be 'users' of the products or outcomes of engagement. These products can include but may not be limited to knowledge, capacity, or recognition of legitimacy.

The dissertation shows that GbE can take the form of both a legitimation practice and a tool that empowers actors to shape research and decision-making towards public goals. In short, the form GbE takes and the effects it generates depends. It argues that assuming a priori that GbE takes on either form or will have certain legitimating or empowering effects is limiting. Instead, to gain a greater understanding of how engagement matters in the climate intervention issue area and beyond, scholars need to study how engagement is practiced and understood in context-specific cases, including how it potentially functions as a source of governance. Doing so draws analytical attention towards how closely entangled relationships of power, authority, and legitimacy are produced, contested, maintained, and transformed as engagement practices are deployed in context-specific cases to steer or influence behavior towards

public goals. This has broad implications, as engagement is commonly practiced across a range of areas of public policy, including health, environment, and development.

This is important because, as the dissertation shows, engagement is a double-edged sword that can both contribute to and undermine our ability to govern in just and effective ways. We need to better understand how and why it does so, particularly as attention ramps up towards climate intervention technologies and other emerging technologies, and as engagement takes on an increasingly taken-for-granted and central role in proposals for research governance.

Below are brief overviews of the dissertation's three chapters.

Chapter 1: Governance by Engagement in Global Climate Governance: Cases from Solar Geoengineering

The first chapter develops and applies the Governance by Engagement (GbE) conceptual framework. The framework defines GbE and specifies the roles of different actors (initiators, facilitators, participants, target audiences) and the modalities GbE may take on, specifying three non-exclusive models of GbE: 1) the perspectives elicitation model, which elicits informed perspectives from an invited set of participants to inform research or decision-making; 2) the capacity building model, which engages participants in a longer term process to build or strengthen particular sets of capacities; and 3) the legitimation model, which aims to secure public approval or mitigate opposition to predetermined directions of research, development, or decision-making. The framework also builds on the literature on public engagement in

science and technology to develop a typology of four categories of governance effects that may flow from GbE (adapted from Stirling 2008; Fiorino 1990). The analytical element of the framework specifies a set of research questions that aim to explain why different models of GbE are employed and why GbE produces different effects and outcomes.

Chapter 1 uses these novel conceptual and analytical tools to demonstrate how two cases of engagement govern SG research, each of which draws our attention to different forms GbE may take. The first case reflects the perspectives elicitation model of GbE and analyzes how the United Kingdom's Research Councils initiated a series of public deliberative workshops in early 2010's to inform an advisory panel's decision-making surrounding whether an outdoor experiment as part of the Stratospheric Particle Injection for Climate Engineering (SPICE) project should proceed. The second case reflects the capacity building model of GbE and analyzes how the Degrees Initiative's research-based capacity building programs engage researchers and scientists from the Global South to build expertise that can then inform international negotiation and decision-making. Various aspects of these models are further explored in Chapters 2 and 3.

Chapter 2: Global perspectives on solar geoengineering: A novel framework for analyzing research in pursuit of effective, inclusive, and just governance (with Arien Hernandez, Shuchi Talati, and Sikina Jinnah)

Chapter 2 considers the importance of evaluating GbE through a justice centered lens. Specifically, chapter 2 aims to better understand the perspectives elicitation model of GbE by focusing analytical attention on a growing body of research that aims to produce knowledge of what and how different groups of people think about SG, for the purpose of informing policy-making and research on SG. Chapter 2 develops a novel analytical framework for understanding the equity and justice implications of perspectives research and applies the framework to an original database of SG perspectives research consisting of 132 studies published between January 2009 and September 2024. The chapter provides the most comprehensive analysis of the SG perspectives literature to date. Drawing on document analysis and review research, the novel framework treats the literature itself as an object of study by scrutinizing whose perspectives are collected, by whom, using what methods, following which questions, and crucially, for what purposes. The framework can also be applied to perspectives research in other issue areas to identify gaps and limitations and can ultimately enable comparative analysis of this research across issue areas.

Chapter 3: Building capacity to govern emerging climate intervention technologies (with Sikina Jinnah and Shuchi Talati)

Chapter 3 is a practice bridge that focuses on the capacity building model of GbE to explore the role of capacity building in the theory and practice of climate intervention governance. Using SG as a case, chapter 3 underscores the importance of focusing attention on the need to build capacity to govern emerging climate intervention

technologies. The chapter shows that capacity building has been a neglected concept in the SG literature and existing capacity building efforts in the issue area (chapter 1) focus on building expertise and research capacity in climate experts. It therefore underscores the need to widen capacity building efforts to other societal actors that are expected to play important roles in governance. The chapter proposes the concept of governance capacity building to highlight the importance of building a wide range of governance capacities in multiple types of actors to enable their participation across "upstream" and "downstream" stages of governance (Sagar and VanDeveer 2005).

Four Central Themes

There are four central and synthetic themes surrounding the politics of engagement in climate intervention research that emerge throughout this dissertation. Here I briefly highlight how the dissertation's chapters produce insights that advance our understanding surrounding these themes.

Theme 1: The dual potential of engagement to contribute to and undermine just and effective governance:

First, all three chapters underscore how, under varying conditions, GbE can either strengthen and undermine just and effective governance. Chapter 1 shows how GbE is not always a legitimation practice and when it takes on different forms, it can instead empower actors and open up research and decision-making to new perspectives and knowledge, thereby possibly strengthening the robustness and inclusiveness of research

and governance. Chapter 2 chapter argues that current trends in SG perspectives research may undermine just and effective governance, finding specifically that the research currently centers perspectives from the Global North, underrepresents youth and Indigenous perspectives, and some research aims to build public support for SG. However, the research could instead enable just and effective governance by institutionalizing the inclusion of climate vulnerable communities in perspectives research and integrating their perspectives into decision-making. Similarly, chapter 3 builds on the capacity building literature to underscore how older models of capacity building focused on short-term workshops can undermine just and effective governance by reinforcing capacity gaps between North and South. Instead, to instead enable just and effective governance, it echoes calls from the Global South for a new model of capacity building owned by the Global South, meaning impacted communities are empowered to decide what capacities will be strengthened and how (Khan et al. 2018).

Theme 2: The varied motivations that drive the uptake of engagement:

All three chapters explore forms of engagement that are driven by multiple and sometimes competing motivations, reflecting existing wisdom in the literature on public engagement with science and environment (Stirling 2008; Fiorino 1990; Delgado et al. 2011). This demands careful analytical attention to identifying nuanced and conflicting motivations in cases of engagement. Chapter 1 shows how legitimation concerns are present in both cases of engagement but unexpectedly appear to be secondary to other normative or substantive motivations. Interview participants

elaborate complex reasons for initiating engagement that challenge existing categorizations. Similarly, chapter 2 highlights how some researchers produce SG perspectives research to democratize governance and advance justice, while others aim to inform communication strategies that shape public support for research. Finally, paper 3 highlights the multiple motivations that can drive capacity building initiatives, underscoring the need to be attentive to what ultimate goals capacities are intended to be used for. Understanding the varied motivations driving engagement is important because the initiator actor's motivations appear to structure the process of engagement, thereby making some governance effects more or less likely to manifest.

Theme 3: The importance of engaging diverse climate vulnerable communities particularly from the Global South in discussion, research, and decision-making:

The dissertation echoes and builds from many voices advancing calls for meaningful engagement of climate vulnerable communities in the Global South on normative and substantive grounds. The dissertation, most centrally in chapter 1, also shows empirically how existing efforts are currently putting these calls into action and are already generating impacts that are likely to be important for the next stages of SG governance (see also Jinnah and Dove 2025). It also argues in chapter 2 that by broadening research to capture more diverse perspectives from the Global South, perspectives research can ensure diverse forms of knowledge inform assessment, research, and decision-making, thereby increasing collective capacity to tackle pressing policy challenges and develop a robust understanding of SG impacts from the

perspectives of vulnerable communities. Chapter 3 explains that governance capacity building initiatives need to focus on the Global South, and argues that failing to build research and governance capacity in vulnerable communities and countries risks creating a severe procedural injustice, whereby these actors are unable to shape research and decision-making, thereby increasing the risk of harm from SG activity.

Theme 4: The limitations of an ad-hoc approach to initiating and integrating engagement in research and governance:

Several insights from the dissertation highlight the limitations of an ad-hoc approach to engagement, in which engagement initiatives can be uncoordinated, poorly resourced, and separated from decision-making processes. In these cases, actors may lack the capacity to adequately initiate, facilitate, participate in, and make use of engagement, particularly in the long-term; the efforts may leave gaps, neglecting certain perspectives or capacities; and the knowledge and capacity produced may have little impact as they have "nowhere to go" (Corner et al. 2012, p. 462). Specifically, chapter 2 highlights how social scientists produce perspectives research on an ad-hoc basis and primarily to inform decision-making, but it is unclear whether and how the research is brought to the attention of decision-makers. There are also large geographic gaps in whose perspectives are studied as most researchers, who are primarily based in the Global North, study perspectives in their own countries. Similarly, chapter 3 underscores the importance of coordinating between capacity building initiatives to comprehensively build the full range of capacities needed across all relevant sectors of

society (Khan et al. 2018), and to leverage those capacities to contribute to key governance tasks. It warns against a focus on building only one set of governance capacities, which is likely to occur when only a small number of initiatives with limited funding are active. Overall, the dissertation suggests that the overall impact of GbE may rely on whether GbE is deployed in a coordinated and comprehensive fashion and linked directly to relevant research and decision-making processes.

Future Research Directions and Next Steps

The research undertaken in this dissertation has opened new research questions and lines of inquiry. Several areas of research can be pursued to build off and solidify the theoretical contributions of this dissertation, enabling a new research agenda to further enhance our understanding of various aspects of the politics of engagement in emerging technology issue areas and beyond.

First, the dissertation generated a preliminary conceptual framework for GbE that ultimately aims to be applicable across a range of empirical contexts and issue areas. However, the framework was empirically grounded in two cases of engagement in SG research that emerged out of the UK context, which has a distinct culture and history with respect to involving citizens in scientific decision-making (Stilgoe 2015). However, engagement can take on many different forms across the world (Carr et al. 2013; Fritz et al. 2024; Jasanoff 2011). There may also be characteristics of the SG issue area that encourage the employment of some forms of engagement over others. An open question therefore is whether GbE operates differently in other empirical

contexts and issue areas: the framework may need to be refined or adapted to better capture how engagement is used to govern in different socio-political contexts and issue areas. There is therefore a need to apply the novel conceptual and analytical tools to new issue areas and socio-political contexts to clarify their scope and strengthen their relevance and applicability. Once the generalizable validity of the GbE framework is further established, the conceptual framework can enable a systematic and comparative research agenda that maps engagement practices across various emerging technology issue areas and assesses the impact of the engagement practices.

Second, future research should use the GbE framework to account for variation in engagement practices. The GbE framework identifies a set of factors that are expected to explain why different models of GbE are employed and generate contrasting outcomes. However, in this study, the small number of cases and especially the lack of an empirical case that reflects the legitimation model of GbE constrains the dissertation's ability to explain, ultimately, why GbE ends up legitimating the interests of an initiating actor in some cases and empowering actors to shape research in others. Further comparative cross-case research drawing on a larger number of theoretically selected cases is needed to yield this explanatory leverage, generating further confidence in the relevance and scope of the explanatory conditions. Two lines of inquiry should be pursued. First, the models of GbE can be used as the dependent variable, in which case research aims to identify the factors that help explain why some models of GbE are employed more frequently than others or in some cases and not others. Second, the models of GbE can be used as the independent variable, in which

case research aims to identify what factors account for variation in the governance effects of different models of GbE. Specifically, future research should be designed to explore how well the following factors account for variation in the models and effects of GbE: initiating, participant, and target audience actor type and composition; the nature of the governance challenge GbE is employed to address; the nature of the issue area including level of social controversy; and the characteristics of the socio-political context (Low et al. 2022; Wynne 2006; van Boven et al 2025; Fritz et al. 2024; Zürn 2018; Delgado et al. 2011; Zaum 2013). The list may not be exhaustive, and future research may identify additional factors.

Both lines of inquiry can benefit from new empirical developments related to engagement and outdoor research in the SG issue area that have occurred since the start of this dissertation in 2020, opening new cases and opportunities for the empirical study of engagement and SG research governance (see Jinnah and Dove 2025; Low et al. 2022). Additionally, looking to the future, the United Kingdom's Advance Research and Innovation Agency (ARIA) recently announced funding for five outdoor experiments that will require community engagement to proceed,[5] and several social science projects were also funded that will also conduct engagement with publics and other interest groups across the Arctic, the United Kingdom, the Philippines, and Pakistan.[6]

[5] Reef Restoration and Adaptation Program. Stakeholder and Traditional Owner Engagement. Available at: https://gbrrestoration.org/program/engagement/ Accessed June 8, 2025.
[6] https://www.aria.org.uk/opportunity-spaces/future-proofing-our-climate-and-weather/exploring-climate-cooling/

These recent developments also underscore the continued relevance and importance of efforts to further our understanding of how engagement is employed to govern climate intervention research and what implications this has for justice.

Broader Implications and Recommendations

The dissertation has produced insights that are relevant for policy-makers, research funders, practitioners, researchers, and others. Below are brief implications and recommendations for each, starting with recommendations that are relevant for all.

For all: as engagement is used to govern research and development of climate intervention and other emerging technologies, using engagement as a tool of legitimation to generate support for pre-determined research or decisions carries sociological and normative limitations. Sociologically, doing so may backfire and instead provoke greater controversy. Normatively, using engagement as a legitimation practice violates key principles related to procedural justice. This can be avoided most easily at the outset of the engagement, by incorporating substantive and normative goals into the aims of specific engagement initiatives and designing engagement to achieve those goals. Ultimately, engagement initiators, facilitators, and users should remain open to the possibility that engagement can draw on or generate diverse forms of knowledge, information, perspectives, and values that can make research and decision-making processes more robust (Stirling 2008; Carr et al., 2013; Corner and Pidgeon 2010; Stilgoe et al. 2013b). Additionally, meaningfully engaging diverse and

particularly vulnerable participants and effectively and appropriately considering and incorporating their perspectives into research and decision-making may ultimately build trust in scientists and policy-makers and strengthen a publics belief that a research program, experiment, or policy process is legitimate (Stirling 2008).

As previously discussed, further research is needed to better understand the conditions under which engagement takes on different forms, including as a practice of legitimation or a tool for empowerment. However, this research suggests that the form engagement takes depends greatly on the motivations of the initiating actors, and their beliefs related to why engagement should be practiced and the (in)appropriateness of using engagement narrowly as a tool of legitimation.

For *policy-makers*: A collective capacity to initiate meaningful engagement with publics and other interested groups on pressing issues should ultimately be seen as a public good because it can enable discussion and debate on the tough decisions and options we may soon face. Opportunities for meaningful engagement may give publics a sense of greater ownership or input over decisions that are otherwise made by distant scientific and political elites and may therefore reverse declining trust in political and scientific institutions. Building capacity for communities and other types of actors to effectively initiate, facilitate, participate in, and make use of engagement will require public support, dedication, and resources. Policy-makers should explore options to create or leverage civic programs with sufficient mandate, reach, resources, and capacity to ensure publics and other impacted groups are informed and capable of

contributing in meaningful ways to discussion, research, and decision-making. Additionally, to facilitate the integration of diverse perspectives into research and decision-making, as recommended in chapter 2, policy-makers should also consider an international stocktake, assessment, and synthesis process for SG and CDR perspectives research that would provide balanced synthesis summary reports for a range of users. Such a process could be one component of a broader international assessment process for SG or it could inform the design of a broader assessment. Finally, greater public funding for engagement and capacity building initiatives can help ensure these activities are transparent and consistent with public goals. To ensure mitigation and adaptation remain priorities, overall funding levels in the climate intervention field must be appropriately proportioned.

For research funders: Requirements to conduct public or community engagement surrounding some research programs and in particular outdoor experiments are needed, but doing so can incentivize researchers to approach engagement instrumentally, treating it as little more than another box to be checked. Research funders can encourage researchers to adopt engagement practices that are more meaningful for participants and likely yield greater value to the research process by providing researchers with information and training on the potential benefits of meaningful engagement and pitfalls of perfunctory engagement. It can also provide training to ensure researchers are well prepared to interact with diverse participants and integrate their insights into research. In the absence of public funding for engagement, funders

should also adequately fund engagement at the programmatic level and funders should ensure the expertise needed to either facilitate or make use of engagement outputs is available at the outset. Research funders should also be mindful of the long time it may take to build authentic relationships with local communities, initiate and facilitate meaningful engagement, and carefully analyze the results of engagement and integrate it into research and decision-making. Project and funding timelines must build in time to do engagement well. To ensure engagement precedes important decisions publics and other interested groups may wish to weigh in on, research funders should also consider using engagement to inform the overall design of research programs, as well as at the level of funding specific projects. Funders may wish to consider commissioning perspectives research aimed at producing knowledge needed to address pressing challenges funders may face, such as knowing when and how different communities expect to be engaged in different forms of research and decision-making.

For *engagement and capacity building practitioners*: In addition to refraining from designing engagement initiatives that function narrowly as a legitimation practice, practitioners should be mindful of how engagement practices construct participants in particular ways, including with particular understandings of who they are (identities) and what they want (interests). Caution is particularly warranted when engagement is initiated in the Global North and invites participation in the Global South. For capacity building initiatives based in the Global North, transferring ownership to the Global South in the near-term through joint decision-making and authentic partnerships, is key

to ensuring impacted communities decide which capacities are built and how, the capacities that are built are durable and remain in communities over the long-term, and unequal power dynamics between North and South are transformed and not reinforced.

Overall, this dissertation emphasizes that engagement can have important governance effects. Those practitioners that are aware of how their expertise and activities may be leveraged to steer or influence behavior are best positioned to ensure that engagement contributes to and does not degrade just and effective forms of governance. They can do so by being attentive to the power dynamics between initiators, facilitators, participants, and target audiences, and to the appropriateness of using engagement to steer or influence behavior in different scenarios.

For climate intervention researchers: Meaningful engagement is difficult and for many researchers, engagement is far removed from their 'comfort zone'. However, avoiding engagement altogether likely creates more problems than it solves. Instead, researchers should view engagement as an opportunity to enrich the research process by learning something new. By appropriately integrating diverse knowledge, information, and perspectives, particularly from those that are most impacted by an issue or that are most familiar with a particular place, researchers may ultimately be able to develop more robust and comprehensive knowledge of how climate intervention technologies impact human and natural systems. Enabling this possibility requires, once again, a genuine attempt to initiate forms of engagement that empower diverse and vulnerable actors to contribute to and shape research and decision-making.

Chapter 1

Governance by Engagement in Global Climate Governance: Cases from Solar Geoengineering

Introduction

Several sets of emerging climate intervention technologies, including carbon dioxide removal (CDR), solar geoengineering (SG), and atmospheric methane removal, are increasingly prominent, to varying degrees, in climate politics, research, and discussion (NASEM 2019; NASEM 2021; NASEM 2024). As controversy and uncertainty surrounds their social and ethical desirability, technical feasibility, environmental impacts, and distribution of risks and potential benefits, calls for governance have featured prominently in discussion on whether, and how, research, development, and deployment of specific technologies should proceed (NASEM 2019; NASEM 2021; NASEM 2024). One element of governance consistently called for is public

engagement and engagement with other interested groups (Burns and Flegal 2015; Carr et al. 2013; Nawaz et al. 2023; Scott-Buechler and Jinnah 2024).[7]

By engagement, we mean participatory processes in which individuals or groups are invited to participate in structured activities focused around learning about, discussing, researching, or making decisions about emerging technologies. High level authoritative assessments and expert governance reports and proposals on these emerging technologies, and others, consistently articulate a central role for engagement in governance principles, proposals, and guidelines for research (e.g., NASEM 2019; NASEM 2021; NASEM 2024; UNEP 2023; Chhetri et al. 2018), and a burgeoning literature explores the role and importance of public engagement in, for example, solar geoengineering governance (Carr et al. 2013; Burns and Flegal 2015; Flegal et al. 2019; Fritz et al. 2024; Bellamy et al. 2016; Bellamy and Lezaun 2017).

Widespread calls for engagement clearly suggest that engagement is expected to matter for governance of emerging climate intervention technologies, among others such as artificial intelligence, synthetic biology, and nanotechnology. However, we know little about how engagement matters for governance and empirical evaluation and analysis is lacking (Reynolds et al. 2023). This is particularly true for emerging technology issue areas characterized by factual uncertainty, disputed values, societal controversy, risk-risk tradeoffs, ethical dilemmas, and high stakes (Funtowicz and

[7] Although the term "stakeholder" is commonly used in the literature, following NASEM guidelines the dissertation does not use the term "stakeholder" in our study unless quoting or citing the work of others (NASEM 2023). Instead it uses the term "interested groups".

Ravetz 1993). More troubling, we lack the conceptual and analytical tools to help us advance this understanding.

We argue that not only does engagement matter *for* governance, but engagement is itself a mode of governing. In this article, we aim to build a theoretically informed and empirically grounded framework for understanding of how engagement governs. Given the high level of demand for engagement surrounding emerging technologies that may be used to address climate change, we examine this phenomenon through the lens of solar geoengineering. Solar geoengineering (SG) (also called solar radiation management or modification) is a set of proposed technologies that would aim to limit climate impacts by reflecting incoming sunlight back into space, thereby cooling the planet (NASEM 2021). To that end, we develop the concept of *governance by engagement* to highlight how and under what conditions engagement efforts generate important governance effects. These effects can include steering and/or influencing the behavior of the participants and targets of engagement alike as well as shaping research and governance trajectories.

Specifically, we conceptualize governance by engagement by drawing on the literatures on transnational climate governance and global governance. Reflecting the diverse forms that engagement can take (Jasanoff 2005; Rowe and Frewer 2005; Arnstein 1998), we elaborate three models of governance by engagement, including a *perspectives elicitation* model, a *capacity building* model, and a *legitimation* model, each of performs a distinct governance function. We use the literature on public engagement in science and technology to distill a typology of four categories of

governance effects that we expect to flow from governance by engagement (Stirling 2008; Fiorino 1990). Briefly, *normative* effects relate to empowering an actor or community and democratizing decision-making; *substantive* effects relate to improving the process or outcome of research or decision-making; *instrumental* effects relate to normalizing an issue or legitimating an actor; and *productive* effects relate to constructing particular configurations of actors and communities. Based on these categories of potential effects, the typology can be used to analyze whether governance by engagement empowers, informs, legitimates, and constructs actors in particular ways across a diverse range of issue areas and cases.

We draw on empirical data from two cases of engagement surrounding solar geoengineering - one that fits the perspectives model and one the capacity building model. Using these data, we illustrate the utility of the governance by engagement framework. The first case, illustrating the perspectives elicitation model, analyzes the SPICE project, an early proposed outdoor solar geoengineering experiment. The second case, illustrating the capacity building model, analyzes the Degrees Initiative, an NGO that engages Global South scientists in solar geoengineering research. In both cases, we demonstrate how the engagement activities were initiated by authoritative actors in response to a perceived governance challenge and aimed at addressing public goals. Our analysis then explains how the engagement activities generate potentially significant governance effects on target audiences, decision-making processes, and broader research and governance trajectories.

Our results contribute to ongoing debates on whether engagement primarily legitimates predetermined decisions, and/or empowers participants to shape decision-making. Specifically, we challenge a dominant view of participation in the global governance literature, in which participation and engagement are understood centrally as a legitimation practice (Tallberg et al. 2018; Tallberg and Zürn 2019). Legitimation can be understood as a practice that aims to enhance beliefs that an exercise of authority is appropriate (Tallberg and Zürn 2019). The legitimating effects of engagement are undoubtedly present in many cases (Stirling 2008; Bellamy and Lezaun 2015). However, restricting our understanding of engagement practices as a narrow legitimation practice obscures its other important governance functions (see also Burgess 2014). As our cases show, engagement activities can have a much more complex set of motivations that indicate a broader set of potential governance effects, of which legitimation is but one function. Rather, understanding how engagement matters requires examining a broader set of potential governance effects that may flow from engagements. In our view, governance by engagement does not only legitimate - it also purposefully and authoritatively shapes, in discernible ways, research and governance itself.

We proceed as follows. First, we outline our methods and detail our two cases. We then draw on literature on transnational climate governance and public engagement to conceptualize *governance by engagement*, detail how it operates across two different engagement models (i.e. perspectives elicitation and capacity building) and build a typology of four categories of effects expected from governance by engagement (i.e.

normative, substantive, instrumental, and productive). This is followed by our empirical analysis of the interventions and effects of governance by engagement across our two cases. Finally, we conclude by briefly discussing the implications of our findings for future research and practice.

Engagement and Solar Geoengineering Governance Frameworks

To demonstrate that engagement is imagined to be a central component of solar geoengineering governance, here we highlight how a selection of influential governance reports and assessments that propose governance frameworks and principles for on solar geoengineering research consistently articulate a central role for engagement in governance. Brent et al. (2024) identify public engagement as a common principle across 10 influential governance proposals for solar geoengineering research (see also Morrow 2017; Reynolds 2019; NASEM 2021; Flegal et al. 2019). Indicative of the governance role engagement is intended to fulfill, Brent et al. (2024) explain that these proposals do not merely aim to evaluate governance challenges and responses. Rather, the governance "proposals seek to *identify and articulate* norms to influence how SRM R&D is conducted" (Brent et al. 2024, emphasis original).

The influential 2009 Royal Society Report recommended that the Royal Society and others "initiate a process of dialogue and engagement to explore public and civil society attitudes, concerns and uncertainties about geoengineering as a response to climate change", recognizing that public attitudes and "public engagement in the development of individual methods proposed, *will have a critical bearing on its future*"

(Royal Society 2009, p. xii, emphasis added). The report argues that research on public perceptions "should be carried out in parallel with technological R&D, and accompanied by appropriate educational and knowledge exchange activities, to enable better informed debate and policy making" (Royal Society 2009, p. 43).

The Oxford Principles is an influential list of 5 principles for geoengineering governance submitted by an ad-hoc group of academics to an inquiry initiated by the United Kingdom's House of Commons Select Committee on Science and Technology on how geoengineering should be governed (Rayner et al. 2013). The second Oxford Principle is public participation in geoengineering decision-making. Noting that this requirement "suggests a primary concern for legitimacy" (Rayner et al. 2013, p. 505), the Oxford Principle explain that wherever possible, "those conducting geoengineering research should be required to notify, consult, and ideally obtain the prior informed consent of, those affected by the research activities" (Rayner et al. 2013, p. 502).

In 2010 the Asilomar International Conference on Climate Intervention Technologies produced a report entitled "Recommendations on Principles for Research into Climate Engineering Techniques." The report included recommendations to adopt 5 principles to "promote the responsible conduct of research on climate engineering" (Asilomar Scientific Organizing Committee 2010, p. 2). The fifth principle is that "public participation and consultation in research planning and oversight, assessments, and development of decision-making mechanisms and processes must be provided" (Asilomar Scientific Organizing Committee 2010, p. 2). The report asserts it "will be essential to ensure a strong public information and education effort so that those likely

to be most affected have the information needed to participate and contribute to informed governmental decision-making" (Asilomar Scientific Organizing Committee 2010, p. 24).

The US based Bipartisan Policy Center convened a Task Force on Climate Remediation Research "to develop recommendations for the US government concerning geoengineering research and oversight" (Bipartisan Policy Center 2011, p. 2). The Task Force released a report in 2010 documenting their conclusions, which includes discussion of 5 principles that should guide research programs. Principle 3 calls for oversight of research programs and explains the direction of research should be based on expert and government advice, and it should also be "informed by a robust process of public engagement" (Bipartisan Policy Center 2011, p. 14).

The Solar Radiation Management Governance Initiative (SRMGI), which is the precursor to the Degrees Initiative, released a report reflecting the expert and stakeholder deliberations on solar geoengineering governance that were stimulated by the activities of its first year in operation, which focused on an international conference to discuss solar geoengineering. SRMGI released its report in 2011, titled "Solar Radiation Management: The Governance of Research." The report asserts that public engagement should aim towards "improving the robustness of analysis and decision-making, through the inclusion of public attitudes, values and opinions. If this can be achieved, it should contribute to better governance and provide a forum for the early expression of opinions and concerns" (SRMGI 2011, p. 41). Moreover, the report

asserts that in addition to other criteria, "participation in decision-making is a key feature of a process that will be perceived as legitimate" (SRMGI 2011, p. 41).

In 2015 the European Union-funded EuTRACE project (European Trans-disciplinary Assessment of Climate Engineering) released its final report on a transdisciplinary assessment of geoengineering (Schäfer et al. 2015). The assessment identifies "strategies that could broadly be applied across all climate engineering approaches in support of developing effective governance", the first of which is "early public engagement, including targeted public communication platforms" (Schäfer et al. 2015, p. 15). Reflecting three commonly cited rationales for public engagement (Fiorino 1990; Stirling 2008), the assessment suggests that early public engagement can be based on procedural justice, and it can also be "instrumental in building trust in scientific activities (Bodansky, 2013) and in improving the quality of socially robust scientific and technological solutions, especially in situations of uncertainty (Stirling, 2008; Carr et al., 2013; Corner and Pidgeon, 2010; Stilgoe et al., 2013)" (Schäfer et al. 2015, p. 110).

Legal scholar Hubert developed a Code of Conduct (2017, updated in 2021) to provide concrete guidance for geoengineering research based on a study to identify legal concepts, norms, and processes of relevance to geoengineering research governance (Hubert 2021). Hubert notes that a right of public participation in decision-making is echoed across international and domestic legal norms, laws, agreements, and decisions in the environmental issue area and others including human rights and science

and technology. Build off this, the Code of Conduct devotes an article to public engagement, stating:

> "To the extent practicable, the interested public should be provided with timely access to all relevant information pertaining to geoengineering research, especially all outdoor experiments on geoengineering, and *be given notice and the opportunity to comment, at appropriate stages and while options are still open, concerning decision-making about such research"* (Art. 8, emphasis added).

The Academic Working Group at the Forum for Climate Engineering Assessment is a group of over a dozen global governance experts brought together to develop a consensus report, released in 2018, outlining near term actions that can be taken to effectively and responsibly govern solar geoengineering. Noting that poorer climate vulnerable communities will be disproportionately impacted by SG and have less access to international decision-making, the report asserts that "decisions about whether and how SRM should be researched and deployed must hear, respond to, and integrate concerns of vulnerable and marginalized communities" (Chhetri et al. 2018, p. 33). The report calls for the creation of a 'Global Forum on Stakeholder Dialogue' with the central purpose "to initiate a learning-oriented dialogue, bringing together voices and perspectives that might otherwise not be engaged in dialogue about SRM" (Chhetri et al. 2018, p. 33).

In 2021 the National Academic of Science, Engineering, and Medicine released its 2nd report on geoengineering, this time focused on recommendations for the development of a solar geoengineering research program and a framework for research

governance. Crucially, the report recognizes public and stakeholder engagement as both a primary goal of research governance and a 'governance mechanism' that is needed to promote other governance goals. The report considers "facilitating inclusive and equitable public and stakeholder engagement" as a core goal of research governance alongside advancing and coordinating research and addressing risks and concerns (NASEM 2021, p. 10). Public and stakeholder engagement is then listed as a 'governance mechanism' that can also help promote principles related to inclusivity and transparency (see p. 11). The NASEM report asserts that public engagement and transparency are "mainstays of socially robust research and will be critical for the success of a research program", which is why it envisions "public engagement being woven into both SG research and research governance" (NASEM 2021, p. 142).

Clearly, engagement is consistently articulated as a core element of proposals for solar geoengineering research governance. Next we turn towards an outline of our research design to show how empirical research can help us better understand how engagement can govern solar geoengineering research in practice.

Methods

Case Background and Selection

Because engagement comes in many different forms (Jasanoff 2005), we needed to examine more than one type of engagement in the solar geoengineering issue area in order to produce a comprehensive understanding of how different forms of engagement

may operate through different interventions and generate different governance effects. We use two cases of engagement in the issue area that draw our attention to two different ways engagement is being used to govern solar geoengineering. The cases are summarized in **Table 1.1** below.

Table 1.1: Cases of Governance by Engagement in Solar Geoengineering Research

	SPICE Public Deliberative Workshops	**The Degrees Initiative (SRMGI)**
Governance challenge requiring engagement	Potential for societal controversy, risks to research councils, epistemic uncertainty	Lack of awareness, capacity in Global South, who are most affected by SG decision-making
Motivations for initiating engagement[8]	Make SPICE stage gate decision-making more robust; strengthen democracy; avoid previous engagement missteps	Empower Global South and level playing field; inform societal conversations and policy-making
Engagement activities	Deliberative workshops	Outreach workshops; research funding; other events
Model of Governance by Engagement	Perspectives elicitation	Capacity building
Initiating actors	UK Research Councils (EPSRC)	Royal Society, EDF, TWAS[9]

[8] These are consistent with public goals and aims required for an activity to count as governance.

[9] In the early days of SRMGI, SRMGI was the facilitator of engagement and the initiators were the Royal Society, Environmental Defense Fund (EDF), and the World Academic of Sciences (TWAS), who formed SRMGI through a partnership. After The Degrees established itself as an independent non-profit, it took on the role of initiating actor and also carried out facilitating functions.

Facilitating actors	IAGP engagement experts	The Degrees Initiative
Participant actors	United Kingdom public	Global South scientists, researchers, climate professionals
Target audience	Stage gate panel, EPSRC, SPICE researchers	Global South policy-makers, negotiators, experts, publics; Northern researchers

Case 1: Perspectives Elicitation Model - Stratospheric Particle Injection for Climate Engineering (SPICE)

The Stratospheric Particle Injection for Climate Engineering (SPICE) project (2010 - 2015) is an early solar geoengineering research project which in three parts aimed to investigate potential stratospheric aerosol particles, their potential delivery mechanisms, as well as their potential impacts (Owen 2014; Stilgoe 2015). Significantly, in addition to modelling and laboratory research, the project included a proposed outdoor solar geoengineering experiment (called the 'test bed') that was set to take place in the United Kingdom. The project was funded by the UK Research Councils, led by the Engineering and Physical Sciences Council (EPSRC). A 'stage gate' process was established by EPSRC to govern the outdoor experiment portion of the project (Owen 2014). The SPICE research team would need to progress through several 'gates' in order to receive funds to commence the experiment.[10] A 'stage gate

[10] A stage gate is "an established mechanism used in innovation management (particularly in new product development) in which investments in the innovation process are phased (or staged), with

panel' was set up to advise the EPSRC on the decision to release funds and allow the experiment to proceed.

As part of the stage gate process, the EPSRC initiated a series of public deliberative workshops to understand broader societal views surrounding the outdoor 'test-bed' field trial portion of the SPICE project. The workshops were carried out by experts in public engagement on a separate project funded by the UK Research Councils, the Integrated Assessment of Geoengineering Proposals (IAGP). The workshops would inform the 'stage gate' advisory panel's recommendation to EPSRC on whether the test bed should proceed or not (Stilgoe et al. 2013b; Macnaghten and Owen 2011).[11] The principal investigator of the SPICE project ultimately cancelled the experiment after the workshops took place, citing concerns surrounding intellectual property, governance issues, and the need for more public and stakeholder engagement. The project was marred by controversy, including surrounding a patent application and opposition from environmental NGOs.

This case was selected for several reasons. First, it's an example of a perspectives elicitation engagement model in that perspectives from public participants were elicited to help decide whether an outdoor experiment should proceed or not. The

decision 'gates' where decisions are made to progress, stop, refine, redefine etc., usually on the basis of technical feasibility, market potential and risk" (Owen 2014, p. 232, citing Cooper 1990).

[11] The public engagement work was only one half of the criteria; stakeholder engagement was the other half. We focus on the public deliberative workshops because these were completed in time to inform the stage gate panel's decision-making and because the methods and results are detailed extensively in published research. Jack Stilgoe carried out the stakeholder engagement work but this was initiated after the experiment had already been cancelled and information on the methods and results are more scarce; these were written up in Stilgoe et al. (2013a), see also Stilgoe (2015).

clear motivation to use engagement to inform a governance decision indicates potential governance effects. Second, it is also the only case of public engagement surrounding a specific outdoor experiment to have been carried out at the time this project was initiated in 2018.[12] Third, there is available data documenting the process as a sizable body of literature has been published by individuals involved in various parts of the project and its governance (e.g., Stilgoe et al. 2013b; Macnaghten and Owen 2011; Stilgoe 2015). Finally, the SPICE project is quite significant in the history of solar geoengineering governance (Stilgoe 2015; Jinnah and Dove 2025). The project is credited with bringing solar geoengineering to broader public attention and the opposition from environmental NGOs arguably helped set the stage for the polarized and deadlocked debate that continues to shape the politics of solar geoengineering to this day (Stilgoe 2015; Owen 2014).

Case 2 - Capacity Building Model - The Degrees Initiative

Our second case of governance by engagement is the Degrees Initiative, an NGO-led capacity building program that engages scientists and researchers from the Global South in solar geoengineering research to ensure informed representation from Southern countries in international assessment and decision-making. Its precursor, SRMGI, was initially a formed in 2010 as a partnership between the Royal Society,

[12] The one partial exception is the engagement program surrounding Australia's Reef Restoration and Adaptation Program, which conducted outdoor experiments to test whether it would be feasible to use marine cloud brightening to protect the Great Barrier Reef. However under Australia's research program, marine cloud brightening is also framed as exploration of a regional adaptation measure, rather than a potential method to intervene in the climate on a global scale.

The World Academy of Sciences (TWAS), and the Environmental Defense Fund (EDF). The Initiative hosts a physical and natural science modelling research fund started in 2018 called the Degrees Modelling Fund (DMF) and a newer social science fund started in 2024 called the Socio-Political Fund (SPF). Solar geoengineering experts, called 'research collaborators', are paired with funded research teams as part of a broader effort to build international and regional communities of solar geoengineering experts.[13] Prior to the creation of the research funds, which remain the focus of the Degrees Initiative's work, SRMGI's strategy revolved around hosting outreach workshops which aimed "to start well-informed conversations about SRM in the local climate community and to get participant ideas

on any next steps in their countries or regions."[14]

We selected this case because it is an example of the capacity building model for engagement. Further, the Degrees Initiative (through its precursor, SRMGI) is the longest running effort to expand awareness and discussion of solar geoengineering in the Global South. As a result, observation of potential governance effects of their activities is likely to be easier relative to newer efforts, such as the Alliance for Just Deliberation on Solar Geoengineering (DSG). Additionally, the Degrees Initiative has had a clear impact on shaping where solar geoengineering research is being done, indicating important potential governance effects. The DMF and SPF are the first research funds focused on funding SG research in the Global South and together they

[13] Jinnah is a research collaborator with the Degrees Initiative.
[14] The Degrees Initiative. "Early Days". Available at: https://www.degrees.ngo/about/early-days/ Accessed June 10, 2025.

are "now the largest [SG] research programme in the world and have supported over 170 researchers working across 37 projects in 22 developing countries."[15]

Both cases showcase forms of engagement that are at the same time similar and distinct. The former includes a more 'typical' model of invited public engagement whereby a sample of individuals are invited to discuss a particular issue in a deliberative workshop format, the views of the participants are analyzed and ultimately written up in a report, which is then disseminated to inform decision-making surrounding whether an experiment should go ahead or not. In the latter, an NGO invites scientists, researchers, and other environmental or climate professionals to discuss solar geoengineering in a series of outreach workshops and to apply for grants to research SG to develop expertise. Clearly, the invited audience, format, duration, and purpose of each form of engagement vary in important ways. However, in both cases, an initiator invites a particular group of people, or an audience, to participate in structured activities focused around learning about, discussing, and researching solar geoengineering.

Some may find our decision to conceptualize a capacity building program built around research funding as a form of engagement to be controversial. After all, applying for research grants is a routine and essential part of scientific and academic life. We argue that the Degrees Initiative can accurately be characterized as an engagement effort because engagement, and not research funding, is the overriding

[15] The Degrees Initiative. "Our work". Available at: https://www.degrees.ngo/our-work/ Accessed April 1, 2025.

mode of activity: staff explain the research funds are a means to a broader end focused around broadening engagement in and empowering the Global South. Specifically, according to Degrees Initiative staff, the research funds are the most effective strategy to engage Global South scientists and researchers in solar geoengineering discussions as it more effectively enables them to build their expertise than participating in on-off outreach workshops. In the words of one longtime volunteer we interviewed, "we felt that actually funding researchers was the most effective way of doing the education." This reflects the long-standing wisdom in the capacity building literature that sustained and long-term programmatic efforts are more successful than short-term and ad-hoc trainings or workshops (Dove et al. 2024a). In other words, while the means shifted from workshops to research funding, the broader ends related to engagement remained constant. As one staff member explained in an interview, "the first stage was the workshops. The next stage was funding research and supporting southern climate people for as long as they needed to become SRM experts and take their place in a global conversation."

The two cases also make for an interesting pairing because they were both catalyzed directly by the highly influential 2009 report from The Royal Society, showing how distinct forms of engagement can follow from the same context.

Qualitative research design

In line with our aim to develop a theoretically informed and empirically grounded understanding of how engagement is used to govern solar geoengineering research, we

conducted semi-structured key informant interviews with individuals involved in varying capacities in each of the two cases to better understand the context, motivations, process, and effects of engagement from the perspectives of those involved.

We conducted in total N=45 semi-structured interviews with participants from each of the two cases between July 2024 and March 2025.[16] We interviewed N=9 participants involved in some capacity surrounding the SPICE project and the public workshops, including members of the SPICE team, members of the stage gate panel, researchers involved in designing or facilitating the public deliberative workshops, and others involved in the stage gate process. We interviewed N=36 participants involved in the Degrees Initiative or its precursor SRMGI as staff, expert research collaborators and other volunteers, and principal investigators and researchers of projects funded through its research grants. Of these, N=17 participants are from countries in the Global North, and N=19 participants are from countries in the Global South. Given the small number of individuals involved in each of the cases, in an effort to ensure participant anonymity, we keep demographic information reported here in summary form and when we report interview data, we only briefly describe in general terms their relevant role.

[16] This study received human subjects research approval from the UC Santa Cruz IRB as study #HS-FY2024-73. One researcher submitted written answers to questions we sent, this is not included in this count. All interviews were with one participant only with the exception of one interview with the principal investigator and four team members of a project.

Interview participants were identified using public websites and documents and in the case of the SPICE project, from relevant academic and gray literature. Participants were invited to participate in an approximately 60 minute interview over Zoom to discuss their experience in either case as well as their perceptions of engagement in solar geoengineering research and governance. Interviews were recorded through Zoom, converted into transcripts using the Zoom transcript feature initially and then later by one researcher to verify and finalize the transcript, and then the transcripts were uploaded to the qualitative analysis software Atlas.Ti for coding analysis. The transcripts were coded using a combination of inductive and deductive thematic coding to identify motivations for and effects of engagement (Fereday and Muir-Cochrane 2006; Nowell et al. 2017). We initially coded expected or actual governance aims and effects inductively. We then used Fiorino (1990) and Stirling's (2008) categorization of motivations for public engagement to organize our initial codes.[17] We used codes that did not fit into their categorization to form the 'productive' category of governance effects, ultimately developing a typology of governance effects based on an expanded adaptation of Fiorino (1990) and Stirling's (2008) categorization. We also marked quotations that helped us better understand and contextualize the governance challenge motivating the need for engagement.

[17] Fiorino (1990) and Stirling's (2008) categorization of motivations was used to provide a categorization scheme for our inductively generated list of effects because it provided an effective way to make sense of a large number of disparate effects. It also reflects the wisdom in the literature on public engagement in science (e.g. Delgado et al. 2010) as well as within our interviews that the motivations for initiating engagement are intrinsically linked to the intended effects.

We also used the interview data as background to help us better understand the activities and context of engagement in each case. Interview participants were asked to describe the importance, motivations, and impacts of the particular cases of engagement in question, and they were also asked to describe compelling reasons for doing engagement more broadly as well as to identify desired outcomes in general. As such, sometimes participants discussed engagement in a more general sense, and sometimes participants also explored these questions in relation to other engagements activities they have been involved in or other prominent cases of engagement in the solar geoengineering issue area. For example, many participants discussed compelling motivations and desirable outcomes of engagement (as well as undesirable outcomes of not doing engagement properly) in relation to recent outdoor experiments, including the cancelled SCoPEx and marine cloud brightening experiment in San Francisco Bay, as well as the marine cloud brightening trails that occurred over the Great Barrier Reef off the coast of Australia.

We supplemented the semi-structured interviews with secondary research in books, articles, newspapers, blogs, public websites, and other public documents, largely but not exclusively produced by individuals involved in each of the two cases. For example, there is a rich literature that explores various aspects of the SPICE project, its governance, and the public deliberative workshops from the perspectives of some individuals involved (e.g., Stilgoe 2015; Pidgeon et al. 2013; Owen 2014; Owen and

Macnaghten 2011; Stilgoe et al. 2013a; Stilgoe et al. 2013b; Parkhill et al. 2013).[18] We drew on this literature for background and to triangulate our interview data, which was limited for some purposes as interview participants were recalling events that had occurred over a decade ago. Additionally, the Degrees Initiative documents its activities extensively on its public website (www.degrees.ngo) and includes expanded information on its approach, activities, and impacts. Its activities and potential impacts are also discussed in some academic literature (e.g., Delina 2021; Horton and Koremenos 2020; Rahman et al. 2018).

Conceptualizing Governance by Engagement

Here we conceptualize governance by engagement and explain how it can be used to analyze the governance interventions and effects of engagement across a range of issue areas. First, we introduce a theoretically-driven conceptualization of governance by engagement and its components. We then describe the interventions through which engagement can generate governance effects by introducing several models of governance by engagement. Finally, we present a typology of categories of governance effects expected to follow governance by engagement.

Governance by engagement: definitions and components

[18] Our use of literature on the SPICE project was not restricted to pieces authored by individuals that agreed to participate in our study.

Our introduction and conceptualization of the term 'governance by engagement' builds on previous work on non-state governance in the solar geoengineering issue area and global environmental governance more broadly.

The term's nomenclature is directly inspired by Gupta and Mason's conceptualization of governance by disclosure, which they use to refer to the "targeted *disclosure of information* as a means by which to evaluate and steer behavior, that is, as a means by which to govern" (2014, p. 6, emphasis original). Whereas Gupta and Mason investigate the governance effects of transparency, our aim is to better understand the governance effects of engagement. Gupta and Mason usefully emphasize that in an increasingly multilevel and multi-actor global governance, transparency is not only being deployed by states to provide information to interest publics, or to other states. Rather, their focus is "on the multiple *instigators*, *architects*, and *recipients* of transparency in global governance, going beyond states to include corporations, civil society groups, international organizations, consumers, and citizens" (p. 5). Similarly, in exploring the governance effects that flow from engagement, we also look beyond states engaging publics and develop an analytical openness to the multiple types of actors that can be *initiators*, *facilitators*, *participants,* and *targets* of engagement.

Briefly, *initiators* start the governance by engagement by process by deciding engagement is needed to address a governance challenge. The initiator funds the engagement and either plans and carries out the engagement or directs a facilitator to do so. They also generally dictate the aims or purpose of the engagement. Multiple

types of actors can initiate engagement, including states and their component public bodies, global governance institutions (Tallberg et al. 2018), transnational networks, public or private funders, NGOs, researchers, or industry. In some cases of governance by engagement, *facilitators* are employed or directed by the initiator to plan and facilitate the structured engagement activities. Facilitators are often professional marketing or survey firms, which specialize in identifying and recruiting samples of participants for research or marketing purposes. They can also be researchers, NGOs, or other entities with expertise or capacity required to plan and implement engagement activities. *Participants* are the audience that is invited to engage in structured activities. Multiple types of individual and collective actors can be invited as participants, generally as determined by the aims and purpose of the engagement. Participants can include publics, communities, scientists and researchers, policy-makers, NGO representatives and practitioners, and other interested groups and their members. Finally, the *targets* of engagement are those actors intended to be the recipients of the effects of engagement, or put differently, the 'users' of the outcomes of engagement, such as perspectives, information, knowledge, capacity, or recognition of legitimacy. Sometimes the targets are a third party, whereas in other cases the target audience can be the participant themselves, or the initiator of the engagement. Again, this role can be performed by multiple types of actors.

Governance by engagement is characterized by fluid actor roles in several respects. First, more than one type of actor can perform each role; no single actor type is required to perform any one role, and the same type of actor can perform multiple

roles.[19] For example, researchers can both facilitate engagement (as is the case in the SPICE project) as well as be participants in engagement (as is the case in the Degrees Initiative). Additionally, the same actor can perform multiple roles simultaneously. For example, in the case of the Degrees Initiative, in recent years the NGO both initiates and facilitates engagement. In the case of the SPICE project, the EPSRC initiated the engagement and was also intended to be the target audience (alongside the stage gate advisory panel) because it intended to use the perspectives elicited during the engagement to inform its decision-making. Finally, the same actor can also transition from one role to another. For example, in the case of the Degrees Initiative, the researchers that are initially participants in the capacity building program in some cases subsequently become initiators of new engagement practices, by starting their own outreach and engagement efforts to promote awareness of SG and their research in their respective countries.

Several prior studies have explored several forms of governance activity in the solar geoengineering issue area that were previously neglected from analysis. First, Horton and Koremenos (2020) build on and expand the transnational climate governance framework to capture a number of important functions performed by non-state actors that contribute to solar geoengineering governance. As our notion of governance by engagement builds off this framework, it is worth elaborating its defining features here. The transnational climate governance framework as introduced

[19] The only required condition is for initiators, who must be recognized as authoritative, as explained below.

by Andonova et al. (2009) and subsequently elaborated and revised by others, has "three common features": "governance is concerned with realising public goals through the process of steering a particular constituency of actors and is regarded as authoritative" (Bulkeley et al. 2012, p. 594).

Therefore, the first feature of governance is that the *goals of governance must be public* rather than private, meaning some version of the common good must be invoked as the justification for the act. Second, governance involves *steering*, which "'means that an initiative aims to somehow change or coordinate the actions of those who participate through the setting of rules, standards, or other kinds of guidelines that aim to regulate the behavior of individuals or corporate bodies or the characteristics of goods or services they produce" (Roger et al. 2018, p. 5–6). Third, the steering must be *purposive*, in the sense that a governor intends to govern (Andonova et al. 2009, p. 56). This suggests as well that the governance need not be effective or successful in achieving its goals; only that it is intentional. Fourth, the steering must be *authoritative* rather than relying on violence, persuasion, intimidation, or material incentive (Andonova et al. 2009, p. 56; see also Hurd 1999; Arendt 1968). This means that governors are recognized by the governed as authoritative on the basis of public mandate, expertise, moral standing, or problem-solving capacity (Avant et al. 2010; Andanova et al. 2009).[20]

[20] According to the transnational climate governance framework, to be considered a form of transnational governance, non-state or sub-state actors located in more than one state must be involved. However given our focus on establishing what counts as governance rather than *transnational* governance, we are less concerned here with where entities are located.

As indicated, authority is a key component of governance as understood under the transnational climate governance framework as well as in competing understandings of global governance more broadly (e.g., Hurd 1999; Lake 2010; Avant et al. 2010; Keohane and Nye 2011; Zürn 2018). We think of governance as a relationship that is closely associated with authority, legitimacy, and power (Zürn 2018; Sending 2017). There are many ways to define and conceptualize authority, including its relationship with legitimacy. We define it as "the ability to induce deference in others" (Avant et al. 2010, p. 9; see also Kirsch 2017), meaning an actor in a sense 'surrenders judgement' to another and voluntarily chooses to comply with their command, request, or suggestion on the basis of their recognition of an actor as authoritative (Friedman 1990; Kirsch 2017; Zürn 2018). In understanding authority as the ability to induce deference, we find the 'liquid' conception of authority to be most helpful in conceptualizing governance by engagement because it highlights the dynamic nature of authority as emerging and transforming over time (Krish 2017; Sending 2017; Zürn 2018). Liquid authority also highlights how a multitude of different types of actors can be involved contesting, producing, and sustaining authority, as well as how authority can be found outside of the formal nation-state and also operating outside the use of formal, legal tools (Krisch 2017; Sending 2017). In this understanding, authority is not a property or attribute of certain actors - it manifests in the context of a relationship in which one actor defers to another, indicating recognition of its authority (Sending 2017). Recognition of authority can come from many different sources, including rational cost-benefit analysis, internalization of a normative belief,

habituation, or privileged access to information or knowledge (Krisch 2017; Sending 2017; Zürn 2018; Avant et al. 2010).

Overall, we prefer this conception of authority because it most accurately matches what we observe empirically; as illustrated in our empirical section below, we see a variety of state and non-state actors that interact to produce, contest, and transform authority in relation to others, making authority in effect hard to locate. Indeed, we see attempts to claim, recognize, and contest authority across initiators, participants, facilitators, and recipients of governance by engagement. However, for an engagement practice to count as governance by engagement, it must be initiated by an actor that is recognized as authoritative by others. In our view, the UK Research Councils, in the case of the SPICE project, and the Royal Society, the EDF, and TWAS in the case of the Degrees Initiative, are recognized by multiple audiences as authoritative on the basis of their prestigious academic stature, connection to public mandate, or capacity to access expertise and information.

The requirement that governance is initiated by actors regarded as authoritative delineates the scope of our study to 'invited' rather than 'uninvited' forms of engagement, reflecting a distinction that has been used in science and technology studies to distinguish between top down forms of engagement initiated by political or scientific authorities and bottom up forms of engagement initiated by grassroots initiatives (Wynne 2007; Irwin 2001). Invited forms of engagement include such techniques as citizen's assemblies and juries, focus groups, deliberative workshops, public consultations or town halls. Uninvited forms of engagement can include protests,

campaigns, and other 'everyday' forms of engagement that are initiated by or channeled through civil society organizations or networks of laypersons (Delgado et al. 2011). Just as Gupta and Mason (2014) restrict their focus to those forms of disclosure initiated by authoritative governance initiatives, our analysis of governance by engagement focuses on a subset of engagement practices that are initiated by recognized authorities, as required by the transnational governance framework.[21]

Steering is also a central component of governance. However, Horton and Koremenos (2018) argue that the exclusive focus in the transnational climate governance framework on steering neglects the activities of several actors that are widely recognized as important players in the solar geoengineering governance landscape. To build a more complete theory that accounts for these activities and therefore is more useful for analyzing non-state involvement in climate governance, Horton and Koremenos (2020) call for integrating *influence* into the transnational climate governance framework - in addition to steering. Horton and Koremenos (2020) argue that by excluding influence, the transnational climate governance framework neglects several important roles for non-state actors in governance because it "equates the act of governing with the condition of governance":

[21] We leave open the possibility that uninvited forms of engagement can also matter for governance. For example, the HOME campaign, led by a network of NGOs opposed to research and consideration of solar geoengineering, mobilizes its constituencies and local communities in opposition to research experiments and other developments, aiming to lobby and pressure decision-makers to oppose decisions seen as enabling development of solar geoengineering technologies. As discussed below, Horton and Koremenos (2020) consider the lobbying activities of the ETC Group (which has played a central role in initiating and coordinating the HOME campaign) likely to be important for governance, without arguing that they are in effect governing.

> "Governing, or steering, entails a direct connection between governor and governed. Governing is clearly the principal component of governance, but just as clearly, there is more to governance than governing. Governance also involves *influencing, or indirect efforts to affect the relationship between governor and governed.* Influencing may target either party to a steering relationship; it includes but is not limited to knowledge dissemination, capacity building, and lobbying." (p. 94-95, emphasis added).

Using this expanded notion of transnational climate governance, the authors demonstrate that the knowledge dissemination activities of the Geoengineering Model Intercomparison Project (GeoMIP);[22] the scientific capacity building activities of SRMGI; and the lobbying activities of the Erosion, Technology, and Control Group (ETC Group) and the Carnegie Climate Governance Initiative (C2G) contribute in important ways to the transnational governance of solar geoengineering.

Importantly for our purposes, Horton and Koremenos (2020) characterize SRMGI's governance activities as 'scientific capacity building', however they note that capacity building is a means to an end that is more closely related to engagement: "SRMGI is principally concerned with *empowering developing country engagement with solar geoengineering through scientific capacity building*." (p. 101, emphasis added). By integrating influence into our understanding of what counts as governance, our study builds directly on Horton and Koremenos' attempt to adapt the transnational climate governance framework to capture a more complete picture of relevant governance activity in the solar geoengineering issue area.

[22] GeoMIP is a network of climate modelling groups that coordinate and standardize solar geoengineering scenario experiments to better inform public policy and discussion.

The second attempt to study previously neglected forms of solar geoengineering governance is Gupta and Möller's (2019) study of authoritative assessments. Gupta and Möller (2019) draw on the notion of de facto governance to explore the governance effects of authoritative assessments in ordering and shaping the field of inquiry into solar geoengineering and in constructing it as an object of governance. The notion of de facto governance as unacknowledged and unrecognized steering is less helpful as it eschews the purposive nature of governance (Horton and Koremenos 2020).[23] Though its intellectual originator suggested that engagement could be one source of de facto governance (Rip 2010), as we demonstrate below, the engagement practices initiated in our cases are explicitly aimed at informing and shaping solar geoengineering research to accomplish public goals and so cannot be said to be either unacknowledged or unrecognized.

However, Gupta and Möller's (2019) analysis of the governance effects of authoritative assessments are useful for demonstrating how early forms of governance shape and steer solar geoengineering research and discussion. Specifically, the authors show how authoritative assessments order the field of inquiry through acts of demarcation and categorization. Gupta and Möller (2019) identify two sequential components of ordering: "normalization and institutionalization of research and

[23] Gupta and Möller understand de facto governance as "sources of governance that are *unacknowledged* and *unrecognized* as seeking to govern, even as they exercise governance effects. Understood as such, de facto governance is distinct both from formal, state-led, legally binding de jure forms of steering, as well as informal, non-state sources of steering, which share the characteristic of intentionally seeking to steer the behavior of certain actors or institutions, in order to realize specific, openly stated goals." (2010, p. 481, emphasis original).

governance directions, with establishment of research programs, delineation of research communities, creation of funding streams and a shift in the nature and direction of the governance conversation serving as indicators through which to ascertain such ordering effects." (p. 484). The authors demonstrate that overall, the demarcation and categorization of the field "play an important role in constructing CE as an object of governance" (Gupta and Möller 2019, p. 497).

Building off this literature, we use the concept of governance by engagement to highlight the idea that when actors regarded as authoritative initiate engagement practices to accomplish public aims, these practices can generate important governance effects. We therefore conceptualize ***governance by engagement*** as referring to *practices initiated by authoritative actors that invite members of a participant audience to participate in structured activities focused around learning, discussing, researching, or making decisions as a way to influence or steer a target audience's behavior, or otherwise shape research or decision-making towards public goals.*

We see a particular need to draw greater attention to this issue within political science and global governance analyses of emerging technologies, where uncertainties and stakes are high, the expected scope of impact is large if not global, expert views are divided, and broader societal awareness is low, as research and discussion are restricted to a narrow range of views, perspectives, and groups of people. In such cases, we argue a crucial governance intervention is to expand awareness, discussion, and knowledge of emerging governance objects. By governance object, we mean "entities or practices that have been constituted as self-constained units distinct from other

objects, events, and actors" (Allan 2017, p. 136), or in short, the thing that is to be governed. Examples include the climate, trade, human rights, warfare, nuclear weapons, the economy, and of course, solar geoengineering and its research.

Governance interventions of engagement: perspectives elicitation and capacity building models

Having set out what governance by engagement is, we now turn towards a discussion of how it works. Following Gupta and Möller (2019), we suggest the interventions of an act of governance are discernable from its effects. We expect that governance by engagement is likely to be central to overall governance efforts when knowledge and discussion of a governance object that is seen as having high stakes and a large scope of impact is initially limited to a narrow range of actors and perspectives.

Crucially, governance by engagement begins with awareness on behalf of an initiating authoritative actor of a governance challenge that can be addressed in whole or part through engagement. Specifically, the practice is initiated on behalf of actors recognized as authoritative when they believe that a salient problem of public concern can be addressed, at least in part, by inviting previously uninvolved groups or actors to engage in various activities related to learning about and contributing to discussion or research surrounding the object or issue of concern.[24] Therefore, governance by engagement emerges as a response to a particular governance challenge.

[24] We take it for granted that in governance by engagement, the initiating actor, or governor, is regarded by others as authoritative at the outset of the engagement process. However, we expect that the legitimacy of the governor may be "obtained, maintained, contested, and withdrawn" (Bäckstrand

In such instances, a crucial intervention early in the governance process, even before the governance object is fully stabilized or constituted (Allan 2017; Gupta and Möller 2018), is a deliberate attempt to expand awareness and consideration of the governance object to broader audiences. This occurs by inviting targeted groups of actors to participate in activities that facilitate social interaction and learning surrounding the governance object, thereby promoting broader awareness and catalyzing the formation of opinions, preferences, and interests with respect to the object of governance. This requires a process of translation of emerging governance objects described by Bentley Allan, as "a process by which the object is transformed into an entity that can be transferred from the laboratory, analytical context, or social situation from which it emerged to a variety of global political contexts", which requires that the object "must be rendered legible to states and publics" (2017, p. 137). Governance by engagement is therefore likely to contribute to processes of object constitution (Allan 2017), issue emergence (Carpenter 2007; Hadden 2015), and agenda setting (Hafner-Burton and Pollack 2002).

We suggest that what comes next then depends on which of three models of governance by engagement is practiced. In the *perspectives elicitation model* of governance by engagement, the formation of informed perspectives is followed by elicitation and dissemination of knowledge of what or how people think about the object, often with the aim to inform research, decision-making, or discussion. This is

and Söderbaum 2018, p. 103) throughout the processes of engagement, and (de)legitimation may be one outcome.

the model of governance by engagement that best reflects the use of invited engagement in a broad range of emerging technology issue areas. Here, the mode of engagement is oriented towards the formation and dissemination of informed perspectives (see Dove et al. 2024b for an analysis of the literature on solar geoengineering perspectives).

In the *capacity building model* of governance by engagement, following the initial formation of informed perspectives, participants are invited to participate in a longer-term process of capacity building, based around structured activities such as a research program. Here, the mode of engagement is oriented towards cultivating capacity, such as expertise, and then leveraging it to accomplish governance aims, such as informing decision-making or reducing unequal power relations surrounding an object of governance. In cases where the development of a community of experts is the goal, this model of governance by engagement operates by forming an epistemic community that informs and shapes state behavior and decision-making surrounding a governance object (Hass 1992).

We expect that other models of governance by engagement beyond what is reflected in our empirical cases are possible. Specifically, we expect a third model of governance by engagement is possible that is purely instrumentally motivated to secure public approval or mitigate opposition to predetermined directions of technology development or decision-making. This *legitimation* model of governance by engagement will likely operate, again, through a set of interventions that are both similar and distinct to the perspectives elicitation and capacity building models. The legitimation model reflects forms of engagement that are sometimes understood and

critiqued as perfunctory, symbolic, 'box-ticking' exercises more akin to public relations exercises, rather than genuine attempts to understand participant views or to empower informed participation in research or decision-making. We therefore expect that persuasion or even manipulation are central interventions in this model of governance by engagement.

Though some instrumental aims and effects are present in our empirical cases (and may always be present in engagement practices to some degree), as we show in our empirical section, the legitimation model does not accurately reflect either of our empirical cases, and their interventions are better captured by the other models of governance by engagement elaborated here.

We suggest that each model of governance by engagement operates through several forms of interventions, initiated and facilitated by authoritative actors, from which specific governance effects are generated. When initiated by authoritative actors and justified with reference to public aims or the common good, these interventions can amount to acts of governance that influence, steer, or shape research or governance trajectories.

Specifically, in the perspectives elicitation model, governance by engagement functions through interventions of invitation, education, deliberation, elicitation, dissemination, and integration. In the capacity building model, governance by engagement functions through the interventions of invitation, education, capacitation, facilitation, integration, and reciprocation. More detailed explanations of each model

of governance by engagement and its component interventions are elaborated in **Tables 1.2 and 1.3** below.

Table 1.2: Perspectives elicitation model of governance by engagement

Intervention / Phase	**Description**
Invitation	An authoritative actor invites a defined collective of persons to participate in structured activities surrounding an object of governance or issue of concern.
Education	Having accepted the invitation to participate, engagement facilitators present participants with information about the object of governance and/or participants engage in research to learn more about the object of governance. Participants begin to generate an understanding of what the object of governance is and form opinions and perspectives.
Deliberation	Having developed an initial understanding of the object of governance, facilitators initiate discussion amongst participants (and possibly others, including experts) on the object of governance in general or on specific aspects or issues. This social interaction can generate a more nuanced understanding of the object of governance and catalyzes the formation of opinions, perspectives, and interests with respect to the object of governance. Note: Deliberation may not always occur where engagements do not include a component of social interaction, such as when surveys or interviews are used as a method of engagement.
Elicitation	Having begun to form perspectives and opinions on the object of governance, elicitation techniques are used to collect, document, record, and analyze participants' perspectives on the object of

	governance. This may be done by engagement facilitators and/or the participants themselves to varying degrees.
Dissemination	Having elicited participant perspectives, engagement facilitators and/or participants present knowledge that describes, summarizes, and/or analyzes participant perspectives in a format that can be disseminated to targeted recipients, often in the form of written reports or studies, and including recommendations. The information is disseminated or presented to recipients. Note: the process of 'closure', or synthesizing participant perspectives and packaging it into summaries, decisions, or recommendations, is more complex than described here and may be subject to power dynamics (Delgado et al. 2011). More detailed investigations of governance by engagement should explore the politics involved in the process of closure.
Integration	Having received information regarding participants' perspectives, recipients may, but do not always, act on the information, including by considering the information in decision-making processes, using the information to chart new directions for research, informing discussions or communication strategies, designing future engagement activities, and more.

Table 1.3: Capacity building model of governance by engagement

Intervention / Phase	**Description**
Invitation	An authoritative actor invites a defined collective of persons to participate in structured activities surrounding an object of governance or issue of concern.
Education	Having accepted the invitation to participate, engagement facilitators present participants with information about the object of governance and/or participants engage in research to learn more about the object of governance. Participants begin to generate an

	understanding of what the object of governance is and form opinions and perspectives.
Capacitation	Having developed an initial understanding of the object of governance, initiators initiate an extended program of capacity building surrounding an object of governance involving participants. The program occurs on a longer time scale and can include combinations of activities, strategies, practices, and techniques aimed at building a specific set of capacities. Participants build a deeper understanding of the object of governance and can claim forms of authority that follow from expertise, credibility, or problem solving ability.
Facilitation	Having developed specialized capacity to assess, research, or govern the object of governance, authoritative initiators facilitate the formation of connections and the building of relationships between participants and recipients, who are often but not always policy-makers. Note: connections are not always facilitated by authoritative initiators. Participants can make these connections on their own, including without the initiator's knowledge. However, the strategic and purposeful efforts to facilitate connections between participants and others is central to this model of capacity building.
Integration	Having formed connections with recipients, participants leverage their capacity to inform and participate in decision-making or research and assessment processes. Initiators also support participants entering into positions of international leadership, enabling them to secure international exposure. Facilitators provide various forms of support to enable successful integration. Participants leverage their authority to maximize their impact and influence.

Reciprocation	Sometimes, participants initiate new engagement practices surrounding the object of governance by inviting groups of people to engage in structured learning and discussion activities. In effect, the participants now become the initiators of governance by engagement. This may result in a cascading effect that expands awareness and discussion beyond the original group of participants through a succession of engagement practices.

Additionally, we recognize that our governance by engagement models were developed based on forms of engagement that were initiated in the United Kingdom context, and so we leave open the possibility that governance by engagement may look different in different parts of the world, including by operating through different models altogether. It is to be expected that the aims, interventions, and effects of governance by engagement may vary in different political cultures, particularly given a diversity of perspectives on the role of the citizen in relation to political and scientific decision-making (Carr et al. 2013). Empirical investigation of governance by engagement in different countries, and particularly the Global South, should be used to refine or adapt the governance by engagement concept.

Analyzing the governance effects of engagement

Our study builds on earlier work on public engagement in science and technology to focus attention on the possible governance effects of engagement practices. Here we distill possible governance effects of engagement from commonly articulated rationales for public engagement in science, technology, and environmental issue areas.

Specifically, we posit that a well-known categorization of motivations and rationales for engaging publics and other actors in environmental, scientific, and technological issues can be used to identify and categorize possible governance effects. Reintroduced by Stirling (2008), Fiorino's (1990) categorization of instrumental, substantive, and normative motivations and rationales is commonly cited and discussed to describe why engagement is or should be practiced. In the solar geoengineering issue area, we build on previous work that used these rationales to describe how "public engagement processes can contribute to SRM research and governance" (Carr et al. 2013, p. 568). We posit that these rationales for engagement are linked to the governance effects that may follow engagement. We briefly describe each category of engagement rationales below. To enable comparative analysis, we then develop a typology of categories of effects expected from governance by engagement.

Normative effects

Briefly, the *normative* rationale is that engagement is the right thing to do on decisions that might impact people's lives. The rationale is often articulated in reference to the morally necessary pursuit of important and widely shared social principles and values related to democracy, justice, fairness, and equity. In the solar geoengineering issue area, the normative rationale is often premised on the large scale and scope of solar geoengineering deployment, the uncertainty and likely unevenness of its impacts, and its potential to reinforce (or ameliorate) existing climate injustices (e.g., Carr et al., 2013; Hourdequin 2019). For example, Carr et al. argue that to avoid compounding the

injustices of climate change, "diverse populations whose lives, livelihoods, and societies could be significantly impacted by SRM should have the opportunity to be informed about the various technologies being proposed and how they might be affected" and "these same populations should be afforded the opportunity to deliberate about, consent to, and agree to bear any possible harms of both field testing and possible deployment" (Carr et al. 2013, p. 570). We assert that these are clear normatively framed public goals and aims that are indicative of a governance aim and possible effects, specifically surrounding the empowerment of vulnerable or affected actors.

Substantive effects

The *substantive* rationale is premised on the idea that experts, and particularly those from a homogenous community, do not hold a monopoly on relevant and useful information and knowledge and therefore 'opening up' research and decision-making processes to broader values and perspectives will produce more robust research and decision-making outcomes (Stirling 2008; Owen 2014). In short, the substantive rationale is that the process of engagement will lead to *better* research and decisions, and can occur in multiple ways, including by scrutinizing pre-existing assumptions or framings, integrating diverse forms of knowledge or information, enhancing anticipation capacities, or by identifying new research directions or governance questions (Stirling 2008; Carr et al. 2013; Owen 2014; Macnaghten and Syzerszynski 2013). As explained by Carr et al., engagement "can help society to decide whether SRM *should* go ahead, but also help define the proper goals and boundaries of that

leverage if it *does"* (2013, p. 572). Through its aim to steer the trajectory of research and governance in directions that are intended to be more socially robust, we assert that this rationale also constitutes a clear public goal that is indicative of governance aims and possible effects related to informing research and decision-making.

Instrumental effects

The *instrumental* rationale is that engagement is a tool that can be used to achieve a broad array of predetermined outcomes, often related to establishing trust in scientists or decision-makers, achieving social-license or increasing public acceptance, minimizing or managing social controversy or dissent, and legitimating certain directions of technology development or decision-making (Stirling 2008). The instrumental rationale is often discussed pejoratively by public engagement experts as an inappropriate or problematic motivation akin to public relations or a performative box ticking exercise, though it is acknowledged that this is in fact what motivates some engagements, depending on who initiates. Others have argued that some instrumental motivations may be desirable, noting that some arguments for public engagement "focus more on the positive indirect effects of greater openness and transparency about science and technology, including increased trust in public institutions, to the extent that those institutions are genuinely willing to open up their assumptions and self-conceptions to challenge and reformulation" (Carr et al. 2013, p. 570, citing Wynne 2006).

Global governance scholars have also shed light on a tight link between engagement and legitimation. For example, work on the (de)legitimation practices and strategies of international organizations and other agents shows one institutional practice entities use to enhance their legitimacy is to promote and broaden the participation of civil society actors and others in policy processes through for example consultative forums, multi-stakeholder advisory boards, and invitation to be included in board and committee memberships (Bäckstrand and Söderbaum 2018; Scholte 2011; Tallberg et al. 2013). Some research shows such attempts are superficial and the expansion of participation is limited in its scope of influence (e.g, Uhlin 2016). Nevertheless, to the extent that effective governance rests on broad recognition of its legitimacy particularly on the global level (Tallberg and Zürn 2019; Hurd 1999), attempts to initiate engagement practices to enhance the legitimacy of a governor are likely to be central to enabling governance (Zürn 2018). More broadly, enhancing legitimacy of decision-makers and scientists, promoting public awareness and debate, building trust in science and public institutions, and enabling response research to proceed can all evoke the common good and therefore indicates clear governance aims and associated possible effects.[25]

Productive effects

[25] As a reminder, just because an actor justifies its activities with reference to a greater public or common good does not mean from a normative or substantive perspective that such activities are in fact 'good'. Actors can contest what this means.

We added a fourth type of governance effect to capture the productive effects of constructing publics and scientific communities through the process of invited engagement (Irwin 2001; Bellamy and Lezaun 2017). Scholars of public engagement with science have recognized that engagement can shape and construct both the object of engagement as well as its participants (e.g., Irwin 2001; Delgado et al. 2011). Bellamy and Lezaun (2017) note that "public deliberation could play an outsize role, most significantly by 'normalizing' geoengineering as both a matter of public debate and a suitable beneficiary of state support" (Bellamy and Lezaun 2017, p. 411). Specifically in instances of 'upstream' engagement where public awareness is low and the objects of engagement are neither realized technologies nor concrete policy options, "public dialogue could play here not merely a legitimizing role, but a performative one as well" (Bellamy and Lezaun 2017, p. 411-412). Bellamy and Lezaun (2017) suggest the normalizing effect goes hand in hand with a performative effect, in terms of constructing publics "able to reflect on the matter in question" (p. 414). The authors explain that the field of public engagement with science, practiced by "highly reflexive practitioners of this art of public-making", is most impactful when it recognizes itself as providing a "mode of intervention that is *expected to stabilize both the object and the subject of engagement*" (Bellamy and Lezaun 2017, p. 414, emphasis added). We suggest that the construction of actors as particular social beings is an overlooked but potentially important governance effect because it produces agents with particular identities and interests, thereby shaping how they understand themselves and what they want with respect to the governance object.

Analyzing governance effects

To sum up, in analyzing the effects of governance by engagement, we distinguish between normative, substantive, instrumental, and productive effects, and analyze whether governance by engagement empowers, informs, legitimates, and constructs actors in particular ways.

Just as a diverse array of motivations and rationales underpin engagement (Delgado et al. 2011), the effects of governance by engagement are also diverse. We build off the previously articulated engagement rationales to develop a non-exhaustive typology of four categories of possible governance effects expected from governance by engagement, displayed in **Table 1.4.** We expect, and find empirically, that the overlapping but distinct set of interventions embedded within each model of governance by engagement generates a similarly overlapping but distinct set of governance effects. Overall, and as we illustrate in the next section, governance by engagement can shape, and can be shaped by, the agents that interact to research and govern an object as well as the normative and institutional context in which the governance object is discussed, researched, and ultimately governed more formally.

Table 1.4: Typology of potential governance effects of engagement

Type	**Effect of Governance by Engagement**
Instrumental	Normalize solar geoengineering, research
	Enhance legitimacy

	Promote awareness, stimulate discussion
	Set agenda
	Combat misinformation
	Shape understanding, support
	Build trust
Substantive	Shape research questions, directions
	Inform decision-making, research
	Anticipate futures
	Initiate social learning
	Enhance understanding of impacts
Normative	Empower actors
	Democratize research, decision-making
	Promote justice
	Level playing field
	Institutionalize inclusion
Productive	Form opinions and preferences
	Construct identities, interests
	Facilitate socialization
	Build, expand, diversify community, networks

We do not claim that our typology of effects of governance by engagement is exhaustive to the extent it covers all possible functions of governance by engagement. We think it is comprehensive enough to be immediately useful for analysis, however more empirical work is needed to be confident it is exhaustive of all possible governance functions. Additionally, as public engagement scholars have noted, the motivations driving engagement, and therefore by extension the types of governance effects of engagement are not mutually exclusive (Delgado et al. 2011). Some

motivations arguably fall into multiple categories. For example, as Delgado et al. (2011) note, the motivation to engage publics to create "capacities for social empowerment" (Stirling 2008, p. 269) aims to achieve the end of social empowerment (instrumental); would produce better decision-making by enabling informed participation (substantive) and also stems from a normative commitment to democracy and related ideals (normative). We add it is also productive in that it constructs particular publics as empowered and capable agents. Overall, we think the typology is comprehensive and disaggregated enough to provide a framework useful for future research spanning specific actors, cases, and contexts.

Governing solar geoengineering research by engagement: The SPICE Deliberative Public Workshops and The Degrees Initiative

We now turn to our analysis of governance by engagement in two cases in the solar geoengineering issue area. For each case, we highlight how authoritative actors purposely invite a targeted selection of actors to participate in structured engagement activities in order to achieve public goals and in the context of a governance challenge. We then draw on our typology of governance by engagement functions to identify the effects that are most likely to be consequential for governance, demonstrating how the engagement practices in each case enhance and expand capacities needed to govern solar geoengineering, thereby potentially enabling informed more informed and inclusive decision-making surrounding whether and how to research, develop, and deploy solar geoengineering.

In focusing on the most important interventions and effects, our goal is to be illustrative not exhaustive. We do not claim that the interventions in each case of governance by engagement generate all possible types of governance effects. In both cases we provide evidence that, in our view, shows some types of governance effects were likely generated following the engagement interventions. We also show that the engagement interventions in our cases are sometimes *intended* to achieve certain governance effects, which is the purposive element needed to establish these activities as acts of governance. As a reminder, according to the transnational climate governance framework, "[t]o be considered a form of transnational governance, … networks must seek to address some form of public goal (though they may not accomplish it)" (Andonova et al. 2009, p. 56).

The Perspectives Elicitation Model of Governance by Engagement: The SPICE Deliberative Public Workshops

Catalyzed by the Royal Society report's recommendation to fund an SRM research program, multiple UK Research Councils hosted a workshop in October 2009 to scope a geoengineering research program "which will allow the UK to make informed and intelligent assessments about the development of climate geoengineering technologies" (EPSRC–NERC–LWEC 2009, cited in Stilgoe 2015). This was followed by a research 'sandpit' under the leadership of the Engineering and Physical Sciences Research

Council (EPSRC) in March 2010 (Owen 2014; Stilgoe 2015).[26] Two research projects were funded out of the sandpit. One was a desk-based project aiming to develop an integrated assessment framework for geoengineering technologies, called the Integrated Assessment for Geoengineering Proposals (IAGP). The other project funded was the SPICE project, which included an outdoor engineering field test of a scaled down tethered balloon and hose delivery system, which would have pumped a small amount of water through a hose and out of a tethered balloon 1km in the air to test the dynamics and behavior of the tethered balloon (called the 'testbed') (Stilgoe 2015; Kuo et al. 2020).[27] In recognition of the wider societal significance of an outdoor experiment related to solar geoengineering and the additional scrutiny that was warranted, it was suggested that a 'stage gate' process should govern the outdoor experiment, in which the research team would need to progress through several decision 'gates' in order receive funds for the testbed (Stilgoe 2015; Owen 2014; Macnaghten and Owen 2011).

At the same time, several social scientists (Phil Macnaghten, Richard Owen, and Jack Stilgoe) were working for the UK Research Councils on a separate project to develop a framework for governing science and technology in responsible ways (Stilgoe et al. 2013b; Owen 2014). These social scientists were asked to use their framework to develop the criteria for the stage gates, and which would be used to

[26] According to Owen (2014), sandpits are an innovative funding approach in which participants (e.g. scientists) are encouraged to work across institutions and disciplines to develop novel project ideas over an intensive couple of days with help from mentors, and using an iterative process of real time peer review, with the intention of funding one or more projects by the end of the process" (p. 232).
[27] See SPICE. "Delivery Systems". Available at: http://www.spice.ac.uk/project/delivery-systems/ Accessed June 10, 2025

support a decision that the testbed can go ahead or not (Stilgoe et al. 2013b; Owen 2014). The decision would ultimately be made by EPSRC, the lead funder, based on a recommendation from an independent stage gate panel consisting of several academics (natural and social sciences) and an NGO representative (Owen 2014). Of the five criteria the SPICE research team would need to address in order to proceed, and reflecting the inclusive deliberation dimension of the framework for responsible innovation (Stilgoe et al. 2013b), the fifth criterion addressed engagement. This criterion required that "[m]echanisms have been identified to understand wider public and stakeholder views regarding [the] predicted applications and impacts" of the testbed (Macnaghten and Owen 2011).

The governance challenge: Previous mistakes, democracy deficit, epistemic uncertainty

Indications that the testbed portion of the SPICE project could potentially prove controversial began to emerge at the sandpit (Stilgoe 2015; Owen 2014). Interview participants describe how several overlapping concerns related to avoiding previous mistakes related to public engagement with science, correcting a democracy deficit, and reducing epistemic uncertainty, warranted caution in decision-making surrounding the testbed, ultimately driving the decision to use the responsible innovation framework to govern the experiment, including engagement as a central component.

One social scientist, who was serving on the EPSRC's Societal Issues Panel, which was asked to comment on the newly funded SPICE project, described the advisory panel's deliberations as follows:

> "[W]e very quickly came to the view that there were lots of, you know, quite substantive issues which could be of strategic importance to the research council, which we did not believe had been properly and adequately set out. So we therefore thought, well, this actually posed a risk to the research council, because what was being done was the first kind of field trial of its kind. It was a test bed of a geoengineering technology, the first that had been developed through public funding. This was quite an important sort of sociopolitical event, and it was one that needed to be thought through quite carefully."

This awareness was also quickly developed within the SPICE research team, though it was not present initially. One scientist explains that early on,

> "The EPSRC particularly were very interested because what they wanted to do was to fly a plane here to take photographs of what we were doing so that they would have something that could be put on press releases. This is before the days where anybody thought that this was ever going to be an issue. You know, pretty soon we realized that this technology, this whole idea was a bit more - we had to go through this space a bit more carefully."

A member of the stage gate panel described a primary concern of uncertainty stemming from the uncertainty that arose from the novelty of solar geoengineering and the lack of previous experience in governing this kind of research:

> "[N]obody kind of knew what the stakes were around conducting a project such as this one. It was completely unknown. And it was a sort of "unknown unknown" because we didn't know how to think about it. But what we did know was that the modes in which projects were governed principally, by concepts of informed consent or a narrow view

> of ethics or through risk assessments, were not insufficient in and of themselves."

One of the key sources of uncertainty related to how the public would react to the testbed and to the idea of geoengineering more broadly. The United Kingdom had recently undergone a tumultuous experience with public engagement on genetically modified organisms (GMOs) surrounding a public dialogue called GM Nation, which was marred by widespread protest and controversy (Owen 2014). Another social scientist suggested the research council's impetus for implementing the stage gate process was to avoid repeating this controversy for geoengineering, which required knowing how publics were likely to view the test bed:

> "I suspect one of the main reasons for [the stage gate] was [the research councils] knew, as I said, that this was going to be potentially an area that could be quite contested by the public. And we had had GM before this in the late 90s. So, they were probably a bit concerned about the fact that there was going to be a field trial, and they wanted to ensure that they weren't just walking into this without understanding what was going to happen in terms of the public views and so on."

The social scientist further explained the need to avoid repeating the GM experience and emphasized the central role engagement would play in that:

> "The whole point of this was to try to take a measured, responsible approach to this before it was too locked in, before it was too polarized. That's what happened with GM, which left talking with the public to too late. It had become really polarized and there were massive protests and scenes which cast shadows even now in Europe with GM. I think that there was this feeling, we could do a lot better than that. We can do this right. We can take a responsible innovation approach … and engagement was central to that."

However, the motivations for establishing the stage gate panel, and commissioning the public engagement in particular, reflected a wider set of rationales, including not only instrumental but also normative and substantive. One stage gate panel member also highlighted clear substantive motives for initiating the stage gate process and downplayed instrumental motives:

> "[W]e did see not so much a potential proximate public concern [driving the stage gate process], but rather that there could be a significant sort of sociopolitical importance associated with the research. And of course, if we didn't get that right, then that could potentially lead to public protest. But we weren't worried about managing protest. We were much more worried about, well, what was this? What were the social and ethical aspects associated with this research? And what would it mean to do this responsibly?"

Sometimes instrumental motivations were blended into substantive ones, for example, to explain that engagement is needed to improve decision-making to avoid repeating past mistakes. For example, a social scientist explained that

> "The main rationale for the SPICE project engagement in geoengineering was that we wanted to have more robust, socially robust decision making that took into account the views of different publics in terms of that work … But the key reason was that this was an area of huge uncertainty, hugely potentially contested. We've made some big mistakes with not engaging properly with the public in the past and then making decisions which were pretty poor. So, this time it was about getting that right. So the SPICE project embedded an [responsible innovation] approach in which there were several stage gate criteria for this test bed or field trial, a central one of which was engagement with the public to understand what they thought about both the research and deployment"

One researcher involved in the public deliberative workshops acknowledged an instrumental motivation but explicitly aimed to move beyond it:

> "... there was an instrumental part of it. We needed to know what people think about this testbed idea. But I didn't want that to be the only thing. I wanted to understand what people even think about this notion of climate engineering … So I wanted to hear from different people from different backgrounds what their thoughts were about this thing… So that was my goal was to sort of understand what people think about this thing."

However, one stage gate panel member did think the EPSRC was primarily instrumentally motivated in requesting public engagement work and was not interested in any substantive benefits:

> "I mean, I guess I'd have to say that they were primarily interested in the sort of instrumental legitimacy of the decision reasoning. I didn't get a sense that they anticipated any different forms of knowledge that would be of relevance but then yeah, they probably would have had a nod towards the normative - Yeah, these are people living in the area. I think in both the instrumental and the normative, the idea that it should be localized to where the trial was being proposed then makes sense in understanding it in those terms."

A social scientist also suggested a normative motivation for the engagement work relating to democratizing decision-making in response to a democracy deficit:

> "But when we come down to things like the SPICE Project, which was a case in point, there was no kind of major political agenda or a manifesto - "we're going to do climate engineering" - which was voted on by the populace who voted in whatever the government was at the time… In fact, I seem to remember very few people made that decision to fund that piece of research to make that case … that decision to do that sand pit was done by a few people in EPSRC, perhaps with some advice… But the point is, these processes are not democratically robust

> anyway at that level. So the idea is that we have to sort of support that by going directly to the public at a more micro level."

Governance intervention: Disseminating elicited perspectives to the stage gate panel

To fulfill the part of the fifth stage gate criteria which required understanding broader public views surrounding the testbed and its future applications, the EPSRC asked public engagement experts in IAGP to complete public deliberative work on the SPICE testbed (Parkhill and Pidgeon 2011). EPSRC funded this extra 'work package', on recognition that the SPICE team had neither the funding nor expertise to conduct such work (Pigeon et al. 2013; Stilgoe 2015). After a process of developing and pilot testing a deliberative workshop format, public engagement experts on IAGP completed three 1.5-day deliberative workshops in three UK cities with 8-12 participants each (32 total). In addition to two IAGP social scientist facilitators, a scientist from IAGP was present and a member of the SPICE research team was present for parts of each workshop to answer questions about the testbed. The goals of the workshops included giving "an overview of the likely varied and nuanced perspectives of the members of the general public and report" to the stage gate panel, thereby providing "one piece of evidence that [the stage gate panel] might deem useful when completing their stage gate evaluation" (Parkhill and Pidgeon 2011, p. 6).

Illustrating the *invitation* intervention of the perspectives elicitation model of governance by engagement, participants were recruited from a professional recruitment agency and sampled for socioeconomic representativeness across categories of gender,

age, socio-economic status, educational level, ethnicity and location to capture a diverse range of viewpoints (Parkhill and Pidgeon 2011). The format of the workshops "combined a mixture of presentations from the facilitators and experts, whole group discussions, world café style small group discussions and individual written responses" (Parkhill and Pidgeon 2011, p. 7).[28] Pidgeon et al. (2013) provide a summary of the workshop format which is worth providing in full as it clearly illustrates the *education*, *deliberation*, and *elicitation* interventions of the perspectives model of governance by engagement:

> "Day 1 began with facilitated discussion about climate change, followed by a World Café style discussion about potential societal responses to climate change (mitigation, adaptation and geoengineering), and then introduction to four geoengineering approaches by a geoengineering expert (N.V.): biochar, air capture, cloud whitening and stratospheric aerosols … This was followed by a further World Café including social and ethical prompts on SRM and CDR. These four examples were selected to give a snapshot of the range of most plausible geoengineering approaches and were repeatedly described as being just that, and not an exhaustive list. Following advice from the IAGP independent advisory panel, examples were given of research currently taking place, including the full-scale 20-km pipe proposal for SRM, but without mentioning the SPICE project explicitly at that point. Day 2 began with discussion of the homework task (to describe to a friend or relative what people had learned from day 1), a brief overview of the SPICE test bed, the RCUK Stagegate process, and the reason why the workshops were being held. Participants then developed together a series of questions that they wished to see answered about SPICE. We viewed this question generation as the most important activity of the whole workshop, in that it elicited, in all three workshops, a very wide

[28] See Parkhill and Pidgeon (2011) and Pidgeon et al. (2013) for methodological details on how the workshops were designed and facilitated as well as results.

> range of responses to the proposed field trial, ranging from the very practical to the philosophical. This was followed by the opportunity to question a member of the SPICE research team from the Cambridge Engineering Department about any of these, ending with final parallel small group discussions about SPICE and a wrap-up plenary." (Pidgeon et al. 2013, p. 455-466)

Illustrating the *dissemination* intervention in the perspectives elicitation governance by engagement model, preliminary results of the workshops were presented to the stage gate panel in June 2011 when the panel convened to recommend whether EPSRC should allow the testbed to proceed (Pidgeon et al. 2013; Parkhill and Pidgeon 2011). The preliminary results were presented in a written report (Parkhill and Pidgeon 2011) that included detailed information on workshop background and methodology. One section presented preliminary results of the workshops organized by theme, including perceptions and participant questions related to: solar geoengineering and SAI; SPICE test bed methodology and justification; test bed safety and impact; limitations of the knowledge obtained by the test bed; governance and communication of solar geoengineering and the test bed; and apathy and affect surrounding local consultations.

A concluding section provides a set of recommendations for the research councils and for the SPICE team. For example, the report discussed that participants expressed:

> "a desire that Research Councils themselves should make transparent their strategy for funding and supporting geoengineering research. Specifically regarding the test-bed, RCUK should clarify their objectives and reasons for funding such a project emphasising how this fits within their strategy for supporting research more widely and

> specifically that connected to responses to climate change." (Parkhill and Pidgeon 2011, p. 24)

The preliminary results report also urged the SPICE team to

> "operate in a transparent and open manner engaging with those publics living in close proximity to the test-bed site through a variety of means. This includes directly through for example, leaflets and other forms of information provision, and through actively engaging in local democratic processes. Engagement should be ongoing with the objectives for engagement being clear (e.g. is the goal information provision and/or consultation)." (Parkhill and Pidgeon 2011, p. 25).

Alongside the preliminary workshop results report, the SPICE team also submitted documentation of their efforts to address the other stage gate criteria.

At that meeting, the panel decided that two of the criteria that related to safety, risk management, and regulatory compliance were passed, however three were 'passed pending', meaning, in the words of one member of the stage gate panel, "we didn't say we could see no possibility of these dimensions not being met but we did say that these certainly had not been met insofar as they had been set out."[29] Specifically as related to the fifth criteria about engagement, the panel considered the public engagement component to be passed due to the public deliberative work that had been done (Pidgeon et al. 2013) but further requested the team to conduct a more robust stakeholder engagement process, which social scientist Jack Stilgoe was brought on to lead (see Stilgoe 2015).

[29] Another stage-gate panel member put it more bluntly: "there was quite a lengthy debate about the phraseology that we could or would use. And you may find this strange term - pass pending. Pass pending, which to be blunt meant failed. Which meant, at that point, 'this is not adequate, go away, do more work' as you said."

One stage gate panel member said they got the sense that that the research councils were pushing for the stage gate panel to recommend the test bed could proceed:[30]

> "The research councils, and this is where I sort of stray towards the thinking it was pretty instrumental for them - they were very keen to nudge - possibly even I would say push us to say, 'yeah this is okay, go ahead. We've covered our' - they didn't say this, but you know the tone was very, 'we've covered our asses, we've got the paper trail. This is now fine, we'll release the funding.'"

Overall, the stage gate panel asked the team to "develop a revised communications plan to inform further public debate, a review of the risks and uncertainties of solar-radiation management — including social, ethical, legal and political dimensions — and a thorough process of engagement with stakeholders" (Macnaghten and Owen 2011, p. 293). The June stage gate panel meeting was the only time the panel met to form an advisory decision about whether the test bed should proceed, as the test bed was subsequently cancelled, discussed more below.

Governance effects: Informing decision-making and raising new governance questions

Here we analyze the governance effects of the SPICE public deliberative workshops as a case of the perspectives elicitation model of governance by engagement. Looking back to our typology of categories of effects expected from governance by engagement, we focus primarily on substantive effects, as related to informing decision-making to

[30] Multiple other participants disagreed, believing adamantly that the Research Councils were not engaging in "greenwashing" or "box ticking", and that the stage gate process was not "just a piece of PR" and the public deliberative workshops were not "lip service".

enable more robust governance. Specifically, we focus on whether and to what extent the disseminated results of the public deliberative workshops were integrated into the stage gate and EPSRC's decision-making process, as well as how they shaped the SPICE team's internal decision-making, from which the decision to cancel the testbed was ultimately made. Below, we also consider whether and how the SPICE deliberative workshops had any broader impact on the trajectory of solar geoengineering research and governance.

Our interviews provide some evidence to suggest the public deliberative workshops influenced the stage panel's decision-making and were also taken seriously by the scientists on the SPICE team, changing how they interacted with the local community near the experiment site. One member of IAGP that presented the workshop results to the SPICE stage gate panel at the June meeting thought the recommendations to the SPICE team were taken up with sincerity:

> "When we were at the stage gate meeting, they did reflect on the evidence we presented and made recommendations to the SPICE team based on that. So, I think, you know, one of the things that had come up was about publics being informed about what was happening in the local area. So I think they asked the SPICE team to think about like a media briefing - not just the national media, but also for more local ... And by media, I think they meant broader than just the sort of news media. So it definitely felt like it was listened to and taken on board by most of the people."

Scientists from the SPICE project team confirmed that they did conduct public engagement in the local community surrounding the test bed, including by going door

to door to talk to people and hand out informational flyers. One SPICE member explained that

> "Hugh and Kirsty, who are the two engineers that talked to people, they went on local radio in Cambridge and in Norfolk. But they also talked to loads of people that lived around the testbed site."

Interview participants agreed the workshops were of sufficient quality to inform decision-making, though some suggested that because the results were presented to the stage gate panel as preliminary, they were taken with a grain of salt. According to one social scientist intimately involved in the process:

> "As it turned out, Nick did a really very good job about understanding how publics feel, at least in the UK, felt enough to be able to inform people like Matt and the EPSRC about how people feel about deployment. And there were some very strong reservations, how the public felt about deployment. They were okay with the research but once they could envisage this kind of what would happen with deployment then they kind of reflected back and said, actually, do we want that research at all - that leads to [deployment]?"

Indicative of the influence on the stage gate panel decision-making, one member of the stage gate panel reflected that the panel felt the public concerns indicated in the preliminary report did not warrant a greenlight to proceed with the testbed:

> "So my sense was that there was some reason why we weren't yet prepared to accept that as giving a clean bill of health. I don't think it was just… procedural in the sense of, this isn't completed. But I think there were enough hints in what [IAGP researcher] was saying as preliminary findings to suggest that there are - that there might have been public concerns that then merited further investigation rather than [just] better communication".

Some interview participants drew different conclusions from the workshop results, indicating some possible ambiguity in how recipients integrate elicited perspectives. For example, according to one SPICE scientist,

> "I don't think there was anything other than, "wow, fantastic. Really great, great work." We didn't … we didn't probe. So, I thought the deliberative workshops, they were informative. They told us, I think what we kind of knew. But it was good to hear."

Another scientist in the SPICE project explained that he didn't think the engagement was 'lip-service', but rather they found it very helpful. They moreover suggested that if the public reaction to the testbed was negative, the scientists would have rethought the experiment:

> "I think the scientists wanted to know that people understood what and why they were doing. And I think that if a public response to an honest discussion - and in an unbiased a way as possible - was wholly negative, I think we, at least the team in SPICE would have questioned some of the things - or that we would have done soul searching on that front, I think. So, in some ways [the preliminary results] felt a little bit like a validation."

The SPICE team submitted a revised document in August 2011, and then on September 7th, 2011, the stage gate panel wrote to the EPSRC advising postponement of the test bed to allow more time for stakeholder engagement (Macnaghten and Owen 2011). The following sequence of events gets somewhat complex, as after this a whirlwind of events threw the project and all involved into a situation multiple interview participants described as 'traumatic'.

On September 13th, the SPICE team publicly announced that the test bed would proceed (Macnaghten and Owen 2011), with EPSRC's encouragement, initiating media attention to the project (Stilgoe 2015). On September 23rd, during a a meeting between EPSRC, the SPICE team, and Owen and Macnaghten, the SPICE team informed EPSRC about a patent application related to the balloon delivery system that had been submitted by one of the mentors at the sandpit and including two SPICE researchers (Stilgoe 2015).[31] EPSRC was urged by social scientists in attendance to delay the test bed for six months. Following the meeting, EPSRC announced the postponement of the test bed on September 26th to allow time for more engagement with stakeholders", reflecting "the advice that we have received from our advisory panel following a stage gate" (Owen 2014, p. 242).[32] On EPSRC's decision to postpone the test bed, one stage gate panel member said, "certainly it was fair at that point to phrase it as reflecting the advice we'd given them that there needed to be more considered engagement."

[31] According to Stilgoe (2015), and confirmed by an interview participant, the mentor in question highlighted his previous work with the SPICE researchers during the sandpit and recused himself from key decisions. An interview participant said that the mentor even mentioned the patent on a conflict of interest form submitted prior to the sandpit, and it was unclear if anyone from the research councils knew or followed up on this until they were alerted to the patent in 2011. An internal conflict of interest inquiry conducted by EPSRC eventually found no wrongdoing - however another participant said that, to their knowledge, the inquiry had been "very narrowly framed as well, because I remember talking to the guy who chaired it, and he wasn't aware of a lot of the aspects that I was aware of. So, as far as I could see, the inquiry had been set up to examine whether the internal processes of the research council had been followed."

[32] EPSRC's public updates are no longer available on their website. They are reproduced in the Appendix in Owen (2014).

On the same day, a group of NGOs organized under the Hands Off Mother Earth (HOME) campaign sent a letter to the heads of the research councils and copied to UK government ministers and vice chancellors of the involved universities. The NGOs called for the experiment to be shut down, portraying the SPICE project as a first step towards geoengineering deployment and symbolic of the United Kingdom's commitment to geoengineering, in lieu of mitigation (Stilgoe 2015; Owen 2014).

On April 26, 2012, after discussing with members of the SPICE team, the SPICE project PI Matt Watson met with EPSRC and Richard Owen and made the decision to cancel the test bed (Stilgoe 2015). Watson announced the cancellation of the test bed on May 16, 2012 on his public blog titled "the Reluctant Geoengineer", citing concerns surrounding a lack of governance of solar geoengineering deployment, the patent and intellectual property, and the need for more time to conduct deliberation and stakeholder engagement to explore these issues.[33] A formal stakeholder engagement process was initiated by Stilgoe, comprising 29 qualitative interviews with NGO representatives, scientists, and others, as well as a workshop with 15 NGO representatives and scientists (Stilgoe et al. 2013a).[34] The stakeholder engagement process aimed to "understand a wide range of responses" to the SPICE project and to "learn lessons for the governance of geoengineering research" (Stilgoe et al. 2013a, p.

[33] Matthew Watson. 2012. "Testbed news". The Reluctant Geoengineer. Blog. Available at: https://thereluctantgeoengineer.blogspot.com/2012/05/testbed-news.html Accessed January 15, 2025.
[34] See Stilgoe et al. (2013a) and Stilgoe (2015) for more details on the stakeholder engagement program.

2; see also Stilgoe 2015). The rest of the SPICE project concluded research in March 2015.

The public deliberative workshops likely did not have any direct influence on the final point of decision-making concerning Matt Watson' decision to cancel the testbed. However, it is important to note given the preoccupation with avoiding public controversy and past mistakes stemming from GM, it was also not the case, as commonly reported, that the NGO letter and opposition campaign was the driving factor behind the cancellation decision. According to a member of the stage gate panel,

> "If the panel had come out at the end with a "it can go ahead" decision, then EPSRC would have stood up and defended that because they wanted to do it anyway, despite the NGO views… But yeah, I mean, there's certainly a lot of reportage in different circles that says, "oh, yeah, the NGOs stopped this". I am of pretty much - of all the things I'll say to you - I think I'm fairly confident. I'm really very confident that had the patent issue not come up, that the NGO opposition would not have been enough to stop the momentum that was behind saying "yes" to do the field trial."

Similarly, according to SPICE scientist, the decision to cancel

> "was a really, really difficult decision. And so, people on one side of the argument accused us of folding in the face of public pressure which is nonsense and other people assume that actually EPSRC had done a better job of governing and had decided not to allow the test bed to go ahead. Neither of those were true. It was left to the senior leadership team to make that decision."

If not the NGO letter, the patent issue was certainly weighing on the mind of Matt Watson, who cited the issue as a major reason behind his decision to cancel the project, stating in his cancellation announcement that the patent created for many on the SPICE

team, including him, "significant discomfort".[35] However, the entirety of the stage gate process, which required Watson and other scientists to consider issues surrounding possible future applications, public opinion, and ethics, appeared to have played a role in stimulating the careful and reflective thinking that shaped the decision to cancel the test. According to a lead SPICE scientist,

> "The optics of it look like, "science team unhappy plagued by public criticism and opposition from NGOs give in." And that's really not what happened. Irritatingly, that's exactly how the NGOs played it out, particularly ETC. They basically said, "we got this thing cancelled." And that's utterly false. It's completely wrong. It was actually the soul searching that the team did that made that decision."

According to the same scientist, the 'soul searching' was catalyzed by the stage gate process, which "made us think a lot about a lot of things that we wouldn't have thought about otherwise. And in that regard, I think it was rather important."

As the engagement was intended to be a central part of the stage gate process, according to social scientist involved in its design, the public deliberative workshops arguably did contribute overall to a process that engendered deep reflective thinking on behalf of key decision makers in the SPICE project team and therefore appears to have enabled more robust decision-making within the research team. Although the engagement work that had happened so far was not ultimately cited as a key factor in the decision to cancel the test, it is telling that in his cancellation announcement, Matt Watson reemphasized the importance of engagement by asserting "it will take time to

[35] Matthew Watson. 2012. "Testbed news". The Reluctant Geoengineer.Blog. Available at: https://thereluctantgeoengineer.blogspot.com/2012/05/testbed-news.html Accessed January 15, 2025.

explore [governance and intellectual property] issues through deliberation and stakeholder engagement".[36]

One researcher intimately familiar with the SPICE team members said that although the engagement may not have had a clear and direct impact,

> "the commissioning of and initiating the public engagement did open up a whole set of questions that made it clear what was at stake here. It might have been the process and not the outcome of the engagement that was important. And you can imagine how the dynamics of that would happen … the process of engagement would legitimize some of the critiques that had already been made and make it more possible for people to see them."

It appears a broader impact of the public deliberative workshops as a component of the stage gate process more broadly was that it raised questions about governance that spawned new framings, new lines of inquiry, and new research questions. According to one social scientist involved in the project,

> "I think one of the key lessons that came to the fore for us was that the issue wasn't how you get particulates into the upper atmosphere. That is not the big question. So whether it's by jets or balloons or whatever else, that's not the [overriding] question. The more substantial question is, you know, the questions around governance - how do we have a process by which we can arrive at decisions which have a kind of legitimacy and authority."

According to another social scientist,

[36] Matthew Watson. 2012. "Testbed news". The Reluctant Geoengineer.Blog. Available at: https://thereluctantgeoengineer.blogspot.com/2012/05/testbed-news.html Accessed January 15, 2025.

> "Engagement was central in [asking questions about governance] because people right from Nick Pidgeon's [publication in Nature presenting the results of the SPICE public deliberative workshops], people were saying well actually - "No." Once you explain and discuss with people the general public and beyond what it is that is going to lead to they have some really quite grave concerns about whether or not that's a good thing. … So those were the sorts of questions and engagement is central to that, I think."

Importantly, participants understood that the new lines of inquiry sparked through the public engagement work was not only intellectually interesting - lessons from that knowledge could, if integrated, produce more robust decision-making and governance of solar geoengineering research:

> "There's been a rich literature that's been written about governance issues, there's been public engagement work that's been done on it. So, we're actually quite privileged to have a body of work spanning back a decade which can inform decision making and to do this properly … And so in many ways, it would be an absolute tragedy if that work is ignored. That people just start to do this without heeding, what's the motivation for this? Is it to save the barrier reef or is it for commercial purposes? Is it military? What are the motivations? Have you engaged with stakeholders and the public about what you're doing? These sorts of non-regulatory forms of governance that help us to kind of feel our way forward and do this in a proportionate right way. They're all sitting in that literature over there right back to the SPICE Project."

The Capacity Building Model of Governance by Engagement: The Degrees Initiative

Following the recommendations of the 2009 Royal Society report, SRMGI was established in 2010 as a partnership between the Royal Society, the Environmental Defense Fund (EDF, a US-based NGO), and The World Academy of Sciences (TWAS,

an Italy-based international organization acting as the academy of sciences for the developing world). The self-described governance initiative initially aimed to convene experts to develop specific governance recommendations, but subsequently decided to "open up' discussions of SRM governance by exploring and recording the different perspectives that exist, rather than 'closing down' discussions by producing prescriptive recommendations" (SRMGI 2011, p. 12). Reflecting an early embrace of the perspectives elicitation model of governance by engagement, the Initiative early on aimed to "foster an interdisciplinary and international discussion to develop ideas on how SRM research could appropriately be governed…" which was done "by assembling a working group and a range of international partner NGOs, and by producing background papers on SRM research governance, hosting an international conference, and by publishing [a] report of the process" which was hoped to inform SRM policy-making (SRMGI 2011, p. 12) Indicative of its overarching role as a facilitator of engagement, SRMGI's 2011 report explains the organization's long-term objective is to "build a diverse community of well-informed international stakeholders engaged and able to contribute to these ongoing debates" (SRMGI 2011, p. 12). After the publication of the 2011 report, Andy Parker rekindled the Initiative and shifted its focus to the Global South.

The governance challenge: Power disparities, lack of Global South expertise and involvement

SRMGI has throughout the years articulated a clear and consistent rationale for focusing attention on the Global South, premised on addressing an equity-based mismatch between countries that are historically responsible for climate change and have the capacity to research solar geoengineering and lead international decision-making and discussion, and those that are vulnerable to climate change and who will have the most at stake in how decisions are made. In this context, one staff member identifies ethical and political reasons to engage the Global South in solar geoengineering discussion, research, and decision-making (see also Winickoff et al. 2018; Rahman et al. 2018):

> "On the ethical side, there's the simple truth that developing countries will be most affected by any decision to use or to reject SRM. Both can be equally significant. But they've been underrepresented in the debate so far when it's right that they should be central to this. Politically, developing countries have been behind some of the biggest innovations in climate policy in the last 25 years. So [they were] responsible for focus on adaptation back when that was heresy, more recently loss and damage, 1.5 to stay alive, small island states - so developing countries have been instrumental in climate policy innovation and it's likely that they will hold a significant position in decisions about SRM as well because they're most affected and that matters. So ethically and politically, it's the right thing to do to have developing countries involved."

On the assumption that research and discussion will continue to occur in the Global North due to stalled progress on mitigation, a vital intervention of the Initiative is therefore to expand the conversation on solar geoengineering into developing countries. Another staff member further explained that

> "expanding the conversation is at the end of the day, that's like our North Star or our south star or lodestar. Our guiding principle is that there will be SRM conversations. They will grow. We've all seen that. It's not going away because emissions are most likely not going to be cut enough to limit warming to 1.5C. And it would make sense if the Global South constitutes [a large majority of the world's population] - that they must be a significant share, if not a majority of the voices at this table."

One senior social scientist acting as a research collaborator sums up the importance of the Initiative's governance interventions:

> "I think one of the most important, maybe the most important unmet need in the entire space of geoengineering governance is empowering participation from middle- and lower-income countries. And they've been doing it."

Andy Parker and others involved in the early days of SRMGI decided that the best way to empower participation in developing countries was to build scientific capacity and expertise. Key staff and other leaders in the organization view expertise as a form of power that developing countries would need to be influential in international discussion and negotiation on solar geoengineering. Building this expertise in developing countries is seen as a way to "level the playing field." As one volunteer active in the organization since its conception explained,

> "very much the focus was to improve the scientific capacity of the developing world to engage in a serious debate about the potential of the technology on a level playing field with the more developed countries, where the scientific capability tends to be much more developed and concentrated and funded."

Illustrating this thinking, one staff member explained the relationship between expertise, power, and influence in the context of previous negotiations on

geoengineering in 2010 within the United Nations Convention on Biological Diversity (CBD):

> "Yeah, so in my view expertise confers a subtle form of power. Because at the UN, system, as I said before, CBD, even if a country has no expertise in a topic, it still has the power to veto or to approve a resolution that's on the table and that should be the case. However, we can do so much better. Because expertise confers the ability to much more deftly and subtly control the development of an issue as it moves through the UN, through different negotiations in those side friends of the chair negotiations, which is what we had for the CBD... And it will be even more acutely important when we're talking about things like governance of research, transboundary impacts. Are there real physical threats? What are the socio-political implications? All of those things come from expertise, the ability to nudge a resolution one way or another, remove a word, get a word in there that would be better suited to your interests."

Reflecting a sentiment that was widely shared across all participants, a scientist working on a DMF grant explained that a lack of knowledge about solar geoengineering, including how it might affect that country in particular, disempowers developing countries:

> "Because the fear in many Global South countries is that we don't know enough about this. We have no idea how our constituents might feel about it or even what the impacts on our communities might be. So [decision-makers] are, in essence, not empowered to have a discussion about it."

A research collaborator explained this point in reference to several years of experience attending the UNFCCC COP meetings:

> "Something that's really, really apparent there is it's the northern white folks dictating to everybody else essentially. And you can't have an

> informed conversation if you haven't got the research going on in those countries … they can sit at the table, but they aren't able to communicate and participate, making sure that everyone is actually able to get their viewpoints across in an informed way and at a level playing field."

Most participants discussed how critical it is that developing countries can draw on that expertise from scientists from their countries, recognizing that policymakers are unlikely to trust information provided to them by Northern experts. As one DMF scientist explained,

> I guarantee you in every country on the planet. If you were to bring up solar geoengineering, one of the first questions a politician or policymaker might ask is, where are my local scientists on this issue? And if you don't have those local scientists, then you really are, you know, getting your information from a source that is not your own. And no politician worldwide will want to go for information outside of their constituency as a first measure. They want to know who their people are working on this."

This was well understood by all participants, including those from the Global North. As one longtime volunteer acknowledged, "people are much more likely to believe their own experts, people who look like them than they are some random old white man popping up on the screen. That's very understandable and very proper." Several DMF researchers explained that policymakers in their countries would never consider research or assessment of solar geoengineering unless the information came from research conducted by local scientists.

Participants further explained that building solar geoengineering expertise in the Global South was also crucial to create more robust and comprehensive knowledge of solar geoengineering's potential physical impacts and socio-political implications.

Many participants explained that Global South scientists are best positioned to produce knowledge of solar geoengineering's potential impacts on their countries and regions. This is because they know what it means to be impacted by climate change, and they moreover are familiar with their local climate and what issues and potential impacts are important within those contexts. As one DMF scientist explained,

> "We feel that this is something that we can tackle best being the people who wear the shoe. Yeah, because we understand better the effects of climate change, we understand better the actual repercussions on us because we experience the impacts of this climate change … we know well about what really happened in our region in terms of weather, weather change, climate change".

Many participants recognized that researchers select research topics that reflect issues that concern them most, which is in significant part a product of their life experience, including their social and geographic position. One SPF research collaborator explained that this can create a 'group think' concern when a community of researchers is overwhelmingly from the Global North (or anywhere):

> "The more similar the scientific community is to one another, the more likely you're going to focus on a relatively narrow set of concerns and questions. And that means you're going to lose out on people who can use their life experiences to develop innovative methodologies, but also innovative questions, and might have data or access to data or working through data that you don't have."

Many participants recognized that groupthink is particularly problematic when the object of research is a set of technologies that will have impacts that appear to be both global and uneven, and when local concerns and issues are likely to vary.

Reflecting on how engaging researchers in the Global South to build solar geoengineering expertise could matter for governance, a staff member explained:

> "What this will mean for governance is it gives the world a platform to make informed and equitable decisions. Informed in that every region will have experts and they will have evidence. And that can be used to develop national positions, negotiating positions and so on. And equitable in that the Mexican government can be informed by Mexican experts and know what their interests are, know what a good outcome would look like for Mexico and then they can push for it."

Governance Intervention: Expanding conversation, building expertise and connecting it to policy making

Following its publication of the 2011 report, SRMGI began to host outreach workshops in developing countries "to start well-informed conversations about SRM in the local climate community and to get participant ideas on any next steps in their countries or regions."[37] The outreach workshop activities reflect the perspectives elicitation model of governance by engagement, though the focus is more on stimulating deliberation and forming connections than on disseminating elicited perspectives for integration into a decision-making process.

SRMGI works with partner organizations including universities, scientific academics, NGOs, and research institutes in developing countries to host the workshops. The workshops typically follow a common agenda comprising an

[37] The Degrees Initiative. "Early Days". Available at: https://www.degrees.ngo/about/early-days/ Accessed June 10, 2025.

introductory overview presentation of information on solar geoengineering, reflecting the education phase of both models of governance by engagement.[38] In the early days, that information was typically provided by SRMGI staff or a volunteer Northern expert, whereas for more recent workshops, local scientists who are involved in research present on solar geoengineering and their research. Reflecting the deliberation phase of the perspectives elicitation model, the introductory informational session was followed by discussion panels composed of several local discussants, often climate experts or professionals who would have the opportunity to provide their reflections on the presented information and contextualize what they heard. In the afternoon, small groups move into discussion prompted by a range of small group activities and question prompts provided by staff, which locals can discuss in their own language. Finally, a plenary discussion encourages contributions on any topic.

SRMGI has run close to 30 such workshops in 20 countries which it claims has included over a thousand individuals to date.[39] According to the Degrees Initiative, in most of these countries, the workshop was the first event on solar geoengineering in those countries.[40] Reflecting the dissemination phase of the perspectives elicitation model, summaries of the workshops are published online, thereby disseminating a brief

[38] Our description of the outreach workshops relies on interview data.
[39] The Degrees Initiative. "Events". Available at: https://www.degrees.ngo/our-events/ Accessed June 10, 2025.
[40] The Degrees Initiative. "Events". Available at: https://www.degrees.ngo/our-events/ Accessed June 10, 2025 ; The Degrees Initiative. "Impacts of our work". Available at: https://www.degrees.ngo/aboutusold/impacts-of-our-work/ Accessed June 10, 2025.

overview of some of the high-level themes and topics that were the focus of discussion at each workshop.[41]

Degrees staff explained that the impact of the workshops were limited, and they realized that the best way to build expertise is to engage scientists in solar geoengineering research by funding research:

> "We started by running workshops in the Global South. And there was a naive hope that we would run a workshop here in Addis Ababa. That an Ethiopian professor would be fascinated and pick this issue up and run with it and become the East African expert. And it's not how it works. It doesn't work in the South or in the North. Where SRM expertise has developed, North or South, overwhelmingly, it has developed where a person has the resources to spend a fraction of every week working on SRM"

As explained by a long-term volunteer, "In our experience they really need to get involved in a subject, in doing something with that subject before they begin to appreciate it fully. So, we felt that actually funding researchers was the most effective way of doing the education."

However, a staff member explained that the workshops provided the connections, credibility, and knowledge the Initiative would need to build a research program:

> "[The workshops] were a first step towards bigger goals in the longer-term theory of change. It would have been great to have launched a research program in 2011. But I didn't have any - the credibility or institutional backing or knowledge to be able to make that happen. What the workshops were initially was the first tentative steps towards just connecting with and talking to climate people in the Global South and

[41] Workshop summaries can be found online at : https://www.degrees.ngo/workshops/

> talk about SRM … The more workshops we did, the clearer it became that the most common thing people wanted was for local climate scientists to look at the regional impacts of solar geoengineering and report back on what does this mean for our climate in Brazil? This has just happened everywhere we went. And so, make the connections, understand how people saw SRM and once we've got those things, we've got a foundation to build something else on."

In 2018, SRMGI shifted the focus of its activities to research funding. SRMGI launched the DECIMALS Fund (Developing Country Impacts Modelling Analysis for SRM) to engage Global South scientists in research on how solar geoengineering might impact their own countries or regions, by analyzing the outputs of climate model simulations and Geoengineering Modelling Intercomparison Project (GeoMIP) experiments.

In 2022, SRMGI reorganized into the Degrees (DEveloping country Governance REsearch and Evaluation for SRM) Initiative in 2022, with the newly articulated mission to change "the global environment in which SRM is evaluated, ensuring informed and confident representation from developing countries."[42] The DECIMALS Fund is now called the Degrees Modelling Fund (DMF) and has since dispersed three rounds of funding, with some previously funded research teams receiving new grants to continue or develop new research projects.[43] The Degrees Initiative also launched a Socio-Political Fund (SPF) for social science research in 2024.

[42] The Degrees Initiative. "About". Available at: https://www.degrees.ngo/about/ Accessed June 10, 2025.
[43] The Degrees Initiative. "Research grants". Available at: https://www.degrees.ngo/our-work/ Accessed June 10, 2025.

Degrees staff explain they deliberately built a 'firewall' that separates research funding decisions and the research itself from the Degrees Initiative to ensure its research teams independently decide what to study, how, and how to interpret and present the results. According to Degrees staff, the committee that makes grant funding decisions are independent from Degrees, as are the experts that review grant proposals. All DMF and SPF researchers we interviewed agreed they never felt pressured by Degrees staff to ask certain questions or to present their results in certain ways - though only one participant did not think its staff are as neutral on SG as they claim to be.[44]

A central part of the Degrees Initiative's activities and goals relate to community building. Degrees pairs the researchers it funds with research collaborators "to increase international cooperation around SRM research and to build a global community of experts."[45] Describing the importance of an informed community of solar geoengineering experts for governance, a long-time volunteer explained:

> What we wanted to do was to build the nucleus of an informed community as widespread around the world as we could in order that as many people as possible could be involved in substantive discussion if and when such a discussion became necessary."

[44] We suggest it is helpful to make several distinctions when it comes to assessing the positions of individuals or actors on solar geoengineering. On the decision to consider or research solar geoengineering, the Degrees Initiative holds clearly stated positions in favor of further research - it runs a research program and actively calls for more research in the Global South. Neutrality is a different matter when it comes to the decision to deploy solar geoengineering, or the decision on behalf of countries to support bans or moratoriums and other policies. Degrees states on its website: "We are impartial on SRM: on whether it should ever be used and how it should be governed. But we are strong supporters of safe and informative SRM research." See https://www.degrees.ngo/our-approach/

[45] The Degrees Initiative. "Research grants". Available at: https://www.degrees.ngo/our-work/ Accessed June 10, 2025.

As one way to accomplish this, each research team is paired with solar geoengineering experts, called 'research collaborators, that provide mentorship and various forms of assistance to the DMF teams, including assistance accessing datasets, interpreting results of model impacts, and more. The Initiative also hosts an array of activities designed to strengthen capacities and build a sense of community among its researchers, including virtual monthly calls, regional in-person meetings, and research workshops to further develop research proposals. One SPF researcher explains the importance of these research workshops for bringing them up to speed on solar geoengineering:

> "And the main idea of the workshop was, at least for us, I think was to get to know the basics of SRM, in terms of technology advancements, in terms of politics, in terms of governance and… I think for us it was an eye-opener … It was - at least for someone who is getting into the field I think it was very important and was very critical to for us to go to that workshop"

The Degrees Initiative also runs other events aiming to engage others beyond only its researchers. In May 2025 the Degrees Initiative hosted the Degrees Global Forum in Cape Town, South Africa, claimed to be the largest conference on solar geoengineering to date, to "bring together researchers, NGO representatives, policymakers, thought leaders, and journalists from around the world to discuss the scientific, social, and political dimensions of SRM."[46]

[46] The Degrees Initiative. "Degrees Global Forum on SRM." Available at: https://degreesglobalforum.org/ Accessed June 10, 2025.

Degrees views its effort to build community within the South and between the North and South as an important aim, as well as a capacity and resource Southern experts can draw on to enable greater influence as they engage in research and decision-making. These activities are directly related to enhancing recognition of the authority of Degrees researchers within the solar geoengineering field. As a staff member explains,

> "So if you have a scientist in the global south who's worked on SRM for a few years, who understands it well, who's starting to get an evidence base and starting to get a a group of contacts that they can just call on the phone because they've been to our workshops, they get to know each other personally. And if you want a question answered, you can call someone up. So that's the kind of capacity you need, largely based around expertise and community. That's what buys your way into this discussion, whereas it would be hard to just turn up as a climate scientist who knew nothing about SRM, who knew no one who worked on it and be influential in the field."

The Degrees Initiative also provides smaller grants that enable their researchers to attend or host other events or activities to facilitate capacity development and community building, including conference funding to attend prominent geoengineering conferences such as GeoMIP workshops, which rotates annually with the Gordon Research Conference on Climate Engineering.[47] Here, researchers funded by Degrees meet and interact with the rest of the solar geoengineering research community, which prior to 2018 was overwhelmingly composed of scientists from the Global North. Degrees also provides some funding for in-kind research training and hosts topic

[47] See https://www.grc.org/climate-engineering-conference/ Accessed June 10, 2025.

specific workshops and trainings for researchers it funds, such as a media communication workshop.

Importantly, the Degrees Initiative is as of 2025 transitioning to the next phase of its activities and theory of change, which reflects the facilitation, integration, and reciprocation phases of the capacity building model of governance by engagement. This can be summed up in the words of one key Degrees staff member as "if you build expertise and you build a community, good stuff happens". The staff member further explains the next phase, which is to:

> "build the expertise, connect it and then help it to go and do good things within the world. And from our point of view, doing good things includes the informing GeoMIP's next round of simulation design, scenario design, and informing societal conversations and policy processes."

Reflecting the facilitation phase of the governance by engagement capacity building model, the Initiative has recently expanded its staff to enable greater capability to facilitate interactions between its researchers and policymakers, with the aim to boost the engagement of its researchers in policy-making processes. Noting its scientists are producing a substantial amount of research articles, the Degrees Initiative explains "[t]he next step is to bring these results out of the academic realm. Degrees aims to connect researchers with policymakers by supporting them to give briefings, contribute to reports and attend international discussions."[48] Another staff member explains this next phase in the context of Degrees' overall mission:

[48] The Degrees Initiative. "Degrees now supporting southern SRM experts in policy processes" News article. Available at: https://www.degrees.ngo/southern-srm-policy-expertise/ Accessed June 10, 2025

> "We're not a scientific funding organization. We're an organization dedicated to changing the environment in which SRM is evaluated and eventually governed. And as such, the next logical step is to say as the world moves towards explicit governance decisions on SRM, our objective is to say the Global South needs to have an independent informed voice in such conversations. The informed part of that is there. So it does require in the near term starting to connect the expertise, the experts that we have catalyzed - whose development we have catalyzed - connecting them with decision-makers, policymakers."

It's also important to identify a related intervention the Degrees Initiative practices, which is to encourage and support the efforts of its researchers to further expand the conversation on solar geoengineering within their own countries and regions. Reflecting the final reciprocation phase of the capacity building model, Degrees helps its researchers host events that engage local communities, policymakers, and others to inform them about solar geoengineering and the research ongoing in their countries. The Degrees Initiative provides small grants and other logistical support to help its researchers carry out this engagement. In this sense, the Degrees Initiative is also a funder of engagement activities, and the researchers, who were once the targeted audience for engagement, now become initiators of engagement, by aiming to invite local communities, scientists, policymakers, and others to learn about and discuss solar geoengineering. For the DMF teams, these engagement activities provide a way to raise awareness of solar geoengineering, disseminate the results of their research, garner support for their work, and understand broader views on solar geoengineering, including what concerns and questions are of interest locally. For some SPF teams,

engagement is also built into their research as a central part of the research process. For example, one SPF project in Brazil will:

> "examine perceptions about the social, political, ethical, economic, and environmental impacts of SRM across a range of key stakeholders in Brazil including experts, productive sector representatives, government agents, and other sectors of public. The team will stimulate a process of discussion and seek to build capacity in Brazil to better evaluate SRM, and to participate in wider global conversation for equitable decisions and governance on this topic."[49]

Another SPF researcher describes how engagement activities in the form of co-production are a core part of their research project:

> "There'll be some engagement at the local level, at the regional level and then at the national level. At the national level will be like through a workshop where I'll bring key representatives around the table to validate some of the research findings and also create awareness of what we have seen, and co-develop recommendations for policy uptake. So that kind of national level engagement will be mainly through a workshop. But then we plan to create awareness about what we found from the research."

One long-time volunteer explained how Degrees aims to further expand the conversation on solar geoengineering through a 'cascade' process by encouraging its researchers to initiate public engagement:

> "So far as I'm aware, Degrees hasn't attempted to go much beyond [scientific community building] other than encouraging its research teams to conduct public engagement exercises in their own countries. So, this is where the cascade aspect comes in. There's no way that - well it would cost an awful lot of money for Degrees to try and do public

[49] The Degrees Initiative. "Understanding Brazilian stakeholder knowledge and perspectives on SRM." Available at: https://www.degrees.ngo/our-work/projects/brazil-2024-guivant/ Accessed June 10, 2025.

> engagement exercises in all of 100 countries, so Degrees tries to get that local expertise built and then rely on those local experts to spread the discussion within their own field of influence."

Governance effects: Empowering Southern scientists, shaping research, building research communities

We now turn to our analysis of the effects of the Degrees Initiative's interventions on solar geoengineering research and governance as informed by our typology of the governance effects of engagement. In contrast to the SPICE public deliberative workshops, which aimed to inform a particular set of decisions, here we consider a broader array of governance effects, organized by all four categories of governance effects included in our typology.

Many participants including staff, research collaborators, and researchers generally agreed that while the Initiative's activities are currently showing some promising results, the full impact of the Degrees Initiative's activities will not be evident until some point in the future.[50] This reflects the wisdom in the capacity building literature that capacity building is and should be a long term process (Dove et al. 2024a; Khan et al. 2018). We focus on effects that are discernable now, but we also indicate effects that are anticipated in the future to illustrate the possible full potential

[50] Several research collaborators also described how the emerging impacts of the Degrees Initiative are promising but also small relative to the need - some described the impacts as a 'drop in the bucket' compared to what would be needed to effectively level the playing field and create a more equitable distribution of research capacity and expertise.

of the capacity building model of governance by engagement. As explained by one research collaborator,

> "Where they have had a difference is in involving a lot more people from a lot of different parts of the world that were never involved and wouldn't have been otherwise. And I think the potential of that is in the future. Not in the present. So, I still think it's very much an organization whose work may pay off in decades to come."

1. Normative effects

The Degrees Initiative's activities appear to have normative effects related to empowering experts in the Global South to participate in research and discussion on solar geoengineering, and institutionalizing their inclusion into the broader solar geoengineering research community. One SPF researcher explained the mission of the Degrees Initiative is important because it aims to include:

> "those who are mostly affected and most vulnerable and to have the voices of those mostly vulnerable heard in shaping solar geoengineering via its governance. … And so this mission is very, very important. And that's how I see it. It brings about inclusivity. And also to make sure that voices from the global south are heard."

DMF and SPF researchers describe how they learned about solar geoengineering through the Degrees Initiative, and they attribute its activities to enabling greater awareness and informed participation in solar geoengineering discussions:

> "Before being involved in the Degrees Initiative I never heard about SRM. … they tried to make sure that we were interconnected with other teams with other researchers in the SRM field, through the different workshops, conferences, and so on. We try to foster all researchers to

> have a voice. To tell what you think about the implication of SRM. So the mission is very important. In the past only the Global North countries were involved in the research on SRM. But I think now more and more researchers from the Global South are interested or are aware to what is SRM. Yes, and I think the Degree Initiative is responsible for what happened."

Another DMF scientist echoes this sentiment:

> "The Global South requires to be given an opportunity. Which, until recently, was not there. Yeah, before [Degrees] came about there was no - we didn't have - we were not given an opportunity because we didn't even know what was happening."

This is one area where the full normative effects of increasing awareness and empowering Southern experts are imagined paying off more fully in the future. Reflecting the aim to level the playing field, participants discussed how this could enable a future international decision-making process that is more inclusive and features informed and empowered participation of developing countries. An African DMF scientist explained the importance of their efforts to create an African solar geoengineering research community:

> "So, it's very much preparing African negotiators to be able to authoritatively speak into this whole SRM space. … I mean we're on the receiving end of climate change. We'll very likely be on the receiving end of anything SRM. And yeah, we just - we don't want to not be a part of this. So, if we can develop a very proficient, competent, authoritative African negotiating team or community then that represents African interests in these global discussions, and we don't get swamped by the Europeans and the Americans and the Chinese in these discussions."

Some participants referenced the recent negotiations surrounding solar geoengineering at UNEA-6, in which a proposal for an international assessment process was ultimately withdrawn after strong opposition from some developing countries, including the Africa Group (McLaren and Corry 2025; Jinnah and Dove 2025). Several participants, including researchers from Africa and collaborators from the Global North - viewed the Africa Group's position as being swayed by unreliable information on solar geoengineering provided to African delegations by NGOs from the Global North. As one African DMF scientist put it:

> "So, the UNEA meeting last year - the African voice was incredibly influential in those meetings. They basically killed that motion. But none of the information that came to the African negotiators in that space came from Africans. It all came from the NGOs, the European NGOs who are anti-research. We have no position on whether we do SRM or not. Because that's going to be for a later time to decide. But we do want our knowledge to be indigenous, to be African knowledge and not knowledge that's imported from - Europe, at the moment really."

In this context, a research collaborator discussed how Degrees' activities could in the future enable Global South countries to autonomously develop their own interests and proposals surrounding solar geoengineering:

> "I think they're looking for it to begin to pay off in terms of building up knowledge and confidence in those countries that's capable of pushing back against nonsense and capable of sort of putting forward policy views and ideas and proposals without having sort of prompted by anybody except for those who live in the country and their own colleagues, sort of come to the table with their own ideas and table those ideas and take part in conversations."

An African researcher echoed this sentiment, and indicated that the Global South needs to be able to articulate its positions independently as well from Global North actors that may overemphasize the benefits of solar geoengineering:

> "Sometimes it's also not clear from the Global North the risk and the benefits among others. And so when given the opportunity from Global South to draw on our own expertise, what we have been able to find out from research, whether supported by Global North or not in negotiations, it will ensure that what is our unique vulnerabilities are very clearly heard, our ethical concerns would come on board. … And then if you are taking this any decision via its governance or whatever, it's more informed and we know that it's going to promote something more equitable."

A Degrees Initiative staff also emphasized the anticipated future benefits of expertise in empowering developing countries to form their own positions independent of both staunch proponents and opponents of solar geoengineering. The staff member argues that at the 2010 Convention on Biological Diversity negotiations, because they lacked expertise, developing countries were:

> "susceptible to the overbearing attention of snake oil salesmen who'd already made their minds up on SRM. And SRM expertise is a counter to this. With expertise, then developing countries won't just be passive recipients to decisions made in Washington or London. … That comes from expertise, and it also allows you to push back on the tricksters who already know that SRM will either be useful - Make Sunsets - or they already know that SRM will be disastrous, and we have to oppose it – Non-use Agreement. So, expertise allows you to avoid being fooled by ideologues who've already made their minds up."

2. Substantive effects

We find clear evidence that the DMF researchers that became involved in solar geoengineering research have altered the trajectory of solar geoengineering research, and this is widely perceived as leading to a more robust and comprehensive knowledge of solar geoengineering. Participants explained that scientists in the Global South tend to be specifically interested in better understanding the *impacts* of climate change and, by extension, the potential *impacts* of solar geoengineering on natural and human systems (as opposed to, for example, modelling changes in temperature). Because the Degrees Initiative enables its researchers to select the research topic, most of the projects funded through the Initiative aim to better understand the potential impacts of solar geoengineering on natural and human systems, sectors, and issues that are most important and relevant locally or regionally. Many participants explained that their involvement has had a tangible impact on shaping the field of inquiry. As one DMF scientist explained,

> "All of the research until Degrees started with the exception of maybe five or six academic papers has been done in the Global North … The approach to SRM research generally, so climate research and SRM research - is heavily global north-centric. And that was about experimentation and modeling. None of the experiments were designed to try and look at what were the potential impacts of SRM - what could they be. And what Degrees and the Global South researchers through Degrees have facilitated in the larger global SRM community is an acknowledgement that actually we need to understand the impacts of what SRM might have on sectors like agriculture and health and energy and hydrology. So as the Global South community within this larger global SRM community we really have shifted the - maybe not shifted but introduced the idea of impacts to the community because it was a very physical climate science climate modeling engineering type community before."

Several senior research collaborators explained that they have learned a lot in this respect from their interactions with DMF scientists from the Global South. One research collaborator explained that "[w]hen you have people from diverse backgrounds, you realize better where your gaps are." The collaborator gave the example of listening to an African DMF scientist at a Gordon Research Conference:

> "It was the first time I'd ever heard anyone mention livestock in the context of SRM. And it was sort of like, "holy shit, of course livestock is important. Why didn't I think of that?" Well, I wouldn't have. But someone who - like that's a major source of wealth, a major source of nutrition. It's part of their lives. Of course, they're going to think about that."

As participants explained, DMF scientists study the potential impacts of solar geoengineering by taking the output of model simulations designed and carried out by modelling groups in the Global North, such as those that run experiments coordinated by the GeoMIP. The high cost, supercomputing power, and skilled labor required to develop and run climate models make it all but prohibitive for most countries in the Global South. This means DMF scientists rely on data from scenario experiments that have been designed and run by Global North scientists, which as explained by participants, are designed to meet the needs of Global North scientists, and which are not always consistent with the needs of Global South scientists. As one DMF scientist explains:

> "The current set of model simulations that exist were designed by the Global North, so they serve the Global North paradigm, of which is improve climate modeling: "what if we inject, what if we do SRM in these places as opposed to these places?" That's looking at very first

> order model responses or potential responses to different strategies of SRM. … But there's no real policy relevance to it … but that's what we would like to do is think more about the experiment design and therefore the model simulation design that can be relevant to policy and by policy, I guess I am implicitly saying be relevant for impacts. Because our policies are designed around impacts. How does it impact hydrology or agriculture because that will then steer very heavily the decisions that you make in the policy space."

Several participants explain that DMF scientists raised this issue at GeoMIP's semi-annual conference and as a result initiated a dialogue surrounding how Southern scientists can inform and influence the way experiments and models are designed. As explained by a Degrees staff member, this is a clear example of what they mean by "good things will happen":

> "And based on Degrees sending southern scientists to GeoMIP last year, some scientists pointed out that actually what matters to them is not average temperature since the moisture is much more important for subsistence agriculture. And so, they might want to see a GeoMIP model run where that is what you try and control, not just global temperature. So, because of that, at next year's GeoMIP meeting, which we're going to be partners on in South Africa, they're looking to how can we set up a session to discuss this with the Southern scientists and find out what kind of things they want in their region."

A research collaborator and member of a modelling team in the United States confirmed the central role of the Degrees Initiative and the Southern scientists in initiating awareness on the need to work with Southern scientists on model and experiment design:

> "Yeah, the Degrees Initiative has really helped broaden that conversation and the awareness around [the need to co-create SG

> simulations and models] and just by bringing people in its helped us to kind of start those conversations and have the ongoing dialogues."

In general, several participants reflected on the overall importance of a large output of solar geoengineering research coming from the Global South, and how the Degrees Initiative is responsible for this. One researcher explains,

> "I mean, just in terms of - the mere fact that you have however many hundreds if not thousands of scientists from developing countries who have taken part in research, have co-authored papers. … That begins to change the face of the research community slowly. … And I think [Degrees has] been the principal driver of that."

A DMF scientist explains that although the amount of funding Degrees has been able to provide has been small compared to larger amounts of funding that have recently been announced,

> "That drop in the bucket has produced some of the most effective results because they've now got over a hundred peer-reviewed publications, they now have researchers on every continent, across multiple countries, 30 plus countries, you know writing peer-reviewed publications that will ostensibly make their way into the IPCC and AR7. … So yes, in that way, it's very crucial."

These impacts are more easily discernible for DMF research rather than the SPF because the DMF teams funded in earlier cycles have already published papers and some have even completed their projects. The SPF funds were only announced in 2024 and so many of the SPF researchers we spoke with were in the early stages of their research. However, the future impacts of this fund may be equally significant. As one research collaborator explained, concerning solar geoengineering related social science research focused on the Global South:

> "That kind of research is just not being done. It wasn't being done before Degrees. It used to be that pretty quickly; I could talk to you about all the papers that had ever been published that looked at the Global South. And the only non-Western research group were people like Masahiro Sugiyama. But now you have a lot of papers coming out there, including by people that are Degrees affiliated. And that can only be a good thing."

We also expect potential substantive effects related to informing and enabling more robust decision-making to flow from Degrees' efforts to facilitate connections between Southern researchers and policymakers and to elevate Degrees researchers to important leadership positions within bodies at the science-policy interface, such as the Intergovernmental Panel on Climate Change (IPCC). Participants from several DMF teams discussed how Degrees was assisting their efforts to form connections with policymakers in their countries to share their research. This is perhaps most evident in Africa. As explained by a DMF scientist, Degrees helped its African researchers host a meeting to connect with ministers from across the continent:

> "But what we are doing at the Degrees Global Forum is inviting policymakers from across Africa to a closed door African, 'come and meet the scientists who are working in this space - And let's just chat and get to know each other.' So that'll be our first major engagement as the African research community within the policy space. Degrees are helping a lot."

According to another DMF scientist, after completing some research, The Degrees Initiative helped the team organize:

> "a workshop inviting some representatives from the government of [country] and then journalists and several others, NGO and so on. So, we tried to introduce them with the concept of [stratospheric aerosol injection] and that one was also the opportunity for me to share the result

> of my research to them so they will know exactly what will be the impact. …. especially from the Ministry of Environment, they say that 'Okay, this is good that I do this research, and they really support me to continue the research' because … they understand that … the result of the research will be quite important for them to know what would be the impact on [country]."

Participants from a handful of countries described similar attempts to engage policy-makers to raise awareness of solar geoengineering and inform them of the research occurring in their country. Though substantive benefits to decision-making are by no means guaranteed, we expect that policymakers will be more capable of making robust decisions about solar geoengineering after being informed by local researchers on how it may impact their country.

In at least one case, Degrees' scientists are themselves entering high level government positions on the national level. One DMF scientist gave the example of Nana Klutze, the principal investigator of a DMF project in Ghana:

> "And she is now slated to become the CEO of the Ghana Environment Protection Agency. …To have somebody who has that intimate level of understanding of SRM within her region - to now be holding among the very top positions on environment and climate in her country should be helpful in making sure that SRM is discussed in a nuanced risk-risk framework."

More robust decision-making on solar geoengineering at the science-policy interface is also a potential outcome resulting from the elevation of many researchers funded by the Degrees Initiative into positions of national and international leadership. According to the Degrees Initiative, 24 of its funded scientists are now IPCC authors,

including several who are vice-chairs. Degrees researchers have also been authors of recent high level reports and assessments on solar geoengineering, including the One Atmosphere report from UNEP, UNESCO's Report of the World Commission on the Ethics of Scientific Knowledge and Technology (COMEST) on the ethics of climate engineering, and the American Geophysical Union's (AGU) Ethical Framework for Climate Intervention Research, in addition to previous IPCC assessment reports. One research collaborator explained the potential substantive benefits of including Degrees researchers in authorship of assessment reports: "in an assessment, you want to essentially find sort of a summary of different positions and different perspectives. And so, if you have more perspectives that's just better for you."

For example, the research collaborator recently attended the IPCC's scoping meeting to decide what would be included in the seventh assessment report, such as solar geoengineering:

> "And in the room and in the various breakout groups where we discussed, there were multiple representatives from Global South countries and focal points and many of them were climate researchers and essentially all of them were involved with the Degrees where they were either current or past PIs for Degrees and now, they're also advisors."

The research collaborator also discussed his experience attending recent meetings or conferences attended by Degrees researchers, including some where the researchers had speaking roles: "So I would say just with actual worldwide global participation in meetings where in a way, if not that decisions are made, definitely

opinions are shaped by the recent participation of Degrees researchers."

3. Instrumental effects

The primary potential instrumental effects of the Degrees Initiative revolve around normalization of solar geoengineering research. This occurs via expanding the conversation on solar geoengineering and promoting awareness of it. We find that these are aided by the efforts of the Degrees Initiative to build trust and recognition of their researcher's expertise and authority in relation to both global audiences as well as publics and policymakers in their countries. Importantly, while proponents of the solar geoengineering non-use agreement assume that normalization of solar geoengineering is undesirable and to be avoided (Biermann et al. 2021; Stephens et al. 2021), we use normalization here to describe, not evaluate the process of moving a governance object from something that is largely strange and unknown to known and legible in different contexts (Parson et al. 2024; Allan 2017). In our view, the Degrees Initiative, as well as the researchers it funds, likely play vital roles in this process as they seek to expand awareness and discussion of solar geoengineering across the world.

Participants provided numerous examples of how they aim to or are in effect spreading the conversation on solar geoengineering in a sort of cascade or ripple effect in preparation for a future point of decision-making. According to one Degrees staff member, in expanding the conversation,

> "the hope is that once you've got researchers in Malaysia who know about this, they will have conversations over the water cooler in their office. Some of them write newspaper articles. They talk to journalists. Sometimes the government wants to know what's this crazy thing that we're hearing about. All of that spreads this conversation and gets more people thinking about SRM for the day when there's really, really hard decisions to make."

One DMF scientist described what this looks like in terms of their efforts to spread awareness of solar geoengineering:

> "So, this is the way we are discussing with them at the local level at the radio stations and also the local communication people to explain in our local language. So we are interacting like that. Even [at the] university level we have a meeting with the local community to show what we are doing in our university because our university is in a rural area…. And each meeting I have to present what I'm doing now, what is SRM, what is SRM in local language, what we want to do is to explain [to] them."

A longtime volunteer involved in the Degrees Initiative explains that "[w]hat we were trying to do was to start a … you know where you do one thing and it leads to another and it leads to another, and it actually expands – a cascade."

A SPF researcher described how they aim to 'cascade' information about solar geoengineering using social media:

> "For example, after we do the community engagement…. to make our project visible, our research associate writes something about what we have done. And then we post it in a social media. And then, you know, in social media, a lot of people will notice… And then that person will tell, "yeah, it's because of our project." "What's your project?" It's all about…" and you share about SRM. Then from there, they learn about SRM. You cascade the information about SRM."

Additionally, a few researchers explained that they wanted to raise awareness among the public to 'push' policymakers to consider solar geoengineering, suggesting Degrees scientists are not only actively engaged in agenda setting processes, but some view public engagement as a core part of their strategy for doing so. As explained by one DMF scientist,

> "most of our policy makers, their decisions are always influenced by [the] number of people talking about something. And so, we have to use these strategies to inform more people to talk about what we are doing. So, to do that, we need to give them some information about what we are doing and get their feedback. …. If we give them the information, they will start talking about it and the policy makers in local level, they will start looking at this. We need to push them. This is our strategy."

Others aim to engage important government officials and other influential actors directly for this purpose. One SPF researcher explains why they are planning a workshop with public and private decision-makers to present their research:

> "Since we're aiming that people that will attend have some sort of power in decision making either in the public government, either in the private sector, that somehow we aim that people that will attend and later on, they will be able to do something about it."

Finally, across all interviews, many participants were concerned about the role of conspiracy theories and dis/misinformation, including but not limited to the chemtrails conspiracy theory, in undermining prospects for robust societal discussion, responsible governance, and public engagement. Some viewed public engagement also to combat or inoculate publics from disinformation. One research collaborator suggested that

building expertise in the Global South could be one way to prevent conspiracy theories from becoming prominent in those countries:

> "I think coming back to the Degrees, when we are focusing on countries in the Global South, I'm very optimistic that, with such a capacity building and community building there you reduce the chances of really bad conspiracy theories emerging on the ground there. Can you prevent it? Probably not. I really believe that you reduce the probability of that happening."

4. Productive effects

Finally, we see some evidence that the capacities, preferences and interests, and even identities of researchers funded through Degrees are constructed because of Degrees Initiative's efforts to build an international and regional communities of solar geoengineering experts. In short, in our view, many of the Initiative's activities - including its workshops, monthly calls, research collaborators program, and funding of researchers to attend international conferences - provide the social interaction that that facilitates the construction of - literally, 'Degrees researchers' - as particular "kinds of social beings" (Barnett and Duvall 2005, p. 52), or as a particular kind of public capable of knowing and researching solar geoengineering (Bellamy and Lezaun 2017).

All but two researchers we talked to described being unaware of solar geoengineering prior to their participation in Degrees' activities. Through this participation, they learned about solar geoengineering and discussed it with others, in the process forming relationships with research collaborators and other Southern

researchers. Along the way, they developed positions on solar geoengineering based on their understanding of how it might impact their country, and their identities as Global South researchers. Participants describe over time forming positions (and sometimes reforming them) on key points of the solar geoengineering debate, such as whether they are in favor of or against the Non-Use Agreement.[51] For some, they come to see and describe themselves as 'SRM researchers', or 'members of the SRM research community,' or more specifically 'Global South SRM scientists' or members of, for example, an 'African SRM community'. For example, as explained by one DMF scientist:

> "With Degrees, we know that we are part of the research. We are doing all the funded projects across Africa, their topics are on the specific interests of their own region. … We have now the community of practice of this solar geoengineering in Africa - this is from the Degrees Initiative."

For some, this means building an actual institutional infrastructure to enable and support their interactions and research activity as a regional community of solar geoengineering experts. This is occurring most prominently in Africa, where Degrees researchers are working together to build an African 'hub' for solar geoengineering research, called the African Climate Intervention Research Hub. As explained by an African DMF scientist:

> "So what we're doing at the moment is building a research hub and this is like a month old now. So, it's still very immature. Building a research

[51] All participants are generally careful to emphasize that they are neither 'pro' or 'anti' solar geoengineering, but again we suggest that most individuals in the field have formed positions on the matter of whether solar geoengineering should be researched, and if so, how.

> hub that will try and help steer and direct and coordinate the African research into SRM over the next five or so years. And that facilitates a bunch of different things. It coordinates research, it facilitates trainings and workshops and really building capacity to do … climate and SRM research. But then also trying to work with the policy community in thinking about what are their questions."

Another DMF scientist explained the sense of community formed by the Degrees Initiative is stronger than in other research communities they are a part of:

> "I'm involved in different groups of research. But with Degrees it's totally different. We have monthly meetings. We are in contact. Always. The other groups we have meetings, maybe two months or three months so there is no feeling of [an] integrated group."

The productive effects are in some cases explicit and intentional, most clearly demonstrated by the Degrees Initiative's explicit aim to build international and regional communities of solar geoengineering experts. For example, as explained by one staff member, because the climate community acts as an epistemic community:

> "it's important to integrate the emerging global south scientists and other researchers into the global SRM and wider climate science community. As well as to foster a sense of community within the global south and the regional elections of scientists and other researchers."

The productive effects possibly also flow to the construction of researcher's interests, as well as that of their countries. Degrees Initiative staff explain that a central part of their theory of change is to "empower developing countries to

identify their own interests as related to solar geoengineering, and as informed by research findings."

While the Degrees Initiative does not appear to intentionally shape researcher's understanding of what their interests are or should be, it does of course aim to develop their social capacities as authoritative experts. As such, one potential productive effect is to construct the researchers it engages as authoritative, credible, and experienced experts, able to shape both national priorities and international discussion. As several research collaborators and staff explained, this is part and parcel of the Degrees Initiative's attempts to elevate its researchers into positions of leadership and enable them to be influential in shaping solar geoengineering discussion and decision-making. One research collaborator suggested that on a pragmatic level, this requires a process of 'socialization' through which researchers could learn how to speak and interact in a particular way to maximize their influence in international negotiations:

> "I also think that expertise also, to a certain extent, appearing to be an expert is an important element of people's ability to kind of like be socially influential and persuasive. And for better or for worse, that means sort of adopting - we might call logics and vocabularies of certain kinds of expertise. …. And I think that - the more people are able to sort of engage with these discourses in ways that people find legible, persuasive, credible, the more successful they're going to be at getting their interests represented."

We also suggest that productive effects may flow more broadly because of the Degrees Initiative's interventions, beyond the researchers it engages. As already discussed, one explicit aim is to integrate engaged researchers into the broader solar geoengineering community. Altering the composition of this community by diversifying its membership may end up shaping how members of the broader community understand their own identity and interests. One research collaborator asserts that by engaging Southern scientists in solar geoengineering research, "that begins to change the face of the research community slowly."

Several research collaborators and researchers also described how researcher's attempts to engage local communities in their countries also contributed to community building on a local level. According to one research collaborator:

> "But it's also the research that I'm seeing done in the sociopolitical fund is community building in a very direct sense that these researchers are going into places like Bangladesh or Pakistan and talking to people. So they're building communities in that way as well and networks around this issue."

In our view, as the conversation on solar geoengineering expands through governance by engagement, this likely goes hand in hand with productive effects, as people learn about solar geoengineering, discuss it with others, and form opinions and preferences on it based on their own understanding of who they are and what they want.

Conclusion

We have highlighted how engagement practices initiated by authoritative actors in the pursuit of public goals can generate important governance effects, a phenomenon we have termed governance by engagement. Overall, we have shown how engagement interventions can empower, inform, legitimate, and construct actors, thereby expanding and enhancing the capacities needed to govern solar geoengineering research, enabling a more diverse and capable set of actors to shape research and governance trajectories in particular directions. In so doing, we illustrated how the concept of governance by engagement and the typology of categories of governance effects expected to follow engagement can help us better understand how authoritative actors use various forms of engagement to govern research and development of emerging climate intervention technologies.

Specifically, we have shown how in the SPICE public deliberative workshops case, the workshops informed decision-making surrounding whether the experiment should go ahead and it also likely helped to stimulate scientists' reflective thinking that would ultimately lead to the cancellation of the experiment. The process of engagement also opened up new lines of inquiry and governance questions that, if integrated into decision-making, provide helpful lessons for future research governance processes. In the Degrees Initiative case, we showed how the NGO's activities have contributed to the normalization of solar geoengineering by promoting awareness and spreading conversation on solar geoengineering in the Global South. Its efforts to engage scientists have also altered the trajectory of solar geoengineering research towards investigations of potential impacts and have constructed communities and networks of

solar geoengineering researchers with distinct identities and capabilities. Moreover, its efforts to elevate its researchers into positions of international leadership and facilitate connections between researchers and policymakers may enable more robust and inclusive decision-making by leveling the playing field and promoting equitable participation in international discussion and negotiation.

Our theoretical and empirical insights are particularly relevant as developments in climate intervention issue areas indicate a ramping up of funding and attention towards climate intervention. We expect that governance by engagement will continue to be a central response to the challenges that arise. Specifically, in the solar geoengineering issue area, an explosion of philanthropic funding promises further research activity and growing public awareness and likely controversy (Temple 2024). Additionally, after largely neglecting solar geoengineering research in the United Kingdom for over a decade following the tumultuous public controversy surrounding the cancellation of the SPICE project in 2012, in April 2025 the Natural Environment Research Council (NERC) announced an investment of £10 million in solar geoengineering modelling research (UKRI 2025) and, most significantly, the Advanced Research and Investigation Agency (ARIA) is set to announce funding decisions on a new round of outdoor experiments in the United Kingdom backed by a new £56.8 million research program (Carrington 2025). Demonstrating once again a central role for engagement in research governance, in making recommendations to fund outdoor experiments under the ARIA program, an oversight committee will

consider a set of criteria, including whether "sufficient meaningful engagement with the local community and key stakeholders [has] taken place" (ARIA n.d.).

Governance by engagement in the solar geoengineering issue area has emerged in an uneven governance landscape that lacks an explicit and legalized regime focused on solar geoengineering, but that landscape is also shaped by over a decade of efforts to discuss, propose, and catalyze governance, namely by experts and NGOs (Jinnah and Dove 205). We expect that some form of governance by engagement will continue to be a central governance response to the risks, uncertainties, and challenges associated with solar geoengineering, including if and when states take on more active roles in establishing legalized and international decision-making processes for research or deployment.

On the question of how governance by engagement should proceed, it is difficult to provide a general answer, as the aims, interventions, and effects of governance by engagement can be expected to vary in different socio-political contexts. Governance by engagement will need to be tailored to local contexts to be culturally relevant and politically feasible (Carr et al. 2013). At the same time, we noticed a remarkable consistency with how DMF and SPF researchers discussed the need to share their research with their local and national communities, inform them of what solar geoengineering is and why they should care about it, and to initiate discussions on that basis that would ultimately lead back to policy-makers. We generally agree with Carr et al.'s (2013) suggestion to both expand engagement to more diverse groups and work to better integrate its outputs (elicited perspectives or expertise) into research and

decision-making. To add, we suggest it may be fruitful to look at the intersection of the perspectives elicitation and capacity building models of governance by engagement, which points towards the need to build capacity across a wide range of actors involved in governance by engagement, including: for potential initiators to spearhead engagement with sensible goals; facilitators to design and carry out methods of engagement sensitive to local context; participants to engage in thoughtful and informed discussion; and recipients to integrate the results into their research, engineering, or policymaking (see also Dove et al. 2024b; Jinnah et al. manuscript under review).

Beyond the solar geoengineering and climate intervention issue area, our concept of governance by engagement and typology of categories of potential governance effects provides a general conceptual and analytical framework that can be used to better understand how engagement matters for governance across a range of issue areas and contexts, though, as noted previously, the concept may need to be refined or adapted to better capture political and cultural variation in governance by engagement. The typology of governance effects can enable systematic and comparative research for mapping and analyzing governance by engagement across issue areas. More ambitiously, the concept and typology can be used to account for variation in the interventions and effects of governance by engagement (Bäckstrand and Söderbaum 2018). To that end, one line of inquiry could aim to explain variation in engagement practices, to identify the factors that help explain why some engagement interventions or models are used more frequently than others. Another line of inquiry

could instead aim to explain variation in the governance effects of engagement, by identifying what factors help account for variation in the effects of engagement on governance. To start, we recommend exploring the importance of such factors as the nature of the governance challenge; the motivations of the initiating actor; the maturity of the issue area; the social, political, and cultural context, and the type of actors that initiate, facilitate, participate in, and are the recipients of governance by engagement.

Chapter 2

Global Perspectives on Solar Geoengineering: a novel framework for analyzing research in pursuit of effective, inclusive, and just governance

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1. Introduction

Climate intervention technologies are increasingly being discussed as potential ways to address climate change alongside mitigation and adaptation. This includes technologies such as direct air capture of carbon dioxide, solar geoengineering, and atmospheric methane removal (NASEM 2024). Despite the uptick in political and scholarly interest in these technologies, we know very little about how global publics and other actors might perceive the benefits and drawbacks of their use in climate

response. What we do know is scattered through various literatures and fields, with diverging methods, sample sizes, and research objectives. This study systematically analyzes the interdisciplinary literature on global perceptions of one set of climate intervention technologies, solar geoengineering (SG), with a view to better understand the ethical, political, and justice implications of SG perspectives research. Our analysis has policy relevance not only for SG research but for research into climate intervention technologies more broadly, as the same gaps and limitations we find here are likely to apply to carbon dioxide removal (CDR) perspectives research as well.

SG, also called solar radiation management (SRM), refers to a set of technologies and techniques that aim to artificially cool the planet by reflecting a small proportion of incoming sunlight back into space (NASEM 2021; National Research Council 2015). The most commonly studied method to implement SG is stratospheric aerosol injection, which could potentially achieve this cooling effect by dispersing particles into the atmosphere to scatter sunlight (NASEM 2021; National Research Council 2015).

A growing body of research has emerged since 2009 that has sought to better understand what and how different groups of people think about SG. Researching how various publics and other interested groups perceive SG as a possible climate response is important because the possibility of SG raises profound and challenging social, political, legal, and ethical risks and uncertainties (e.g., Corner et al. 2012), and the trajectory of SG research and development likely rests, at least in part, on public acceptance (e.g., Jobin and Siegrist 2020). In addition to publics, this research also

investigates what other actors think about SG, including experts, policy-makers, and representatives of NGOs, businesses, and other interested groups.[52] We refer to this body of research, which includes the public reports of engagement and capacity building activities with publics and other interested groups, as SG perspectives research.[53]

In this article we present a framework to systematically analyze the interdisciplinary and incongruent literature on SG perspectives through a justice centered lens. Our framework treats the literature itself as an object of study and asks questions such as whose perspectives are being studied, by whom, using what methods, following which lines of inquiry, and crucially, for what purposes. Our framework can be applied beyond SG to assess research that investigates perspectives of other emerging technologies, with a view to enabling perspectives research to enhance effective, inclusive and just governance of emerging climate technologies more broadly.

A comprehensive analysis of SG perspectives research is needed now because recent activity has elevated SG as a topic of public, policy, and scientific discussion. SG has been the focus of several recent reports and assessments conducted at national

[52] Although the term "stakeholder" is commonly used in the literature, following NASEM guidelines we do not use the term "stakeholder" in our study unless quoting or citing the work of others (NASEM 2023).

[53] The literature uses different terms to refer to what and how people think, including perspectives, perceptions, opinion, preference, understanding, judgment, approval, acceptability, and support. We use the term 'SG perspectives' or 'perceptions' throughout this article to encompass these terms. We also use the term 'studies' throughout to refer to articles, reports, dissertations, and other forms of research included in our database of SG perspectives literature. Not all studies provide original data. See the Supplemental Material for more information.

and international levels, including within: the United States White House Office of Science and Technology Policy (OSTP), the United States National Academies of Sciences, Engineering, and Medicine (NASEM), the United Nations (UN) Human Rights Council (HRC) Advisory Committee, The UN Environment Programme (UNEP), the Climate Overshoot Commission, and the World Commission of UNESCO on the Ethics of Scientific Knowledge and Technology (COMEST). A resolution on SG was also a topic of debate in 2024 at the Sixth Session of the United Nations Environment Assembly (UNEA-6) as well as the previous UNEA-4 in 2019. Importantly, a 2021 NASEM report recommends the creation of a public SG research program, underscoring that "[r]esearch on public perception of SG is valuable both to assess the state of public understanding and opinion regarding SG as a potential climate response and to inform measures to engage public and stakeholder input in decision making over SG research and research governance" (NASEM 2021, p. 79). Further underscoring the importance of public perspectives on SG, a February 2023 UNEP report concluded that SG decisions "require an equitable, transparent, diverse and inclusive discussion" and that marginalized groups from the Global South must be brought into a globally inclusive conversation (UNEP 2023 p. 2).

Despite the importance of public and interested group perspectives as governance inputs, nobody has yet to comprehensively analyze this research, or importantly, the quality of it. Our study is the first to systematically analyze this literature with a view towards assessing how it enhances and/or erodes the potential for effective and justice governance. We illuminate important justice and political

questions related to whose perspectives are being studied and for what purposes. We show that SG perspectives research overwhelmingly centers the perspectives of people in the Global North.[54] Of 71 studies that provide original and country-specific data, 32 studies gather perspectives from the United States; 22 from the United Kingdom; and 12 from Germany.[55] Only two studies (Dunlop et al. 2022; Ipsos MORI 2010) aim to capture the perspectives of youth, who must live with the consequences of near-term SG decision-making and whose perspectives may help SG governance fulfill intergenerational obligations by avoiding harms to future people (McKinnon 2019).[56] Moreover, the vast majority of research is produced in the Global North, as 73.9% of the primary institutional affiliations for all researchers come from the United States, the United Kingdom, Germany, Denmark, and Japan.[57] We also demonstrate that, quite problematically, some SG perspectives research explicitly aims to inform public communication strategies for increasing support for SG as a climate response option. As such, if this aim becomes a more central motivation driving SG perspectives research, this research could itself promote unjust and undemocratic forms of politics,

[54] We are not the first to note this, however, to our knowledge we are the first to comprehensively quantify this based on an analysis of all original studies in the SG perspectives literature.
[55] See the Supplemental Material in Appendix A for an explanation of which studies are included in this count. Some studies capture perspectives from multiple countries.
[56] 13 studies involve undergraduate students, but these generally do not aim to understand the perspectives of young people as such.
[57] We acknowledge that our use of the terms 'Global North' and 'Global South' are imperfect as these designations lump together diverse countries, groups, and perspectives. We do not suggest that perspectives within the Global South and North are uniform, and urge that future research is attentive to exploring diverse perspectives within and across both groups of countries. Our use of the terms are intended to refocus investigations of perspectives in countries with higher levels of climate vulnerability.

or even help to create social pressure for unilateral or irresponsible research or deployment.

SG perspectives research also has the potential to enable more effective, inclusive, and just forms of SG governance. It can do this by, for example, informing a more open and democratic discourse on governance (Sugiyama et al. 2020; Cummings et al. 2017), opening up research and decision-making to a wider diversity of values, perspectives, and concerns (Corner et al. 2012; Bellamy et al. 2012; Hourdequin 2019) and by producing knowledge needed to tackle pressing issues. The potential for perspectives research to enhance or undermine effective, inclusive and just governance is a function of researchers' willingness and ability to reflect on the ethics and politics of the research process itself (Cairns 2018), and to identify and rectify gaps, limitations, and other problematic trends in the literature.

Our study moves well beyond a review of the literature, which largely just summarizes and explores common themes in previous SG perspectives research (e.g., Corner et al. 2012; Cummings et al. 2017; Raimi 2021; Burns et al. 2016). Rather, we develop an analytical framework for interrogating the research process itself, using the literature as the source of data and object of study. Our study therefore builds on and advances efforts to recognize review research as a distinct and valuable form of research inquiry that uses scientific methods to analyze prior research in order to produce novel knowledge for use in research, practice, and decision-making (Kunisch

et al. 2023).[58] Specifically, our framework positions us to better understand the ethical, political, and justice implications of SG perspectives research by demanding inquiry into *whose* perspectives are collected, *what* questions they are asked, *how* those perspectives are collected, *why* they are being collected, and by *whom*. Our analysis illuminates gaps and other limitations embedded in the research, which if left unaddressed, limit the potential of SG perspectives data to enhance just and effective SG governance. We conclude by charting a pathway for future SG perspectives research, which seeks to ameliorate some of these limitations and enhance the potential for the research to enable more effective, inclusive, and just SG governance.

The rest of the article is organized as follows. In section 2 we present our research questions, methods, and analytical framework. In section 3 we present the results of our study using visualizations and descriptive analyses of our data. In section 4 we discuss our findings and present recommendations, which aim to empower SG perspectives research to better fulfill its potential of enabling more effective, inclusive, and just SG governance.

2. Material and Methods

[58] As a distinct form of scientific inquiry, Kunisch et al. define *review research* as "a class of research inquiries that employ scientific methods to analyze and synthesize prior research to develop new knowledge for academia, practice and policy-making" (2023, p. 5). Its defining feature is that it uses prior knowledge as a source of data for producing new knowledge.

Our analytical framework interrogates the literature guided by the following six questions:

RQ1. Where is the research being done? Which publics or groups are included?

RQ2. Who is producing the research? Where are those researchers based?[59]

RQ3. How is research interest in SG perspectives changing over time?

RQ4. What lines of inquiry are being pursued? What types of questions are being asked?

RQ5. How is the research being done? What methods are used?

RQ6. Why is the research being produced? What rationales are given for why SG perspectives are important to know?[60]

Our analysis is conducted in three phases: literature identification and collection; coding and database population; and analysis and visualization of the data.

2.1 Literature identification and collection

[59] Future research could also gather data related to researcher disciplinary affiliation and/or epistemological stance.

[60] Future research could expand on this analytical framework by introducing more research questions, such as by investigating whether research meets equity or justice standards espoused by its researchers. It could also investigate more specific lines of inquiry, such as by distinguishing between investigations of support for different forms of research such as outdoor experiments, and support for deployment. Future analysis of the data should also be done longitudinally to identify trends and differences over time.

Studies and reports of SG perspectives must meet two major criteria for inclusion in our study. First, included studies must present or analyze empirical data or review empirical research. Second, the empirical data must shed light on what or how people think about the concept of SG in general or one of the particular techniques imagined to implement it. We therefore excluded studies that capture *only* perspectives of CDR, the other bucket in the 'geoengineering' category. However, relatively few studies focus on SG exclusively, and investigations of 'geoengineering' perspectives are more common. We include studies that also investigate perspectives of CDR or other technologies or policies, so long as SG is explicitly included in the information provided to participants, the questions asked to participants, or in the presented results. Therefore the common denominator underlying all studies in our database is the empirical study or review of *SG* perspectives, though some also explore perspectives of, for example, CDR, other emerging technologies, and climate change or climate policies more generally. Indeed, the purpose of some studies is to compare perceptions of different SG and CDR methods (e.g., Jobin and Siegrist 2020; Baum et al. 2024), or of different climate policy options, including mitigation and adaptation (e.g., Bostrom et al. 2012).

We decided to include articles that review prior SG perspectives research and articles that re-analyze previously reported data. We do so because these studies often provide unique lines of inquiry, research questions, and rationales and because they also contribute to broadening our knowledge of SG perspectives (e.g., Raimi 2021; McLaren et al. 2016).

Otherwise, and in contrast to previous literature reviews, to meet our study aims we did not restrict the included literature to those that use particular methods to gather perspectives, those published in peer-reviewed journals, or those that solely study the perspectives of laypersons or publics.[61] Given our wide net, our database of literature covers a range of methods for gathering SG perspectives, and it also includes studies that gather perspectives from different types of actors, including laypersons; experts of various disciplines; members of government, the media, business and industry, and NGOs; and more. The included studies also provide varied and sometimes conflicting rationales for studying perspectives of SG and explore different aspects of what people think about SG. Though differences in aims and methodology abound (Burns and Flegal 2015), what all these studies share in common is the presentation, analysis, or review of data or research that reflect, albeit in different ways, what or how people think about SG.[62] Our database of SG perspectives research published between January 2009 and September 2024 includes 132 studies, enabling us to provide the most comprehensive analysis of the SG perspectives literature to date.[63]

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[61] Our study analyzes SG perspectives *research*, not any form of public engagement or dialogue related to SG. In order to count as perspectives research, non-academic workshops or dialogues on SG must publish empirical information about participants' perspectives on the topic. For this reason, workshops hosted by organizations such as the Solar Radiation Management Governance Initiative (currently the Degrees Initiative) are not included unless they released a report that presented participant perspectives, such as in (African Academy of Sciences and Solar Radiation Management Governance Initiative 2013).

[62] As our study aims to provide a comprehensive analysis of how and why SG perspectives research is being produced, we must include in our analysis research that has divergent aims and methodology and that may produce incommensurable results. However, we do not compare the results of these studies nor do we claim that they are commensurable.

[63] We list 2009 as the start date because that marks the publication of the very first study of SG perspectives, the influential Royal Society report (The Royal Society 2009). There are no studies published prior to this year that meet our inclusion criteria.

We first identified relevant literature using a series of keyword searches in Google Scholar (see **Table 2.1** below) in addition to a 'snowball' method whereby the reference lists of already identified articles were reviewed for additional articles that met our inclusion criteria. We restricted our study to English language literature due to a lack of translation services. Because a variety of terms used to refer to 'perspectives' and 'solar geoengineering', the searches consisted of multiple combinations of two sets of keywords. The first set of keywords reflects the various terms used in the literature to refer to what or how people think about something. The second set of keywords consists of the various terms used to refer to solar geoengineering, as well as the most commonly discussed technique. The snowball method complemented the keyword searches because it allowed us to identify articles that used different terms altogether (e.g., Raimi et al. 2020). See the supplemental material for a full list of the literature included in our database.

Table 2.1: Sets of keywords used for Google Scholar searches

Set 1	**Set 2**
Perceptions	Solar geoengineering
Opinion	Solar radiation management
Perspectives	Solar radiation modification
Understanding	Climate engineering
Acceptance	Geoengineering
Support	Stratospheric aerosol injection

2.2 Coding of literature and database population

We coded the papers for the data needed to answer our research questions. **Table 2.2** displays our research questions, required coded information, and examples.[64] We adhered to the descriptive type of coding, which when done properly, creates a categorized inventory of the data that summarizes what the data "is about" (Linneberg and Korsgaard 2019; Saldaña 2015). We entered the codes for each paper into Google Sheets.

We used primarily inductive coding for RQ3 and RQ6 to avoid the imposition of a set of previously articulated research rationales or key themes onto the data (Linneberg and Korsgaard 2019). This was important because it allowed us to create novel categories that better capture the full diversity of rationales and objects of study.

Two of the authors worked collaboratively to establish inter-coder agreement. The two authors first discussed and practiced an initial approach by individually coding a subset of the studies and then comparing and reconciling differences through 'negotiated agreement', making changes and decisions as needed (Campbell et al. 2013). One author then proceeded to code all articles first. Both authors met regularly to review progress and address challenges that arose. After the first round of coding

[64] We collected data on sampling methods and research questions but this data is not presented here due to space limitations.

was completed, the other author coded all articles and the two authors met to reconcile any remaining differences. At the analysis stage, data for several research questions went through multiple rounds of coding to simplify the codes until we were confident the codes allowed us to sufficiently make sense of the data. We provide further details on question specific coding methodology in the supplemental material.

Table 2.2: Analytical framework, including coded information and examples

	Research Question	**Coded information**	**Example**
1	1(a) Where is SG perspectives research being done?	1(a) The countries where research respondents or participants are located as reported in study.	1(a): United States; Brazil
	1(b) From which groups of people are data collected?	1(b) The type of actor participating.	1(b) Lay public.
	1(c) How were participants recruited or invited?	1(c) The sampling method used.	1(c) Professional marketing firm; Quota sampling for age, gender, race, and socioeconomic position.
	1(d) How many participants were included?	1(d) The sample size or number of participants.	1(d) 53

2	Who is producing SG perspectives research? From where is the research being produced?	The country where authors are located, based on first listed institutional affiliation.[65]	Japan
3	How is research interest in SG perspectives changing over time?	The year the study was published.	2015
4	4(a) What is being researched? 4(b) What types of questions are being asked about perceptions related to solar geoengineering?	3(a) The primary line of inquiry related to what or how people think about SG. 3(b) The research question the study aims to answer.	3(a) Support / approval; risks and benefits; factors that influence perceptions 3(b) "What communicative resources did the focus group participants use in making sense of climate engineering?" (Wibeck et al. 2017, p. 3).
5	How is the research being done? What methods are used to study perceptions?	The method(s) used to gather perspectives.	Survey experiment

[65] Using primary institutional affiliation may lead to an overestimate of researchers based in the Global North as some scholars that are from the Global South are affiliated with universities and institutions in the Global North.

6	Why is SG perspectives research being produced? What rationales are given for why SG perspectives are important to know?	The rationale and motivation for the study, in the form of stated potential benefits of the research or explanation of why it's important to know what or how people think about SG.	"To assist the policymaking process regarding geoengineering, …" (Wright et al. 2014, p. 106).

2.3 Analysis and visualization

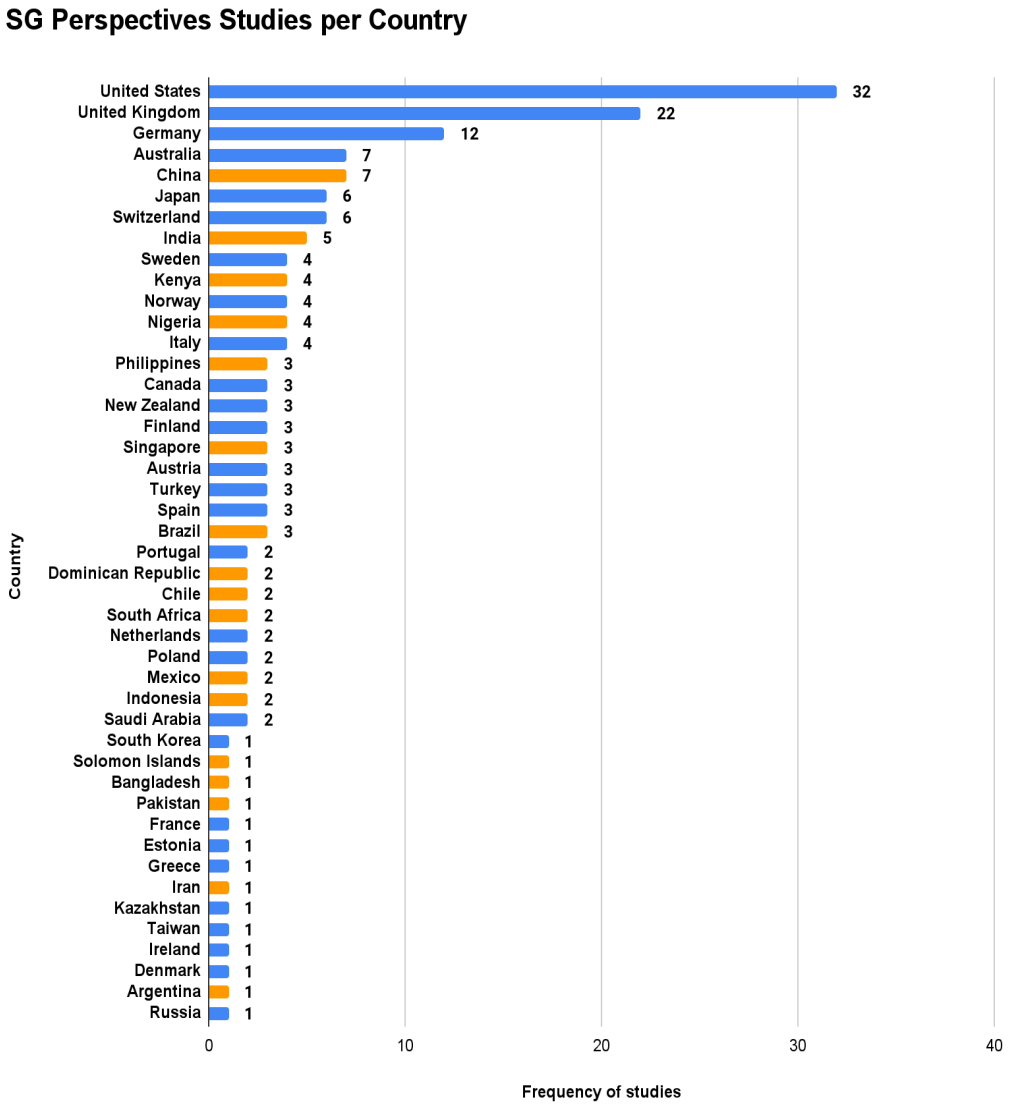
We analyzed our data using basic spreadsheet formulae that primarily provide frequency counts of our codes. Future assessments could perform more complex analyses to, for example, investigate the relationship between different categories of data, such as participant location and research rationale. We visualized our results using simple charts included in Google Sheets.

3. Results

Our results are organized by research question as follows:

3.1 RQ1: Where is the research being done? Which publics or groups are included?

Figure 2.1 below visualizes the number of studies that collect SG perspectives from particular countries. Data bars for countries in the Global South are orange.[66]



[66] Our definition of Global North and Global South follows the Finance Center for South-South Cooperation, which has Special Consultative Status with ECOSOC of the United Nations.

Figure 2.1: Number of studies of SG perspectives in each country. Data bars for countries in the Global South are orange. A single study can be coded for multiple countries.

The vast majority of studies collect SG perspectives from the United States (N = 32) and the United Kingdom (N = 22), and to a lesser extent, Germany (N = 12). Only a handful of studies collect perspectives in Africa (Kenya, Nigeria, and South Africa) and the Pacific Islands (Solomon Islands) (Baum et al. 2024; African Academy of Sciences and Solar Radiation Management Governance Initiative 2013; Hussain et al. 2024; Carr and Yung 2018; Fritz et al. 2024). Several recent large-scale studies have gone a long way towards introducing many more countries including in the Global South to SG perspectives research (Baum et al. 2024; Fritz et al. 2024; Contzen et al. 2024). However as **Figure 2.1** makes clear, much more will need to be done to rectify the overrepresentation of a small handful of dominant countries in the Global North. Far more research exploring perspectives within the Global South is also needed as several studies find differences within the Global South (Hussain et al. 2024; Beyerl and Maas 2014).

Figure 2.1 helps us understand which countries are the focus of study in SG perspectives research. However, these data are limited because they omit studies that do not aim to gather SG perspectives *from people in particular countries*. Several studies have different sampling criteria altogether and instead gather the perspectives of a small number of individuals from a larger number of countries. For example, the

workshop reported by Beyerl and Maas (2014) occurred in Fiji, and included a small number of individuals from the Cook Islands, Fiji, Kiribati, Nauru, Solomon Islands, Tokelau, Tonga and Vanuatu. Additionally, Baum et al. (2022) interviewed 125 climate engineering experts from 21 countries. It would be misleading to code these as studies that gather SG perspectives *from* each of these countries because few individuals from each country were ultimately included.[67] However, these studies do gather SG perspectives and, although they are not capturing large or nationally representative samples of participants, they have contributed to widening the diversity of perspectives that are represented.[68]

Therefore, to better capture who is represented in, and omitted from, SG perspectives research, we created estimates of the total number of participants from each country across all studies that provide original data. **Figure 2.2** below visualizes the total number of people within each country that have been included in SG perspectives research.[69] Data bars for countries in the Global South are orange.

[67] We are not suggesting that the authors of these studies make this claim; we are clarifying why we do not include them in our analysis of the number of studies per country.

[68] We do not suggest that the large-scale survey is "better" than a small deliberative workshop or focus group; only that it obtains the perspectives of more people, which is one advantage of a survey. Deliberative workshops and focus groups have their own advantages (see e.g., McLaren et al. 2016; Low et al. 2024; Bellamy et al. 2017). See Mercer et al. (2011) for a discussion of the disadvantages of surveys.

[69] Our data likely overestimate the total number of participants involved in specifically SG perspectives research because we coded for the total sample size for all studies, rather than coding for only those numbers of participants that were asked about or received information about SG. This applies to studies that ask different samples about different technologies (e.g., Jobin and Siegrist 2020) and to studies that use control groups who are not provided information about SG (e.g., Raimi et al. 2019).

Total Number of Participants per Country

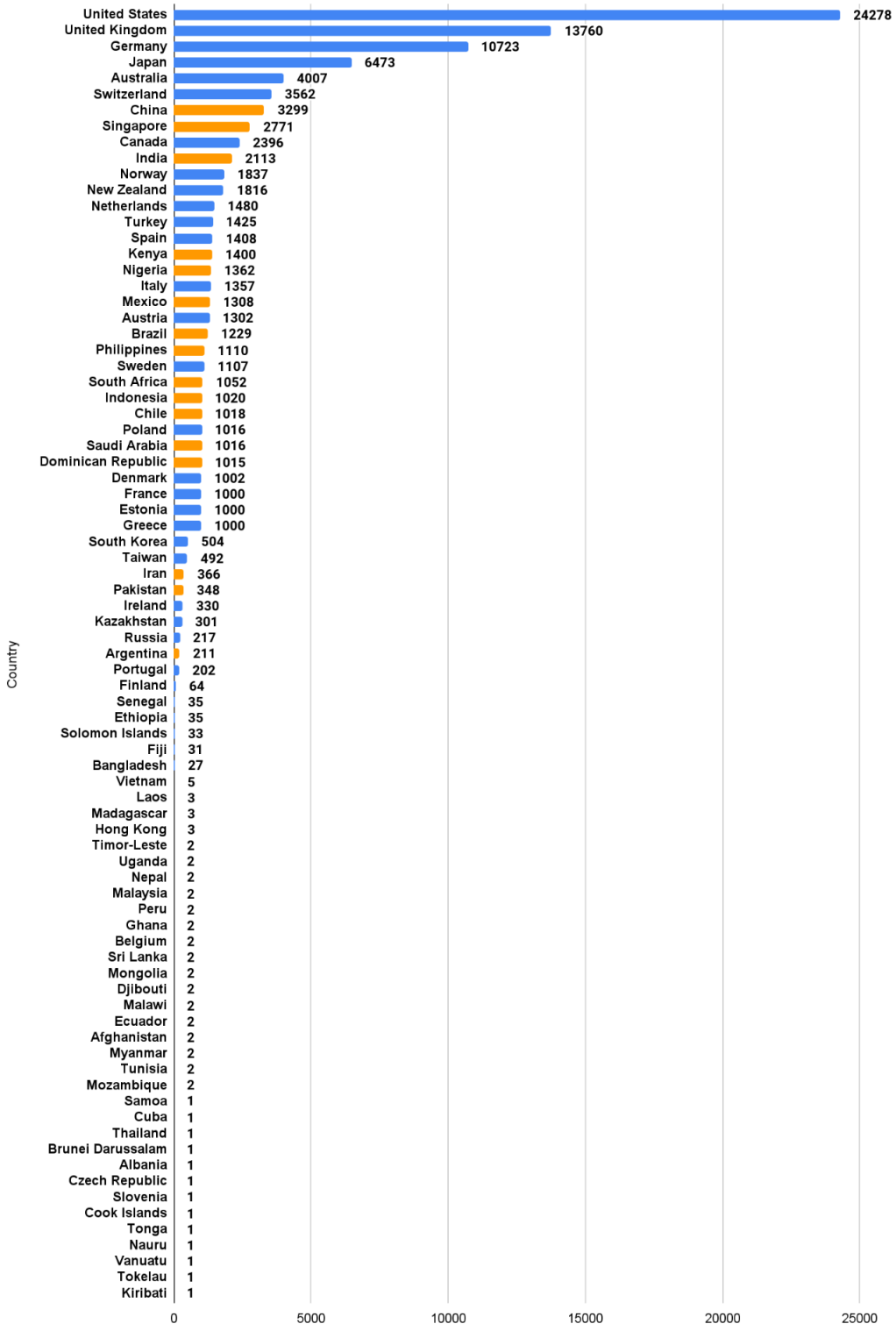


Figure 2.2: Number of participants in each country. Data bars for countries in the Global South are orange. A single study can be coded for multiple countries.

Figure 2.2 also illuminates the overrepresentation of the Global North in perspectives research, and particularly in three countries: the United States (N = 24,278); the United Kingdom (N = 13,760); and Germany (N = 10,723). Just four countries in the Global North (United States, United Kingdom, Germany, Japan) account for over half of the total number of participants (52.6%). However, it also usefully captures important, albeit limited, attempts to include the Global South in SG perspectives research. These data show that a small number of individuals from a wide range of countries have been included, particularly in South and Central America, Africa, Central and Southeast Asia, and the Pacific. And yet, very few individuals from most of these countries in the Global South are included. Of the 50 countries in the Global South that are included, 33 have five or fewer total participants.

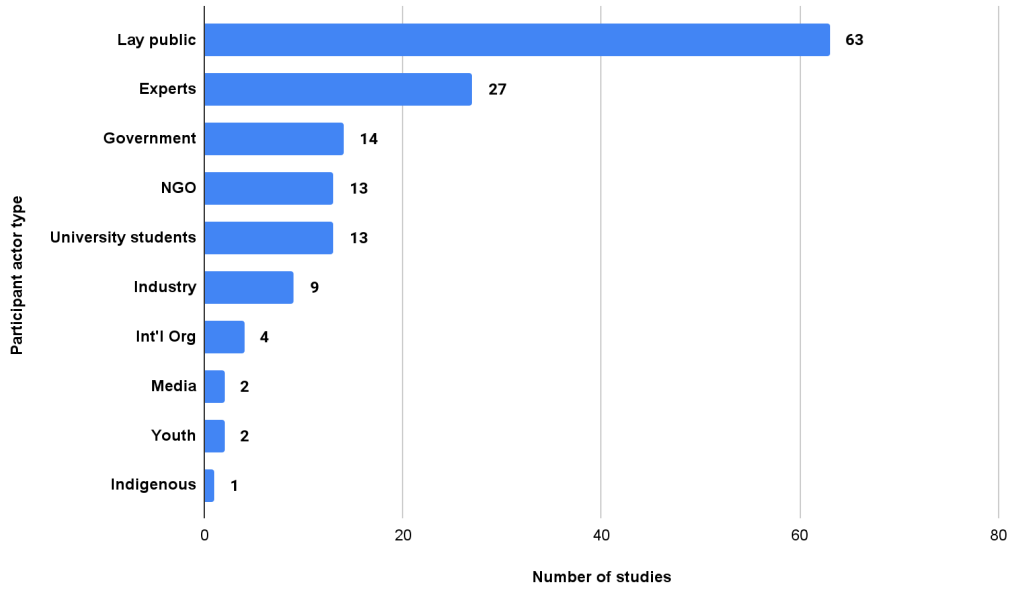


Figure 2.3: Number of studies by actor type. A single study can be coded for multiple actor types.

The majority of original SG perspectives research collects perspectives from lay publics (N=63). Though the distinction between laypersons, experts, and "stakeholders" is problematic (Winickoff et al. 2015), these studies generally aim to gather the perspectives of participants that are nationally representative or of people that do not hold specific SG or climate related expertise and who are not acting in their capacity as members of formal and organized groups, such as governments, NGOs, businesses, or international organizations.

However, other SG perspectives research also aims to understand the perspectives of a wider range of actor types. Some of the literature aims to better understand the SG perspectives of experts of varying disciplinary focuses and institutional affiliations (N=27). These studies collect the perspectives of experts of SG

modeling or governance (e.g. Baum et al. 2022; Merk et al. 2019); climate scientists (Dannenberg and Zitzelsberger 2019); experts in geopolitics (Versen et al. 2022); and others.

Members of government (local, subnational, and national) (N=14), regional and international organizations (N=4), non-governmental organizations (NGOs) (local, national, regional, and international) (N=13), and various professions, businesses, and industries (N=9) are also included in SG perspectives research albeit to a lesser extent.

Notably, youth and Indigenous persons are rarely included in SG perspectives research, with the exceptions of Carr (2016) who interviewed Alaskan Natives; Dunlop et al. (2022) who conducted online workshops with an international group of young people, and the Experiment Earth public engagement that held a discussion group with young people (Ipsos MORI 2010).[70] Studies of undergraduate students are more common (N=13), however, they are often a convenient sample, and these studies generally do not aim to understand their perspectives on the basis of having potentially distinct identities and interests as young people with respect to SG.[71] For example, Amelung and Funke (2015) use a sample of students to study 'laypeople's' perspectives, rather than youth perspectives per se.[72]

[70] Buck (2018) also notes that "some participants had Sámi heritage" (p. 80) but Sámi perspectives were not the focus of study, nor disaggregated for analysis.

[71] We define youth in line with the United Nations definition, as including persons between the ages of 15 and 24 years. Youth are also included in studies that aim to study public perspectives using samples of participants, particularly those that are representative in terms of age. These studies often but not always disaggregate results by age group.

[72] One exception is Carvalho and Riquito (2022) who use a sample of university students to investigate concerns related to intergenerational justice. Sugiyama et al. (2020) also study university students to control for educational level to better enable cross-country comparison.

Although the coding scheme displayed in **Figure 2.3** enabled us to understand in broad strokes which types of actors are commonly studied and which types of actors are neglected, the scheme also importantly elides several more complex attempts to understand the perspectives of a diverse range of actors. For example, Carvalho and Riquito (2022) designed their focus groups not to "represent a broader public" but rather to "politicize the discussion" (p. 5). To emphasize the political implications of geoengineering, they created several uniquely composed focus groups consisting of 'situated publics', including environmentalists, activists, science communicators, and promoters of holistic practices (Carvalho and Riquito 2022, p. 5).

3.2 RQ2: Who is producing the research? Where are those researchers based?

To answer this RQ, we totalled frequency counts of the primary institutional affiliation location for all authors on all 132 items in our database. This count, visualized in **Figure 2.4**, shows the number of times each country is represented in the primary affiliations of all authors of SG perspectives research, with Global South countries in orange.

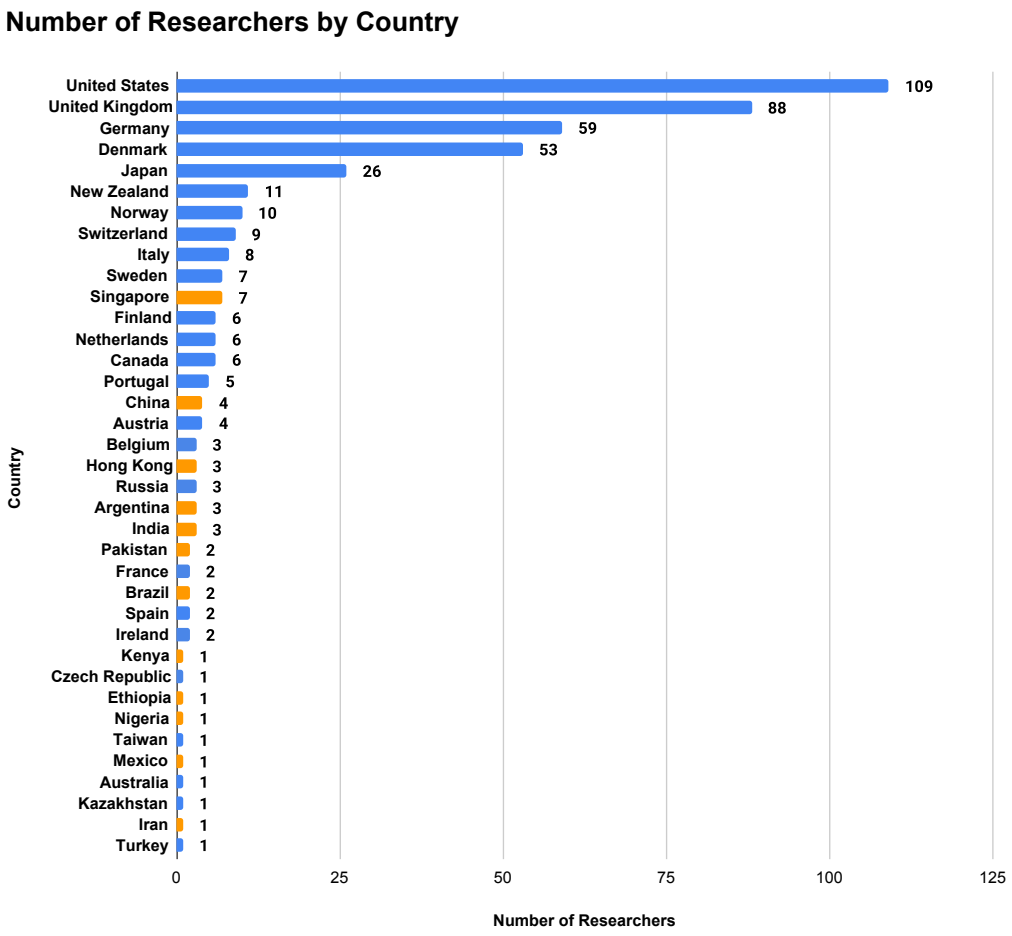


Figure 2.4: Researcher location by country. Data bars for countries in the Global South are orange. A single study can be coded for multiple countries.

The striking similarity between **Figure 2.4** (Research Location) and **Figure 2.1** (Participant Location) suggests that SG perspectives researchers are primarily studying the perspectives of participants in their own country. Indeed, all but two studies of German public SG perspectives have an almost entirely German author team; all but one study of Japanese SG perspectives has an exclusively Japanese author team by

institutional affiliation.[73] One recent large-scale study of 20 countries included research teams from each country (Contzen et al. 2024).[74]

Figure 2.4 again shows the dominance of the Global North in SG perspectives research, now in terms of who is producing the research. The United States, United Kingdom, and Germany account for 56.5% of all producers of SG perspectives research. Countries in the Global South are vastly underrepresented.

Importantly, the data do double count authors that have multiple publications, however this is not necessarily limiting. A single researcher from, for example, the United States that is an author of 10 SG perspectives studies would only further reflect the outsized role of the United States in producing SG perspectives research.

3.3 RQ3: How is research interest in SG perspectives changing over time?

Figure 2.5 shows the number of SG perspectives studies published each year between 2019 and 2023. Our data show an overall increase in SG perspectives research over time, through several waves, culminating in a strong resurgence of interest in 2022 and 2023 after a decline from the initial peak of interest in 2016. 2009 marks the release of the first known SG perspectives study in The Royal Society report (2009), which also

[73] There are exceptions. For example, Fenn et al. (2023) has an entirely German author team by institutional affiliation and study perspectives from the United Kingdom. Baum et al. (2024) and Fritz et al. (2024) also study perspectives from a large number of countries (30 and 22, respectively) but their research team is based in Denmark.

[74] Contzen et al. (2024) was designed by one core group of authors, and then research teams in other countries were invited to take part.

called for “further and more thorough investigations of public attitudes, concerns and uncertainties over geoengineering” alongside technological R&D (The Royal Society 2009, p. 43). From 2011 to 2023, over 8 items have been published on average each year. The data show an initial peak of 12 studies published in 2016 followed by a steady decline to a low of 6 articles published in 2020. The COVID-19 pandemic may have played a role in, though we note the relative decline in interest preceded the pandemic. However, interest in SG perspectives ramped up again in 2022 with a near high of 11 studies, and then sharply increased to a new high of 15 studies in 2023. 2024 is on track to surpass 2023. As of September 2024, 15 studies have been published in 2024.

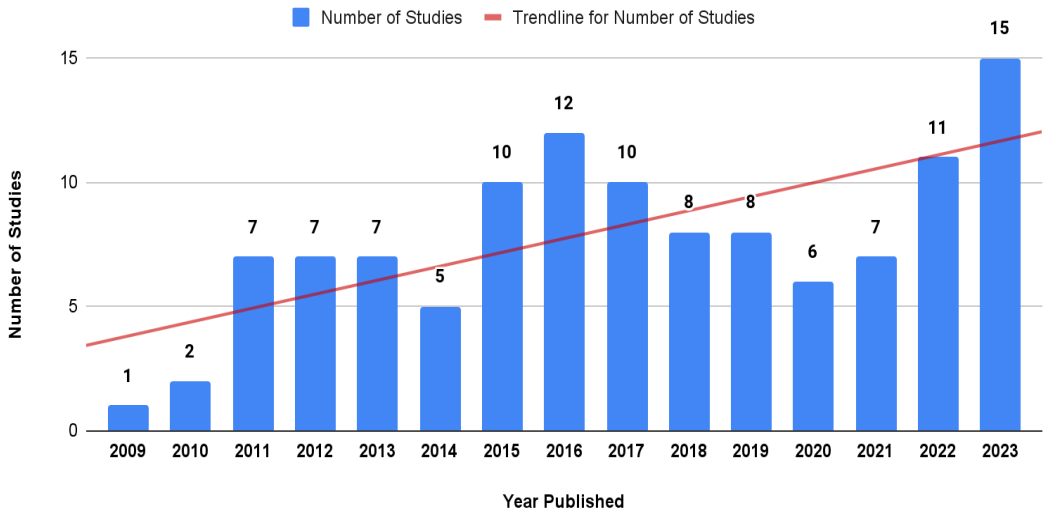


Figure 2.5: Number of studies published per year (2009-2023).

3.4 RQ4: What lines of inquiry are being pursued? What types of questions are being asked?

While some studies obtain reactions to SG in the most general sense, most studies seek to investigate more specific aspects of what or how people think about SG, sometimes using SG as a case to advance disciplinary lines of inquiry or to test competing hypotheses. We refer to these more focused investigations of SG perspectives as lines of inquiry. The lines of inquiry are not mutually exclusive and few studies include only one. We coded each article for the line of inquiry inductively, including both explicit focuses of study as well as key themes that arise in reported findings.

Table 2.3 summarizes the distribution of a non-exhaustive list of 21 lines of inquiry within the SG perspectives literature. **Table 2.3** shows that most SG perspectives research investigates whether people support SG research or deployment (N=84). The second most common line of inquiry explores factors that are associated with support for SG (N=49), followed by risk perceptions (N=44), concerns about physical and social impacts (N=42), and governance preferences (N=41). Receiving less attention are investigations of, for example, perspectives of issues related to justice and ethics (N=19), benefits (N=19), global politics (N=16), public engagement (N=9), capacity gaps and needs (N=7), and security or conflict (N=8). **Figure 2.6** displays the number of articles in our database that include each line of inquiry.

Table 2.3: Lines of inquiry in SG perspectives research, including definitions and references

Line of Inquiry	N	Definition	Key references
Support	82	Whether people support or approve of different forms of SG research or deployment, including in comparison to other climate responses.	Mercer et al. 2011; Mahajan et al. 2019; Jobin and Siegrist 2020.
Predictive Factors	49	Whether and how SG perceptions, particularly support, are associated with individual, societal, or contextual factors.	Merk et al. 2015; Visschers et al. 2017; Klaus et al. 2020
Risk	44	Perceptions of risk and risk-risk tradeoffs associated with SG research or deployment.	Amelung and Funke 2015; Sovacool et al. 2022b; Talati and Higgins 2019.
Impact Concerns	42	Concerns about physical and social impacts or consequences of SG research or deployment.	Mettiäinen et al. 2022; Carvalho and Riquito 2022; Carr and Yung 2018.
Governance	41	Perceptions of actual and preferred forms of governance for SG, including governance challenges, needs, adequacy and feasibility.	Sugiyama et al. 2020; Bellamy et al. 2017; Macnaghten and Szerszynski 2013.

Familiarity	30	Prior awareness of and familiarity with SG and its different methods and terms.	Carlisle et al. 2020; Mercer et al. 2011; Sugiyama and Fujiwara 2016.
Moral hazard[75]	28	Perceptions of the moral hazard hypothesis, or perceptions and behavior that might constitute evidence of moral hazard.	Corner and Pidgeon 2014; Austin and Converse 2021; Fairbrother 2016
Trust	23	Perceptions of trust in or credibility of certain actors associated with SG or of science or scientific knowledge.	Braun et al. 2018a; Klaus et al. 2021; Sugiyama et al. 2024
Framing	22	The impact of framing SG on perspectives, as well as how SG is framed by people.	Raimi et al. 2019; Bolsen et al. 2022; Corner and Pidgeon 2015
Justice, ethics	19	Perceptions of the ethics and justice related dimensions of SG, including ethical concerns and conceptions of (in)justice.	Carr et al. 2012; Sovacool et al. 2022b; McLaren et al. 2016
Benefit	19	Perceptions of benefits or positive impacts associated with SG research or deployment.	The Royal Society 2009; Sovacool et al.

[75] The moral hazard hypothesis suggests that discussion, research, or deployment of SG will inappropriately draw attention away from mitigation.

			2023a; Cummings and Rosenthal 2018
Global politics	16	Perceptions of the global politics and geopolitical issues associated with SG.	Carr and Preston 2017; Versen et al. 2022; Beyerl and Maas 2014
Nature	14	Perceptions of the relationship between nature and SG and of the 'naturalness' of SG.	Jobin and Siegrist 2020; Raimi et al. 2020; Corner et al. 2013
Effectiveness	13	Perceptions of the effectiveness or efficacy of SG and SG methods.	Sovacool et al. 2022c; Mercer 2014; Mahajan et al. 2019
Affect	9	Affect and emotions associated with SG.	Sütterlin and Siegrist 2017; Merk and Pönitzsch 2017; Braun et al. 2018b
Public engagement	9	Perceptions of public engagement issues associated with SG, including its importance and how to do it.	Scheer and Renn 2014; Bellamy and Lezaun 2017; Fritz et al. 2024

Security	8	Perceptions of the relationship between SG and security, conflict, and war.	Versen et al. 2022; Sovacool et al. 2023b
Capacity	7	Perceptions of capacity related issues associated with SG, including capacity gaps and needs.	Winickoff et al. 2015; Sugiyama et al. 2017; Delina 2021
Conspiracy	4	The chemtrails conspiracy theory and its relationship to SG perspectives.	Debnath et al. 2023; Tingley and Wagner 2017; Müller-Hansen et al. 2023
Sense-making	3	How people make sense of the idea of geoengineering.	Wibeck et al. 2015; Asayama et al. 2017; Wibeck et al. 2017
Free-driver	3	Perceptions of free-driving,[76] or studies of behavior that constitute evidence of the free-driver conjecture.	Abatayo 2020; Cherry et al. 2024

[76] The free-driver conjecture suggests that because SG is relatively cheap and may be deployed unilaterally, the country that prefers the most amount of cooling will deploy SG by itself and at a level that is higher than what would be optimal for all countries (Weitzman 2015).

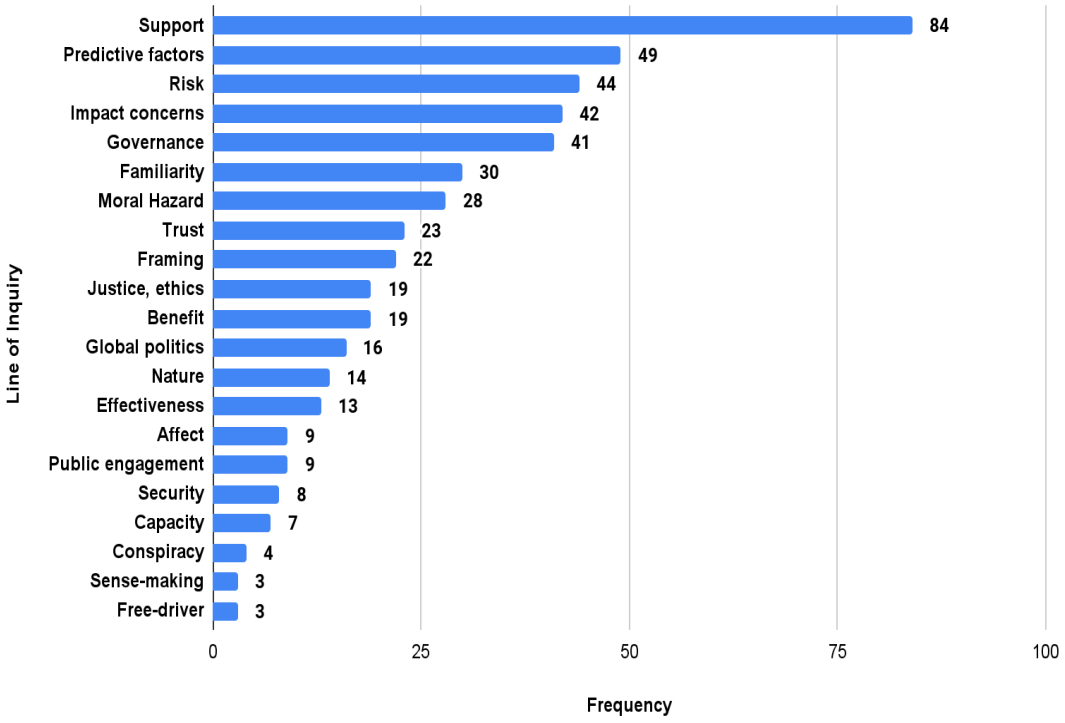


Figure 2.6: Number of studies that include each line of inquiry. A single study can be coded for multiple lines of inquiries.

3.5 RQ5: How is the research being done? What methods are used?

To answer RQ3, we identified the methods used to obtain SG perspectives from all studies that report original data, visualized in **Figure 2.7**.

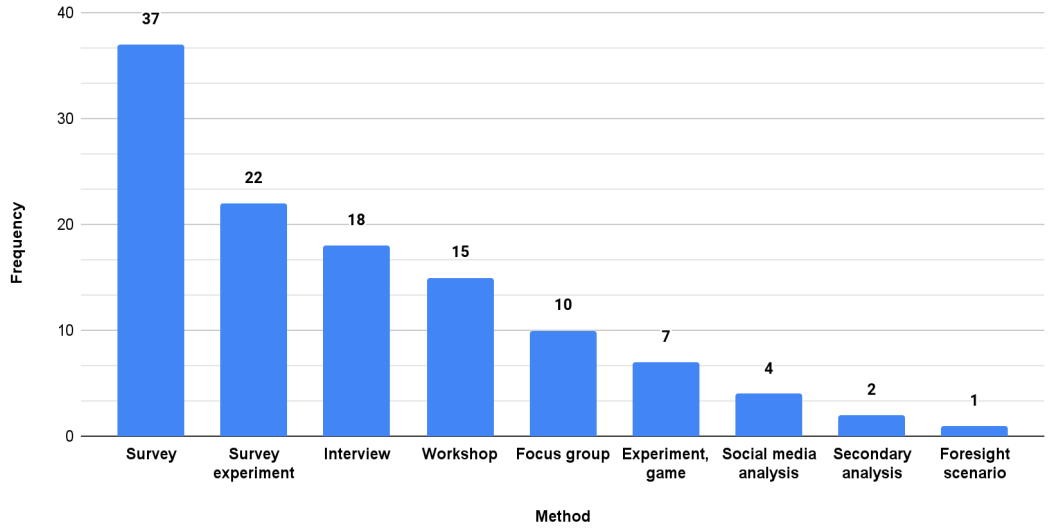


Figure 2.7: Research method used. A single study can be coded for multiple methods.

Figure 2.7 shows that surveys are the most common method of collecting SG perspectives (N=37), survey experiments (N=22), interviews (N=18), workshops and other deliberative formats (N = 15), and focus groups (N=10). Survey experiments introduce some form of treatment effect to study SG perspectives, often by varying the information provided to participants. Aside from survey experiments, Amelung and Funke (2015) conducted an interview based experiment. Seven studies use another form of experiment or economic game to study perspectives and behavior related to SG.

Four studies use some form of technology assisted social media analysis, such as Tingley and Wagner (2017) use a 'supervised learning method' and 'automated sentiment analysis', and Debnath et al. (2023) who use natural language processing, deep learning, and network analysis. Additionally, two studies employ some form of

secondary content analysis of written text to study SG perspectives. Huttunen et al. (2015) used 'frame analysis' of policy documents, and Oldfield and Poberezhskaya (2023) study debates in Soviet and Russian SG scholarship.

Finally, one study uses a foresight scenario exercise to understand expert views (GAO 2011).

3.6 RQ6: Why is the research being produced? What rationales are given for why SG perspectives are important to know?

The literature includes many types of statements that explain why it's important to know what people think about SG. We refer to these statements as motivations, or rationales for producing SG perspectives research. The rationales are not mutually exclusive, and many studies link several motivations together to explain why the particular knowledge a study aims to produce is valuable, or rather what the knowledge can or should be used to do. We coded primarily for explicit rationales, however perspectives research can have implicit rationales as well (Cairns 2018).

Table 2.4 below summarizes the distribution of rationales across the SG perspectives literature and provides an example of each. **Table 2.4** and **Figure 2.8** show that by far the primary motivation underlying the SG perspectives literature is to inform SG related decision-making or governance (N=85). About half as many studies aim to inform or improve SG research (N=43), the second most common rationale. The next most common rationales are to inform SG discussion or debate (N=38) and to inform

strategies for communicating about SG (N=32). Less frequent motivations include enhancing inclusion (N=23), informing public engagement (N=18), advancing democracy (N=10), building capacity or informing capacity building efforts (N=8), advancing justice (N=6), and fulfilling a moral imperative (N=4). Some articles aim to inform efforts to increase public support for SG (N=12).

Table 2.4: Rationales for producing perspectives research, including definitions and examples

Rationale	N	Definition	Example
Inform decision-making	85	Inform, improve, or enable decision-making or governance, encompassing policy-making and decision-making related to research and funding.	"... information on public perception is one important prerequisite for making informed decisions on research and deployment" (Braun et al. 2018b, p. 144).
Inform research	43	Inform or improve SG related research or assessment processes, outcomes, or agendas.	A "wide understanding of public opinion may not only signal research priorities and concerns to regulators, but also may be an aid to

			geoengineering research agendas …" (Cummings et al. 2017, p. 250).
Inform discussion	38	Inform or intervene in public or expert discussion, debate, deliberation, or discourse.	" ... this study aims to inform the debate about public perceptions of SRM …" (Mercer et al. 2011, p. 2).
Inform communication strategy	32	Inform strategies for communicating about SG to the public or other actors.	"... to stimulate people to consider both the risks and the benefits of SRM, risk communication should draw people's attention to the benefits of SRM" (Visschers et al. 2017, p. 541).
Public importance assertion	28	Understanding of public perspectives is needed because SG research and/or implementation requires public acceptance, approval.	"... public acceptance will crucially determine the future of research on [climate engineering] …" (Braun et al. 2018a, p. 472).

Enhance inclusion	23	Enhance inclusion of neglected people, perspectives in SG discussion, research, or governance.	"The study presented below was an attempt to expand the number of perspectives currently being listened to in ongoing discussions about climate engineering research and governance" (Carr and Yung 2018, p. 121).
Inform public engagement	18	Inform the aim or design of public engagement efforts in SG research or governance.	" … scientists and policymakers require guidance on how to engage with public views on climate engineering techniques in a way that will not provoke controversy… " (Feetham 2016 p. 6).
Open up	15	'Open up' SG research, appraisals, discussion, or governance to a wider diversity of perspectives, issues, concerns, and values	Studying public perspectives "can provide insights into value and ethical concerns not ordinarily

			considered by scientists and engineers …" (Pidgeon et al. 2012, p. 4177).
Increase public support	12	Inform efforts to increase public support for SG research or deployment.	Our findings suggest "framing will be very influential in shaping the public's attitudes, and that if widespread support for research is a desired goal, it will be necessary to carefully frame [SG] …" (Bolsen et al. 2022, p. 9).[77]
Democracy	10	Advance or enable democracy or democratic principles in SG research or governance.	Perspectives research "can (and should) be used as a means of informing open, democratic

[77] We provide the extended quote to give context: "Decades of survey research has demonstrated the deep politicization around the topic of "climate change" in the United States. However, our findings show that solar geoengineering is, as yet, a strategy that is unfamiliar to most Americans, and that it also has not yet become politicized. This presents both an opportunity and a challenge. The opportunity will be to take advantage of this lead-time before the issue becomes more central to public discourse to properly frame the issue. The research in this paper suggests that framing will be very influential in shaping the public's attitudes, and that if widespread support for research is a desired goal, it will be necessary to carefully frame solar geoengineering in order to avoid some of the issues that have arisen with vaccines or other issues that became controversial and politicized as the public learned more" (Bolsen et al. 2022, p. 9).

			discourse on SRM governance" (Sugiyama et al. 2020, p. 652).
Capacity building	8	Build participants' capacities as related to SG or inform capacity building strategies.	Our study aims to "enable young people to communicate their perspectives and conclusions with their peers" (Dunlop et al. 2022, p. 63).
Expert importance assertion	7	Understanding of expert perspectives is needed because of the important role(s) of experts.	"Expert opinions are important because … experts typically have greater access to policy makers than do members of the public" (Dai et al. 2021, p. 2).
Justice	6	Advance or pursue justice.	We hope our findings "can inspire all of us to resist the patterns of injustice that are emerging with negative emissions and solar geoengineering

			technologies, and imagine a better future that is more just ….” (Sovacool et al. 2022b, p. 19).
Responsible innovation	6	Contribute to or enable responsible innovation.	Perspectives research should be conducted “with a view to being part of a broader process of responsible innovation …” (Corner et al. 2012, p. 462).
Moral imperative	4	Fulfill a moral imperative to engage publics and/or vulnerable populations.	“ ... those who might be impacted by a technology simply deserve a say in the research and development of that technology” (Carr 2016, citing Stirling 2008).

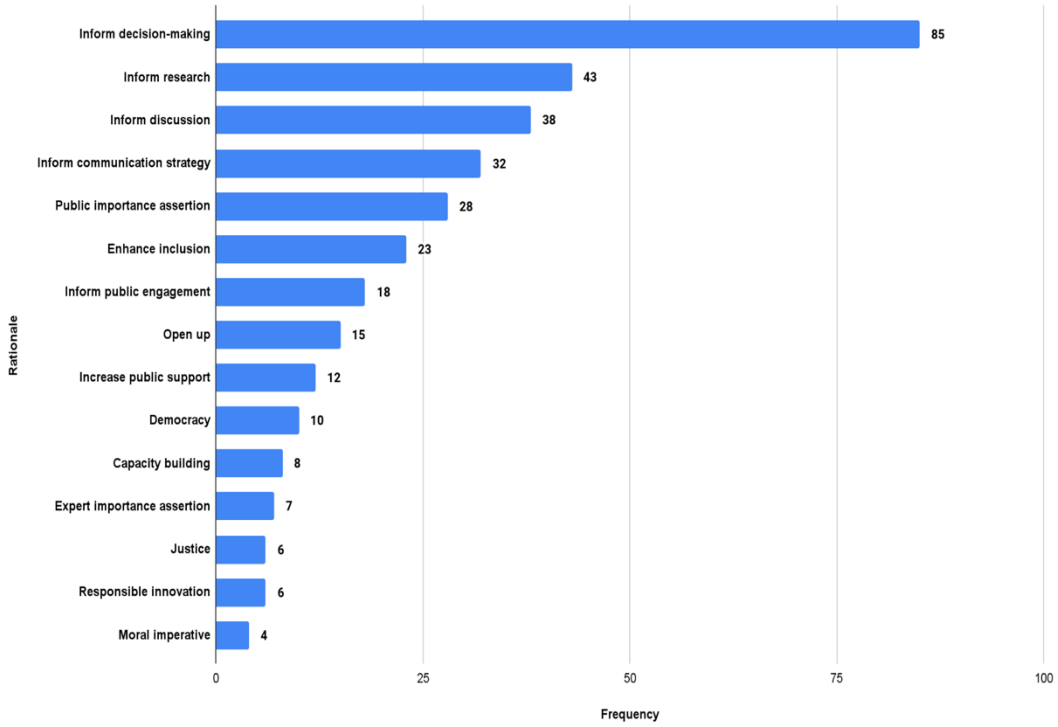


Figure 2.8: Rationales for producing SG perspectives research. A single study can be coded for multiple rationales.

4. Discussion

Centrally, our analysis of 132 items, published between January 2009 and September 2024 demonstrates growing, albeit still limited, attention towards diverse participant locations, many objects of study, and a variety of diverse and sometimes conflicting research rationales. However, our analysis yields four major findings related to the SG perspectives research process that demand attention: (1) the findings are still severely

limited by inequitable geographic and social representation in participants and researchers; (2) investigations of support for SG dominate the literature to the neglect of other important lines of inquiry; (3) there is a widespread motivation to inform decision-making without clear articulation of how to actually do so; and (4) there is an explicit intent to use research findings to increase public approval. We conclude in this section with a discussion of these critically important issues and our recommendations for researchers who wish to enhance the potential of SG perspectives research to enable effective, inclusive and just SG governance.

4.1 Geographic and social gaps and possibilities

SG perspectives research has been heavily dominated by perspectives from the Global North (Sugiyama et al. 2020; Burns et al. 2016; Winickoff et al. 2015) and by perspectives of non-youth participants. Existing studies that do include Global South publics demonstrate that this inequity is problematic because there are clear differences in public perspectives on SG between the Global North and Global South (Sugiyama et al. 2020; Baum et al. 2024; Carr and Yung 2018; Winickoff et al. 2015; Visschers et al. 2017), with data showing publics in the Global South in general are more open to SG than those in the Global North (e.g., Sugiyama et al. 2020; Baum et al. 2024), and there are also important differences in perspectives within the Global South (Hussain et al. 2024; Low et al. 2024). More importantly, an overrepresentation of Global North perspectives and a neglect of Global South perspectives risks reinforcing injustice

“because it can lead to subjugating less powerful to more powerful opinions" (Sugiyama et al. 2020, p. 652, see also McLaren et al. 2016). A lack of knowledge of how the Global South understands SG presents a failure of recognition justice, which demands that SG impacts are understood from the perspectives of vulnerable populations (Hourdequin 2019; Preston and Carr 2018). This inequity also undermines the efficacy of SG research, as “research on SRM cannot fully comprehend or take account of the diverse distributive impacts of this technology without robust engagement and input from those affected and their distinctive cultures, perspectives, and relationships to the natural environment (Hourdequin 2019, p. 465-466). As Stilgoe (2015) has argued, anticipating potential impacts of climate engineering “does not depend on the strength of our crystal balls; it depends on whom we choose to talk and listen to” (p. 35). More broadly, concerns for the inclusion of the Global South and other marginalized communities have long been voiced in the broader SG literature (Szerszynski et al. 2013; Hamilton 2013; Rahman et al. 2018; Biermann and Möller 2019).

Several recent large-scale studies have helpfully enabled many new countries including from the Global South to be represented in SG perspectives research (Baum et al. 2024; Fritz et al. 2024; Contzen et al. 2024). However, as **Figures 2.1 and 2.2** above make clear, this geographic disparity remains stark, and far more research investigating perspectives in the Global South is needed.

Ours is the first study to aggregate and quantify this rich empirical data to enable us to visualize these inequities. We are also the first to analyze author location

data (**Figure 2.4**). When overlayed with our participant location data (**Figure 2.1**) this new data illuminates that perspectives researchers primarily study perspectives from the countries and regions in which they reside. This is not necessarily limiting, as these researchers may be better able to engage participants in culturally appropriate ways and interpret and analyze perspectives because they understand the local context, discourse, and culture. After all, empirical work requires linguistic and cultural competencies (Burns et al. 2016).

However, this does suggest that diversifying SG perspectives research in terms of dramatically scaling up collection of perspectives from the Global South may accelerate when researchers from the Global South are engaged. Diversifying the researchers involved in SG perspectives research may also enrich the literature by catalyzing new research questions and lines of inquiry. And yet, gaps in various forms of capacity, including in the ability for professional survey or marketing research firms to provide researchers with samples of participants from the Global South, may hinder this approach. We suggest the need for capacity building programs with collaboration from SG perspectives researchers from the Global North and Global South, led and informed by the needs of Global South researchers, in line with best practices in capacity building (Khan et al. 2018). The Degrees Socio-political Fund is catalyzing this work (The Degrees Initiative 2023). In 2024, they provided $405,000 USD to researchers from the Global South working on social science aspects of SG with a

strong emphasis on perspectives research.[78] Similar programs should also build capacities that are needed for participation in perspectives research among publics and other actors, notably youth in the Global South.

We also highlight that while most of the research examines perspectives from lay publics and from experts, few solicit the perspectives of Indigenous populations and youth, as well as from other climate vulnerable groups in both North and South. Studies of undergraduate students wherein students are included as a convenient proxy for public or lay perspectives do not sufficiently investigate their perspectives as young people that must live with the consequences of current day decisions about climate responses generally and SG in particular. Rather, this necessitates research that aims to seek out and understand the perspectives of youth.

Importantly, researchers seeking to include Indigenous peoples in research should be aware of different possible models of Indigenous participation and should avoid "extraction-based Indigenous involvement that conform to colonial norms" in favor of models premised on Indigenous rights, sovereignty, and leadership (Liboiron and Cotter 2023, p. 12). Efforts to investigate Indigenous peoples' perspectives and narratives on SG would also do well to be mindful of Whyte's (2018) explanation of why geoengineering discourse is not salient to some Indigenous peoples, and how

[78] Staff informed us through private correspondence that they intend to offer an unknown amount of additional funding as well.

contextualizing SG within broader discussions and concerns surrounding colonialism, power, and risk may be necessary.[79]

Recommendation #1: Institutionalize the inclusion of youth and the Global South by building capacity to produce and participate in SG perspectives research with collaboration from a global network of researchers.

4.2 Focus on support and approval, to the neglect of other pressing issues

Our results (**Table 2.3** and **Figure 2.6**). show that SG perspectives research is dominated by investigations of support and approval for research or deployment, alongside investigations of factors associated with support. While the knowledge produced by this line of inquiry is important, exclusive investigations of support present a missed opportunity to investigate other aspects of SG perspectives that can help address important issues related to the current state of SG research and discussion.[80] We echo Burns et al.'s (2016) call to "pursue new and understudied lines of research and link them to current public policy questions" (p. 541).

Specifically, despite widespread acknowledgement that public engagement is needed, questions about when and how publics and different groups of people should

[79] Some may argue that the study of Indigenous people's perspectives on SG should be left to Indigenous scholars, in pursuit of the goal that they develop their own research, engagement and deliberation on issues that matter to them (Whyte 2018; Smith 1999).
[80] Terms such as support and acceptability also often lack clear definitions and can be interpreted in different ways (Moesker et al. 2024).

be engaged in SG research and decision-making, particularly in different cultural contexts, remain unanswered. Perspectives research is well positioned to produce knowledge that can inform the design of robust and inclusive engagement processes, by for example investigating cross-cultural perspectives of when publics expect to be engaged and the most appropriate and effective way to do so. Doing so may be a way to fulfill the moral imperative to perform "participatory engagement in the design of the processes themselves" (Hourdequin 2019, p. 566).

Additionally, while virtually all authoritative SG assessments and reports agree on the need to include the Global South in SG research, discussion, and decision-making, and some acknowledgement that capacity building is needed to this end (NASEM 2021), many questions remain about the most effective and inclusive ways to build capacities needed for SG governance and research (Dove et al. 2024a). Perspectives research is also well positioned to produce knowledge of what forms of capacity are needed, where, and what are the most effective and inclusive ways to build capacity in different contexts (e.g., Delina 2021).

Finally, much of the expert debate surrounding SG revolves around questions of justice and assumptions about what climate vulnerable populations may or may not want (see, e.g., Biermann et al. 2021; Parson et al. 2024; Stephens et al. 2023; Lin and Hourdequin 2023; Táíwò and Talati 2022). While the perspectives literature has helpfully identified a range of concerns related to justice and ethics, we know little about what climate vulnerable populations understand justice to require in the SG

context and whether justice can be best pursued by restricting or enabling SG research and discussion.

Recommendation #2: Prioritize neglected lines of inquiry, especially as related to current needs and issues, such as informing the design of engagement processes and capacity building programs and informing debates surrounding justice and SG.

4.3 Better integrating of SG perspectives research into SG decision-making, research, communication, and discussion

Our results displayed in **Table 2.4 and Figure 2.8** show that SG perspectives research is overwhelmingly motivated to inform decision-making, followed by research, communication strategies, and discussion. However, and particularly as related to informing decision-making, it is unclear *how* the literature aims to do so. Many articles state their findings can or should inform decision-making but do not explicitly state how decision-makers can make use of the findings, and it is unclear how perspectives researchers expect decision-makers to become aware of their findings in the first place. As such, the relationship between the production of knowledge of SG perspectives and its use remains vague and undeveloped. SG perspectives research risks falling prey to a common limitation of public engagement more generally, which is that "even where a dialogue process is run successfully, the findings may have little impact in policy terms because in effect they have 'nowhere to go'" (Corner et al. 2012, p. 462).

There is therefore a need to institutionalize the integration of SG perspectives research into SG decision-making and research, by providing decision-makers and researchers with a way to integrate the knowledge produced by SG perspectives research.[81] There is a need for an international stocktake, assessment, and synthesis process for SG perspectives research that would provide balanced synthesis summary reports for a range of users, including policymakers, research funders, researchers, government regulators, communication specialists, publics and more.

Proposals to establish an SG assessment at UNEA-4 and SG expert group at UNEA-6 were met with hesitation from some delegates from the North and South, indicating that the establishment of a formal international assessment of SG perspectives will face similar challenges. At the same time, at UNEA-6, most states still wanted to know more about SG and expand access to SG research through a shared repository, and in line with our findings and recommendations, many Southern delegates expressed a desire to counter the dominance of Northern knowledge and fill in gaps in knowledge (McLaren and Corry 2024). The details of a broader SG governance framework should not need to be fully negotiated first: a preliminary synthesis and assessment of perspectives research could provide knowledge on global preferences to inform subsequent international negotiations on whether and how to

[81] Depending on a study's aims, representativeness, and methodological rigor, it may not be appropriate for all studies of SG perspectives to inform decision-making, either on their own or when synthesized or aggregated with other studies. One task for the stocktake and assessment process we outline here would be to determine what sort of decision-relevant perspectives research is needed and to identify criteria for including or excluding specific studies from consideration. It would also need to develop a process for synthesizing or analyzing research with diverse aims and methodologies, including by drawing on innovations and best practices in meta-analysis.

create a broader assessment process and/or to establish more formal governance arrangements.

A more rigorous SG perspectives stocktake and assessment process could build off the assessment framework we developed in this study to identify important gaps and needs on an ongoing basis. The mechanism could also pursue other ways of disseminating knowledge, including through panel briefings and public events, and it could commission tailored reports or research projects based on the specific needs of various actors.

Such a collective process would lessen the need for individual research teams to disseminate results on an ad-hoc basis and would ensure that decision-makers obtain a comprehensive and balanced understanding of all relevant research. The mechanism could also facilitate the coordination of large scale research that requires more time and resources than can be mustered by individual researchers. It could also play a role in coordinating perspectives research capacity building programs for researchers and participants alike.

Recommendation #3: Develop an international stocktake, assessment, and synthesis process for SG perspectives research and link it to decision-making and research programs.

4.4 Consider the ethical and strategic implications of using research to manipulate perspectives

Previous research has identified the "risk that public perception research could be used instrumentally for eliciting the "public" views by the powerful actors to justify their favorable positions" (Sugiyama et al. 2020, p. 652; Hourdequin 2019). Here we highlight the risk that SG perspectives research is used instrumentally to inform the design of communication strategies for fostering support or otherwise shaping or manipulating SG perspectives by drawing on empirical insights from the research, such as the susceptibility of support for SG to the way it is framed (see **Table 2.4**).[82] We identify several studies that explicitly provide recommendations on how to foster support for SG (e.g., Jobin and Siegrist 2010; Bolsen et al. 2022), and we note that other studies more generally discuss the potential for SG acceptance and perspectives to be shaped based on specific research findings (e.g., Klaus et al. 2020; Raimi 2021).

In addition to illustrating this rationale using the quote from Bolsen et al. (2022) included in **Table 2.4**, we provide an extended quote from Bolsen et al. (2025, p. 2-3) to further demonstrate:

> "Despite the publicity surrounding these announcements (NASEM 2021; OSTP 2023), numerous studies have demonstrated that the public is generally uninformed about solar geoengineering in general, and

[82] We recognize that efforts to use research insights to inform public communication strategies are common in perspectives research on environmental issues and other emerging technologies. To be clear, we do not claim that researching SG perspectives to inform public communication strategies is in itself a problematic motivation. In the SG context, the issue lies in developing communication strategies specifically designed to shape support, rather than, for example, to encourage informed reflection and balanced weighing of risks and benefits. While shaping support may be appropriate on broader issues with high scientific consensus, i.e. climate change and the need to adopt climate policies, we are skeptical of its appropriateness for emerging technologies such as SG, where uncertainty about risk and potential benefits is high and the knowledge base needed for informed decision-making does not yet exist.

> Stratospheric Aerosol Injection, in particular (Cummings et al. 2017; Burns et al. 2016; Mahajan et al. 2019; NASEM 2021, p. 81; Raimi 2021). Prior research also suggests that because of this unfamiliarity the way that information about this technology is framed has a major impact on public response (Raimi 2021; Rosenthal et al. 2023). This study focused on media framing of SAI to gain insights into its impact on public opinion formation. Such understandings are important for several reasons. First, policymakers are unlikely to support or invest in the development of these technologies in the face of widespread public resistance (Druckman 2013). Second, engaging the public in deliberations over new scientific technologies fosters transparency, inclusivity, and trust in government decision-making that can improve the likelihood of successful adoption (Stirling 2008)" (emphasis added).

Though the rationale in this quote is more implicit, the authors clearly draw a link between understanding the impacts of media framing on public opinion formation and the need to build support and trust to achieve successful development and adoption. At a minimum, this and other research shows how that support could be generated, including by strategically framing media communications. However, more research and deliberation is needed to responsibly make decisions about whether these technologies should be developed or adopted in the first place (NASEM 2021), and publics should be empowered to play a role in making these decisions early on - even if they ultimately decide not to support development or adoption.[83] If publics decide to support research or development, it should be because they developed their own informed perspectives through honest and transparent exchange of balanced

[83] These issues, including as related to using public engagement to restore trust in science and public deficit models of engagement, have been explored by science and technology studies perspectives on public engagement. See, for example, (Wynne 2006; Delgado et al. 2011).

information and through robust and inclusive deliberation - not because they were exposed to strategically framed communications.

Overall, the production and use of SG perspectives research to shape what and how people think about SG raises ethical and strategic dilemmas that risk undermining the potential of the research to enable good governance. We are concerned that, if this trend continues, it could enable a deceptive and egoist form of politics, whereby powerful actors use research insights to deploy communication strategies to shape perspectives in line with their own preferences or goals. We note that this may not only be unethical but also strategically fallible. Using SG perspectives research for this purpose may counterproductively backfire and increase public opposition and controversy surrounding SG if publics were to believe that their perspectives were being deliberately manipulated. On the other hand, if support for SG were successfully generated, this could create social pressure for unilateral or irresponsible forms of research or deployment, and it could also contribute to undesirable forms of lock-in (Cairns 2014; Lin 2020).[84] For these reasons, we urge caution in efforts to use research insights to shape support for SG and balanced assessment of the risks involved.

We note that researchers do not have control over how and for what purposes their research is used, but we have highlighted here explicit attempts in the research to anticipate and enable this potential. We call for discussion to better understand,

[84] 'Lock-in' describes "how particular technologies—through their co-evolution with social, institutional, cultural, and political systems—may become resistant to change, 'closing down' or constraining possibilities for the development of alternative (possibly superior or more socially/environmentally desirable) socio-technical configurations" (Cairns 2014, p. 650). Social support can be a mechanism for producing lock-in.

anticipate, and address the ethics, appropriateness, desirability, and consequences of using SG perspectives research for this purpose. SG perspectives researchers should embrace the political nature of the knowledge production process, which requires acknowledging that research, and particularly perspectives research, can be used for a wide range of possibly conflicting purposes. As Cairns (2018) argues, perspectives research is a high-stakes activity. SG perspectives research can both enable and degrade just, inclusive, and effective forms of SG governance and politics. SG perspectives researchers should play a conscientious role in deciding which it will be.

Recommendation #4: Reflect on and discuss the ethics, appropriateness, and desirability of using or producing knowledge of SG perspectives to justify particular research or policy choices and to shape support for research or deployment.

These important issues in the SG perspectives literature are likely to apply to the governance of other emerging technologies, many of which also have dedicated bodies of perspectives research. Our analytical framework can be used to determine whether these issues do apply in these other areas. Where they do, our recommendations should be considered and applied to enhance the potential of perspectives research within multiple emerging technology issue areas to enable effective, inclusive and just governance of emerging technology more generally.

Chapter 3

Building capacity to govern emerging climate intervention technologies

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Introduction

Emerging climate intervention technologies including carbon dioxide removal (CDR), atmospheric methane removal, and solar geoengineering offer tremendous opportunities and challenges for the global response to climate change and sustainability more broadly. These forms of climate intervention technologies are receiving growing public, political, and scientific attention as it appears increasingly likely that relying on mitigation and adaptation alone will not be sufficient to avoid severe climate impacts (IPCC 2022). However, these emerging technologies also present a range of ecological and social risks and challenges, necessitating inclusive and effective forms of governance (NASEM 2023; NASEM 2021; National Research Council 2015). Governance refers to the institutions and processes through which

public and private actors work to address political goals in a given issue area, in this case around climate intervention research or potential deployment (Dove and Talati 2023; Chhetri et al. 2018). Governance is needed to accomplish several important functions, such as detecting and deterring irresponsible research or unauthorized deployment, and it can take many different forms, including for different climate intervention techniques and for different stages of any potential research or deployment activity. Some of the forms it might take include, for example, rules and regulations, incentives, voluntary guidelines, public engagement, international cooperation, and disclosure mechanisms that aim to bring transparency to any climate intervention activity. And yet, developing and implementing governance that is just, inclusive, and effective is challenging. Authoritative assessments of climate intervention technologies generally agree that the technologies are currently insufficiently governed, as existing forms of governance are incapable of addressing all risks and challenges associated with their research and deployment (e.g., NASEM 2021; NASEM 2023; UNEP 2023).

Governance requires capacity, which can be understood as knowledge, skills, tools, practices, or resources. Those forms of capacity required by governance can be understood as governance capacity. Where and when governance capacity is lacking - in order for governance to effectively meet its goals - it must be built. Capacity building is therefore needed to enable governance efforts that can ensure emerging climate intervention technologies contribute positively to sustainability transitions by

enhancing, and not degrading, human and environmental well-being.[85] Capacity building can generally be understood as a process through which actors, institutions, or societies enhance their ability to solve problems and achieve goals by building or strengthening relevant skills, knowledge, tools, or practices (Khan et al. 2018). Here we argue for a concerted effort towards what we term '*governance capacity building'* for climate intervention technologies. We define governance capacity building as:

> A process through which individuals and/or organizations mobilize and sustain knowledge, skills, tools, and practices that enable them to engage in the development and *implementation* of local, national, and international forms of governance of research and deployment of emerging climate intervention technologies (DSG 2023).

Governance capacity building is needed to strengthen governance, research and/or deployment of all forms of emerging technologies, including climate intervention technologies. Here we focus on the solar geoengineering case to illustrate the need for near term *governance* capacity building that is inclusive and comprehensive. Research and discussion of SG as a potential response option to climate

[85] We retain the use of the term 'capacity building' mainly to remain legible to other scholars and practitioners working in this space, and because capacity building is the established term in the climate issue area, as the term is used by the United Nations Framework Convention on Climate Change (UNFCCC). We are concerned that adding new terminology would unnecessarily further complicate an issue area already overburdened by the use of many terms to refer to similar phenomena. Some aid agencies and scholars prefer to use the term 'capacity development' to acknowledge that there are existing capacities that should be strengthened. There is some debate over whether they refer to the same thing; at times they are used interchangeably (Khan et al. 2018). We use capacity building but emphasize that it entails strengthening existing capacities. Moreover, we wish to acknowledge that NGOs and various actors in the Global South have done impressive work to improve how capacity building is conceptualized and practiced. We think it is worthwhile to continue to build off of this work rather than to start from scratch.

change has been steadily growing for almost two decades. Solar geoengineering (SG), also called solar radiation management (SRM), refers to a set of technologies and techniques that aim to artificially cool the planet by reflecting a small proportion of incoming sunlight back into space (NASEM 2021; National Research Council 2015). The most commonly studied method to implement SG is stratospheric aerosol injection, which could potentially achieve this cooling effect by dispersing particles into the atmosphere to scatter sunlight (NASEM 2021; National Research Council 2015). SG presents the possibility of both risks and benefits. For example, stratospheric aerosol injection may decrease the health impacts of rising temperatures, but it may also come with harmful impacts on global environmental systems (Tracy et al. 2022). Research is needed to "identify potential costs and benefits and, equally important, the regions, people, or systems that bear them" (Allenby 2014; Patrick 2021).

We focus on SG for two reasons. First, the risks of irresponsible research and unilateral deployment of SG are compounded in the absence of insufficient governance capacity across nations. SG could be deployed by a single country or a small group of countries and the unintended consequences of an irresponsible large-scale field test or deployment could be severe, with potentially devastating impacts on humans and the ecosystems we depend on. Failing to build sufficient governance capacity for SG compounds the risk that global governance institutions are unable to deter one country from deploying SG in a way that reduces climate risks in its own territory but that also creates harm elsewhere, for example by weakening the East-Asian monsoon, thereby sparking regional famine (NASEM 2021). Moreover, failing to build governance

capacity in the communities and countries that are most vulnerable to climate change, and that thereby have the most at stake in SG decision-making, would risk creating a severe procedural injustice, whereby disproportionately affected populations are not meaningfully engaged in key decisions about whether and how to research or deploy SG. This would reinforce and exacerbate current patterns of international domination (Smith 2018).

Second, the recent uptick in political attention to SG makes such irresponsible research or unilateral deployment more likely. Recent activity has elevated SG as a topic of public, political, and scientific discussion, and deployment stunts and field experiments are quickly ushering SG from the realm of speculation and into reality. SG has been the focus of several recent reports and assessments conducted at national and international levels, including within: the United States White House Office of Science and Technology Policy (OSTP), the United States National Academy of Sciences, Engineering, and Mathematics (NASEM), the United Nations (UN) Human Rights Council (HRC) Advisory Committee, the Climate Overshoot Commission, and the World Commission of UNESCO on the Ethics of Scientific Knowledge and Technology (COMEST). A resolution on SG was also a topic of debate at the recent Sixth Session of the United Nations Environment Assembly (UNEA-6) as well as the previous UNEA-4. Moreover, in 2022, a United States based startup company recently performed what it calls the first deployment of SG by releasing two weather balloons filled with sulfur dioxide in Mexico - without notice or consent - and is promising to continue through its sale of 'cooling credits' (Templeton 2022). Mexico responded by

banning SG outdoor experiments (Ministry for the Environment and Natural Resources 2023), however governance capacity will be needed to monitor SG activity and to enforce the ban. Additionally, in April 2024, a research group led by scientists at the University of Washington initiated an unpublicized outdoor experiment in San Francisco to study another SG technique, marine cloud brightening (Thorsberg 2024). Highlighting the lack of existing regulations, an expert petition to the United States National Oceanic and Atmospheric Administration (NOAA) recently warned that under existing rules in the United States, anyone intending to release aerosols into the atmosphere would only need to notify and provide limited information to NOAA 10 days in advance (Bravender 2024).

Centrally, our article demonstrates that governance capacity building is needed to establish effective and inclusive governance of SG. However, gaps in how capacity building is understood in the SG literature and implemented in practice threaten to stifle the potential for capacity building to establish inclusive and effective governance. Our paper is a practice bridge, a theoretically informed paper for improving the practice of capacity building in the SG issue area. We advance several arguments towards this end. First, governance capacity building is needed for both "upstream" aspects of policymaking (e.g. related to research, assessment, imagination, anticipation, societal deliberation, and policy development and design), as well as "downstream" aspects (e.g. related to implementation and enforcement) (Sagar and VanDeveer 2005). This requires a move beyond current efforts that are focused on scientific capacity building, which builds an important but on its own incomplete set of capacities required to

govern SG.[86] Second, governance capacity building efforts must center climate vulnerable communities in the Global South, who are the populations most susceptible to climate impacts and thus have the most at stake in SG decision-making. To do so requires building off of existing expertise in these populations and addressing power relations that are associated with an unequal distribution of the capacities needed to research, govern, and deploy SG. Third, durable forms of governance capacity must remain in the Global South for the long term. Governance capacity building efforts should therefore embrace a new model wherein the process and products of capacity building efforts are owned by recipients, meaning climate vulnerable communities and countries are empowered to decide, for example, which capacities need building or strengthening and what is the best way to do so within their local context.

The article proceeds as follows. First, we discuss how capacity building has been defined in global environmental politics. We then highlight several advantages of our new concept of 'governance capacity building', which seeks to remedy some of the critiques of traditional approaches to capacity building, using SG as an illustrative case. We then explain why governance capacity building must center the Global South,

[86] The same focus on scientific capacity building exists in the CDR issue area as well. For example, NASEM (2022) outlines a recommended research program for ocean CDR, which called for "[c]apacity building among researchers in the United States and other countries …" (NASEM 2022, p. 17, emphasis added). Much of the CDR literature also discusses 'capacity building' in the context of scaling up carbon removal and storage capacity or reporting and monitoring capacity (e.g., Mace et al. 2021; Low et al. 2022); or in the context of transferring CDR technologies to build capacity to implement CDR, not in terms of building capacity to govern CDR (e.g., Honneger et al. 2022). Partial exceptions include Harvey et al. (2023), who call for 'public capacity building', in terms of strengthening public understanding of CDR to enable engagement, ultimately for the purpose of achieving large scale CDR deployment; and Batres et al. (2021), who ask "who should be responsible for building capacity in communities? And what does the process for capacity building look like in policy or regulatory decision-making?" (p. 3).

highlight several limitations in how capacity building is conceptualized in the literature on SG governance, and assess existing capacity building efforts on SG, including by identifying major gaps in that work. To address these gaps and limitations, we conclude with a proposal for how to develop a successful GCB program for emerging climate intervention technologies.

Overall, the SG case illustrates why capacity building for equitable and effective governance of emerging climate intervention technologies is urgently needed. As SG is largely ungoverned, actors currently have tremendous leeway to move forward with SG activity, even where that activity may be irresponsible, secretive, or harmful to others. But governance is needed to also enable responsible SG activity, not just to deter irresponsible activity. Building capacities required for effective, inclusive, and just governance of SG could go a long way towards enabling a responsible and legitimate SG research program that produces critical knowledge needed to inform decision-making. In short, governance capacity is required to both enable and restrict SG activity. Governance capacity building should therefore be an endeavor that unites people who ultimately hold a wide range of opinions on the ultimate wisdom of moving forward with SG research or development.

Capacity building landscape in environmental politics

Capacity building is firmly established as a key element of global environmental politics (Klinsky and Sagar 2022; Khan et al. 2018), especially within the climate

change regime (Ferraz da Silva 2022). In this section we review the literature on capacity building in global environmental politics, with a view towards identifying best practices in the field.

Most academic studies of capacity building suggest that the term is imprecise and somewhat problematic because it has no established definition and often refers to a wide range of different activities. Writing in 2001, VanDeveer and Dabelko (2001) state that although capacity building is "widely alluded to in international organizations, assistance programs, and scholarship", it "often has no clear definition, nor does the term evoke a common set of strategies among its users" (p. 20). The same is true over 20 years later. Morgan (2006) explains that because capacity building evolved as a blend of precursor concepts with different theoretical underpinnings, such as 'human resource development' and 'institutional economics', different disciplines and relevant actors hold a wide range of diverse perspectives on what capacity is and what it means to build it. Capacity building has therefore been described as "puzzling, confusing, and …. vacuous" because there is "no broadly accepted definition" (Morgan 2006), and it is instead often used as a catch-all term that encompasses a wide variety of aid initiatives (Khan et al. 2018, see also Klinsky and Sagar 2022).

While the concept remains imprecise, there is some similarity in how capacity building has been defined by development and aid agencies (see **Table 3.1** and Khan et al. 2018). We note that the structure of various definitions shows a general formula:

> A process through which [actor or societal level] [develops / enhances / builds / mobilizes] its [abilities / capabilities / skills] to [perform functions / accomplish goals / solve problems].

A key takeaway from this formula is that capacity building only becomes a meaningful concept after the 'what' 'who', 'how', 'why' are articulated: what sort of capacities are built, whose capacity is built and by whom, how is that capacity built, and for what purposes? (See also Klinsky and Sagar 2022; Eade 2007).

Additionally, Khan et al. (2018, p. 86-87) note that the definitions share several broad parameters:

- It is a dynamic, not static, process, adapting to evolving developments.
- It invokes change and improvement.
- It is not a one-off, quick-fix solution, but a long-term issue, requiring investment of time and resources.
- It involves people, organizations, institutions and society as a whole and their interactions, ultimately as society-wide development of capabilities.
- It is driven from the inside as an endogenous process and requires ownership.
- It strengthens existing capacities to ensure sustainability.

Table 3.1: Definitions of capacity building and related concepts from relevant organizations.

Definition	Source
"the process through which individuals, organizations, institutions and societies develop abilities to perform functions, solve problems and set and achieve objectives."	(UNDP 2009)
"a locally driven process of learning by leaders, coalitions and other agents of change that brings about changes in sociopolitical, policy-related, and organizational factors to enhance local ownership for and the effectiveness and efficiency of efforts to achieve a development goal."	Otoo et al. 2009; World Bank)
"The process by which individuals, groups and organisations, institutions and countries develop, enhance and organise their systems, resources and knowledge; all reflected in their abilities, individually and collectively, to perform functions, solve problems and achieve objectives."	(OECD 2006).
"the process of partnering with local actors - individuals, organizations, and networks - to jointly improve the performance of a local system to produce locally valued and sustainable development outcomes."	(USAID 2022).

Capacity building has been integral to global environmental governance, especially following the major 1992 Rio Earth Summit where capacity building issues came to the fore (Khan et al. 2018; Sagar and VanDeveer 2005). Khan et al. (2018) note that this is because transboundary environmental policy and management emerged in the last several decades as a new issue that created a governance challenge. This was particularly true in Southern countries, who were experiencing gaps in capacity across a broader range of issue areas. Capacity building for environmental management has become a pillar of development cooperation as a result. It is also a key element of almost all environmental agreements and protocols (Khan et al. 2018). This can be seen

throughout, for example, the Montreal Protocol; United Nations Framework Convention on Climate Change (UNFCCC); the Convention on Biological Diversity; The UN Convention to Combat Desertification; the Stockholm Convention; the Nagoya Protocol; and the Sustainable Development Goals.[87] Here, the focus is on the capacity for primarily Southern countries to *implement* international environmental agreements, as opposed to capacities related to the "upstream" aspects of policy-making, such as agenda setting, framing, and assessment (Sagar and VanDeveer 2005).

In climate change politics, capacity building has become increasingly important throughout the UNFCCC system over time (Khan et al. 2018; Ferraz da Silva 2022). Article 6 of the UNFCCC requires parties to promote: education, training, and public awareness of climate change; public participation in addressing climate change; and training of scientific, technical and managerial personnel. Article 10 of the Kyoto Protocol similarly requires parties to cooperate and promote education and training, including national-level capacity building. Other key developments within the UNFCCC include: the 2001 Marrakesh Accords at COP7, which set a framework, guiding principles, and priority areas for capacity building (UNFCCC, 2001); the creation of the 2011 Durban Forum on Capacity Building at COP17, a multi-stakeholder forum for sharing ideas and best practices; the 2012 Doha Work Programme on Convention Article 6 adopted at COP18 (UNFCCC, 2012), which

[87] See Khan et al. (2018, p. 7-9) for further capacity building related excerpts from the text of these agreements and for a fuller demonstration of how capacity building is integral to environmental and climate governance, including an elaboration of the institutions, funding, mechanisms, and processes devoted to capacity building under the UNFCCC.

requested an annual dialogue on capacity building; the decision to hold a ministerial dialogue on capacity building at COP20; and most recently in 2015, at COP21, the establishment of the Paris Committee on Capacity Building to coordinate capacity building efforts under the Convention and the establishment of the Capacity Building Initiative for Transparency to strengthen countries' ability to meet reporting and transparency obligations under the Agreement.

Prior work has identified two general capacity building models (Khan et al. 2018). First, a 'classic' model characterizes most capacity building efforts across the past several decades.[88] This model is built around ad-hoc short-term workshop-based technical training projects that 'parachute' outside consultants into an area to train personnel (Khan et al. 2018; Asensio et al. 2022). These efforts are often uncoordinated and provide participants with little control over the process or outcome (Eade 2007). Nobody explicitly ascribes to the classic model, yet this is often how capacity building is done in practice.

Second, a 'new' capacity building model that aims to improve upon common critiques and limitations of the classical model has emerged from primarily least developed country perspectives on their experiences with capacity building as well as from expert assessments and from innovative non-governmental organizations (NGOs). This new capacity building model aims to build long term, systemic, and sustainable capacity systems that enable countries to effectively address issues,

[88] Pandey and Kumar (2018) also refer to this model as the "Fly-In & Fly-Out" approach.

accomplish goals, and solve problems over time by ensuring participants have ownership of capacity building processes and outcomes (e.g. Khan et al. 2018; Lafontaine 2000; Commission for Africa 2005; Virji et al. 2012; Lopes and Theisohn 2003). Ensuring these countries have ownership of capacity building programs means enabling these countries to decide, for example, what specific capacities are needed in their local context and how they will build them. This follows from the recognition that there is no one-size-fits-all solution to capacity building and what is successful in one context may not be so in another (Khan et al. 2018). Among other actors, the new capacity building model is being developed within some NGOs seeking to embrace a spirit of innovation and change. For example, after a year of dialogue and review, the International Institute for Environment and Development (IIED) published a manifesto that acknowledges "achieving our mission means we cannot continue doing more of the same and instead must challenge ourselves to take a bold new direction", including by "taking a systems approach and working in dynamic teams to develop new ideas, test innovations and scale what works" (IIED 2024). While innovative NGOs are implementing promising elements of the new model, it remains aspirational; it has yet to be fully implemented in practice, as we demonstrate below in the case of SG.

Why governance capacity building matters

Inclusive and effective governance of climate intervention technologies requires multiple types of capacities and appropriate capacities must be available to the many

types of actors that are expected to play important roles in governance. To help widen our understanding of who needs to be involved in capacity building efforts, what capacities need to be built, and for what purposes, we articulate more fully a conceptual vision for governance capacity building for emerging climate intervention technologies.

In response to previously discussed critiques of the ambiguity of capacity building, we aim to be clear and transparent here about what we understand governance and capacity building to mean. Our definition is based on previous definitions for capacity building in development and environment issue areas, particularly from aid agencies and NGOs, as well as from discussions of capacity needs in relevant literature. These definitions are also applicable to a range of different capacity building providers, such as government agencies, NGOs, or academic institutions. While our definitions are currently specific to climate intervention technologies, they can apply as well to governance capacity building for other emerging technologies, which may require similar forms of governance capacity.

We define governance capacity building (GCB) as:

> A process through which individuals and/or organizations mobilize and sustain knowledge, skills, tools, and practices that enable them to engage in the development and implementation of local, national, and international forms of governance of research and deployment of emerging climate intervention technologies (DSG 2023).

Whereas the capacity to implement climate intervention governance entails:

> the ability to formulate, implement, and enforce local and national actions to govern climate intervention research or potential deployment. This includes the development of policies, rules, practices, procedures, and other regulatory tools or regimes that aim to directly govern climate intervention research or potential deployment. (developed from Khan et al.'s (2016) broad groupings for capacity needs for addressing climate change (cited in Khan et al. 2020, 4)).

Sometimes actors will be able to implement governance in their own right, but actors will also need to engage in governance processes implemented by others. Implementation and engagement both require an overlapping but distinct set of capacities. The capacity to engage in climate intervention governance entails:

> the ability to analyze, negotiate, and articulate individual, community, and national interests in international fora and other transnational, regional, and global governance processes related to climate intervention technologies. This includes the development of civic knowledge, skills, resources, tools, and practices that enable meaningful engagement in discussion, assessment, and governance of climate intervention research occurring in other countries or facilitated by other actors. This also includes skills and practices that enable communities and countries to oppose or dissent to unjust climate intervention research (developed from Khan et al.'s (2016) broad groupings for capacity needs for addressing climate change (cited in Khan et al. 2020, 4)).

GCB provides several advantages that enable researchers and practitioners to conceptualize capacity building more holistically. First, related to the 'how' and 'why',

GCB internalizes the need to put governance front and center in climate intervention activities. The 2009 Royal Society report emphasized that "the greatest challenges to the successful deployment of geoengineering may be the social, ethical, legal and political issues associated with governance, rather than scientific and technical issues" (Royal Society 2009, p. xi). This acknowledgment catalyzed a rich scholarly discussion surrounding SG governance and a wide range of governance needs, rationales, and functions have since been identified (Jinnah et al. 2018; Chhetri et al. 2018; Reynolds 2019). GCB similarly urges us to build capacity to address the social, ethical, legal and political issues associated with climate intervention governance, in addition to the scientific and technical issues.

The second advantage of GCB is that it comprehensively addresses the need to build a range of capacities that are needed across the entire governance process, rather than only those capacities that are needed for one narrow part of the governance process, such as research or assessment (Sagar and VanDeveer 2005). In contrast to capacity building efforts in climate politics which focus on implementation, GCB internalizes the need for capacity building 'upstream' in the governance process, where activities such as framing, anticipation, imagination, consensus building, societal deliberation, and policy design can be thought of as capacities in themselves, as well as governance tasks that require additional underlying capacities to perform. Capacities required to initiate and engage in imaginative and other creative processes, such as scenarios and other foresight activities, are important as well to enable people to imagine just and inclusive governance systems and worlds (Pereira et al. 2019). The

breadth of capacities needed to fully govern climate intervention technologies is also captured in our distinction between the ability to implement and engage in governance (see also DSG 2023).

As we demonstrate below, the focus in the SG governance literature as well as in existing SG capacity building efforts is on scientific capacity building, which aims to build scientific and other research capacities in scientists and researchers primarily by funding scientific research. Scientific capacities help us understand and make informed decisions about SG, and are therefore one important set of capacities that are required to effectively govern SG and other climate intervention technologies. However, scientific capacities are not sufficient on their own, as non-scientific capacities - such as the capacity to formulate national interests and negotiate international agreements in line with those interests- are also needed to manage all risks associated with SG research and deployment. **Figure 3.1** below visualizes this relationship.

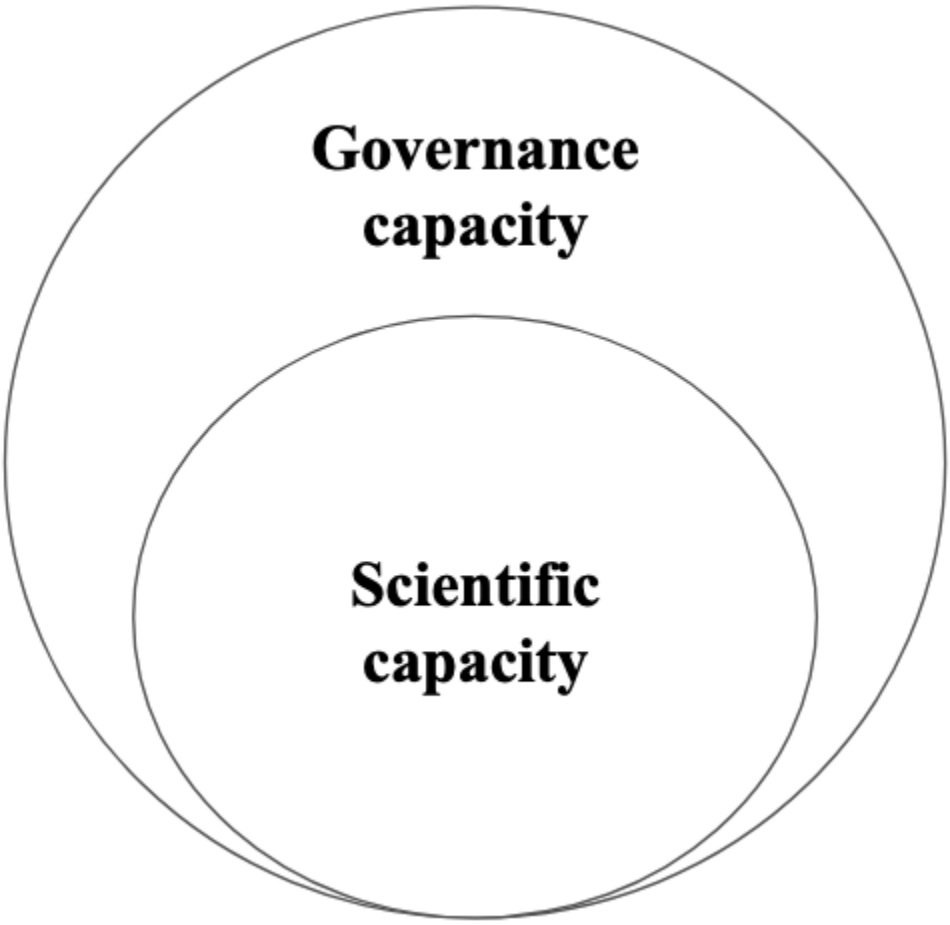


Figure 3.1: The relationship between governance and scientific capacity.

Scientific, research, and assessment capacities are vital governance capacities and scientific capacity building contributes in important ways to governance. At the same time, there are also important non-scientific governance capacities, and a comprehensive governance capacity building program encompasses but stretches beyond scientific capacity building.

We also note that while questions about deployment capacity intersect with governance and scientific capacity, considerations of whether and how to build deployment capacity are beyond the scope of this paper. However, it is useful here to

illustrate a fuller range of potential capacities that may be needed in the future to govern a deployment of SG. First, authorities will need to identify capacities that are required to enable informed and legitimate decision-making about large-scale research or deployment interventions. If actors were to authorize an SG deployment they would need to develop deployment capacity, which would entail sets of technical capacities to implement and monitor a SG technique as well as non-technical capacities to manage the deployment and its interactions and consequences. For example, if deployments are authorized, there is a need to identify and build capacities to:

> "oversee and control them; to adequately monitor and assess their effects; to modify actions in response to advances in knowledge or capabilities; to deal with the consequences of interventions, particularly claims that they have caused harm; to coherently manage strategic interactions of climate engineering with other forms of response to climate change; and to manage associated conflicts" (Parson 2017, p. 3).

Efforts to better identify specific governance capacities can benefit from insights from multiple literatures, including on anticipatory governance, which has generally focused on enabling effective and democratic governance of emerging technologies and integrating public values into the innovation process (Guston 2014; see also Barben et al. 2008; Davies and Selin 2012). Anticipatory governance specifically focuses on the need to develop capacities related to foresight, engagement, and integration, where:

> "Foresight focuses on the construction and evaluation of plural sets of rich and plausible futures as occasions for reflection, tools for planning, and exercises for capacity-building to prepare and respond for a broad swathe of potential developments and implications in emerging technologies. Engagement centers on the substantive exchange of ideas and reasons within and between publics and technoscientific decision-makers, aiming to identify public values at stake in technological development and implementation and to build capacities in publics and decision-makers to shape technologies to respect and support them. Integration refers to development among core research actors and decision-makers of capabilities and institutionalized processes to consider and respond to the social and normative contexts of their work" (Nelson et al. 2021, p. 385).

These examples demonstrate that ultimately a wide array of governance capacities will be needed and - while scientific expertise is vitally important for the functioning of these capacities - building scientific expertise by itself does not enable, for example, the crafting and implementation of policy that effectively manages conflict between SG and mitigation, nor the identification of public values at stake and the shaping of technologies by publics and decision-makers to respect and support them.

Governance arrangements for all emerging climate intervention technologies are likely to share a need for certain capacities, such as the ability to detect and deter irresponsible research and unauthorized interventions (Parson 2017). At the same time, different ways of researching and implementing climate intervention technologies may also raise different governance capacity needs. The capacity needed to govern research or deployment of a technology may also vary depending on specific circumstances,

such as the scale of impact, who is researching or deploying a technology, who is directly affected, and where a project occurs. Depending on the context, different capacities could be needed for different reasons, including in different combinations (Khan et al. 2018, p. 90). For example, the forms of capacity needed to govern even different forms of marine CDR are likely to vary in part (Brent et al. 2019). An ocean alkalinity enhancement research project within a country's territorial waters is likely to require, at least in part, different forms of governance capacity than an artificial upwelling and downwelling project in international waters (NASEM 2022). Different capacity needs may also arise at different times. For example, the capacity to conduct large-scale meaningful community engagement in the United States is needed now as the Department of Energy is already funding projects that aim to develop regional hubs for direct air capture (DAC), an industrial form of CDR (DOE n.d.). Other forms of governance capacity may only be needed in the future, with the question being what near term steps should be taken to ensure this capacity is available when needed (Parson 2017). For example, the capacity to decide when and how to terminate a deployment is not needed yet, however this capacity would need to be built as soon as deployment is under consideration. GCB should therefore proceed based on the specific needs and context of each form of climate intervention.

Finally, the third advantage of the GCB concept is related to the 'who' of capacity building. The concept highlights that a wide range of actors, including but not limited to lay publics, policymakers and government officials, NGOs, farmers and workers, indigenous communities, and others should be involved in climate

intervention governance, and therefore need to build capacity to discuss, develop positions on, and make and implement decisions about climate intervention technologies[89]. As such, GCB internalizes the need to build relevant governance capacities within a range of both state and non-state in the near term (e.g. Jinnah et al. 2018; Jinnah et al. 2019; Reynolds and Parson 2020). The concept of GCB is therefore more inclusive of the types of actors that require sustained capacity building efforts on climate intervention, moving beyond a narrow focus on scientists or policymakers and their advisors (see also Klinksy and Sagar 2022; VanDeveer and Dabelko 2001). For example, environmental or climate NGOs and other civil society organizations will need the capacity to understand SG, to craft an informed position, and to advocate that position effectively in multiple fora. NGOs may need the capacity to facilitate public engagement efforts on SG, inform the public about SG, to capture public perspectives and values, and to ensure these are reflected in policy and scientific decision-making. NGO observers were active players in the past two UN Environment Assembly (UNEA) negotiations surrounding SG. Their ability to play a constructive role in establishing effective and inclusive SG governance rests on their efforts to build several capacities that are needed to engage in these and other governance processes.

Overall, the GCB concept emphasizes the need to build a wide range of capacities that enable diverse types of actors to effectively implement and engage in both upstream and downstream governance processes of research and deployment. As

[89] For those groups that have sovereignty, including indigenous nations, any engagement, which is an inadequate term here, must be premised on indigenous rights, sovereignty, and leadership (Liboiron and Cotter, 2023).

research, discussion, and (in the case of CDR) deployment of climate intervention technologies quickly ramps up, GCB needs to be discussed, planned, and initiated now.

Why focus on the Global South?

In order for SG governance to be both effective and inclusive, and as a requirement for justice more broadly, climate vulnerable communities and countries in the Global South, who are the populations that are most susceptible to climate impacts and thus have the most at stake in SG decision-making, must play leading roles in SG decision-making and other governance activities (Hourdequin 2016; Táíwò and Talati 2021). Capacity building efforts should focus on building and strengthening existing governance capacities in the Global South. Our argument advances recommendations from the 2021 National Academy of Sciences report, which recommended the creation of a public solar geoengineering research program. One aspect of the recommended research agenda focuses on capacity building, specifically surrounding how to build "the capacities needed for all countries to engage meaningfully with SG research and research governance activities" (p. 204). A 2023 United Nations Environment Programme (UNEP) expert report similarly concludes that SG decisions "require an equitable, transparent, diverse and inclusive discussion" and that marginalized stakeholders from the Global South must be brought into a globally inclusive conversation (UNEP 2023, p. 2). Principles related to good governance and justice also require that these communities are meaningfully engaged in SG governance and

research (Hourdequin 2016; Táíwò and Talati 2021; Carr et al. 2013). The social and justice dimensions of sustainability transitions are often neglected, and yet attention towards them may be the key to ensuring human and environmental well-being (Iles, 2019). Climate intervention, as one potential component of a broader sustainability transition, is no different. However, meaningful engagement in and effective implementation of governance is challenging, and it requires capacities that are not yet sufficiently available. Aganaba-Jeanty asserts that in the Global South, "the majority of actors do not yet have the [capacity] systems required for basic research governance" (2019, p. 1; see also Patrick 2021).

One indicator of this lack of capacity is unequal geographical involvement in academic research and discussion of SG so far, leading some to characterize SG as a "rich man's solution" (Biermann and Möller 2019). For example, according to a Web of Science Database search, of the 845 total SG related articles published between 2009 and May 2024, 54% have at least one author with an institutional affiliation in the United States; 22% in England, and 16% in Germany.[90] There are far fewer articles with author institutional affiliations in the Global South. Of the 845 SG articles, only 12% have at least one author with an institutional affiliation in China; 4% in India; and

[90] Results are from the Web of Science Database. To create this analysis, visualized in figure 2, we ran an advanced search in the Web of Science Database using the following search query: ALL = (("solar geoengineering" OR "solar radiation management" OR "solar radiation modification" OR "stratospheric aerosol injection" OR "marine cloud brightening")). We set the publication date range to between January 1st, 2009 and May 1st, 2024. We then used the analyze results feature to analyze the search results by 'Countries/Regions" and selected a bar chart visualization style, including 20 results. 26 records (3.081%) do not contain author institutional affiliation data. To distinguish countries in the Global South, we used the Preview software to overlay an orange rectangle onto the respective bar for each country.

2% in South Africa. **Figure 3.2** shows the total number of SG related articles with at least one author from each country. At least part of the reason for this disparity lies in the fact that discussion, research, and governance requires forms of capacity that are currently disproportionately distributed. Capacity gaps, such as those related to participating in international negotiations and fulfilling international reporting obligations are well documented in Southern countries in the climate issue area, including in the Nationally Determined Contributions (NDCs) of these countries under the Paris Agreement (Khan et al. 2020; Asensio et al. 2022). Capacity building must therefore be a key topic of concern for those who believe that a wider array of countries and communities, and in particular those that are most vulnerable to climate impacts, need to be included in decision-making surrounding climate intervention technologies.

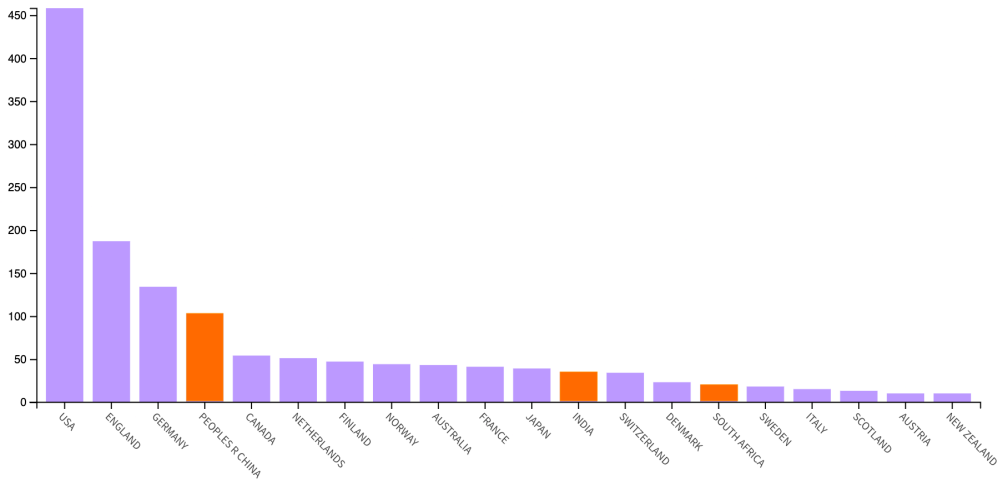


Figure 3.2: Total number of solar geoengineering related articles by author's country published between 2009 and May 2024 (N=845).

The bars represent the number of SG articles with at least one author from each country, based on addresses of institutional affiliations of authors. A paper is attributed to a country if the paper has at least one address from that country. Addresses for all authors are considered, not only of the first or corresponding author. If more than one author on a paper is from a single country, the paper is only counted for that country once. Countries in the Global South have an orange bar. Figure displays results for only the top 20 countries. Results from Web of Science Database. The data for this analysis can be found in the supplemental material.

To be clear, identifying capacity gaps and acknowledging an uneven distribution of capacities does not suggest that the Global South does not have any relevant expertise or capacity, nor that they lack agency to shape the trajectory of SG governance, research, or deployment. To the contrary, the Global South has existing forms of expertise and capacity that will be invaluable in collective efforts to research and govern SG, to design capacity building efforts, and to catalyze sustainability transitions more broadly. The new model of capacity building we are endorsing, for example, was largely developed by actors in the Global South. Embodied in the Least Developed Countries (LDC) Initiative for Effective Adaptation and Resilience's (LIFE-AR) 2050 vision, these countries have created an impressive LDC-led vision for an "effective, ambitious response to the climate challenge, with all countries and communities — from the least to the most vulnerable — working hand in hand for a climate-resilient future" (LIFE-AR 2019, p. 1). This experience and leadership will be vital in collective efforts to establish effective and inclusive SG governance in a manner that advances this vision.

Capacity building efforts focused on the Global South is also vital because much of the Global South's governance capacity was previously systematically dismantled, and justice demands collective support for their efforts to rebuild it, including through transformative social, political, and economic change. This spirit of collective responsibility - in tandem with Global South leadership - is at the heart of the new capacity building model and LIFE-AR. Recognizing that achieving their vision of a climate resilient future is "an ambitious goal that requires partnership on both sides" they invite the international community to "join us in making our climate-resilient vision a reality", and urge the international community to "be part of this historic shift by committing to this long-term collective response to the climate emergency with climate justice at its heart" (LIFE-AR 2019, p. 5). Specifically, the international community is asked to "[w]ork with us in the long term to strengthen our national and local institutional capabilities":

> "We need adequate time and finance to build the knowledge and skills required to strengthen our national and local systems sustainably. Help us strengthen our in-country expertise by drawing in our home-grown experts and younger professionals to deliver technical support, investing in whole-of-society responses, with a special focus on women and youth and working closely with [LDCs Universities Consortium on Climate Change and other LDC institutions] and other LDC institutions in-country to develop tomorrow's leaders and national experts, investing in capabilities, curriculums, training, research and knowledge." (LIFE-AR 2019, p. 5)

There also appears to be demand for SG related capacity building in the Global South. In the limited efforts thus far to engage climate vulnerable communities on SG, the need for capacity building to enable broader populations to contribute to SG conversations has emerged as a common theme in discussions. For example, at three workshops in Senegal, South Africa, and Ethiopia, "participants agreed that it will be important for African stakeholders to be actively involved in deliberations on [SG] research governance, but that capacity-building would be necessary to make this possible" (African Academy of Sciences and SRMGI 2013, p. 10). Similarly, a published analysis of workshops in 2014 that brought together environmental leaders, primarily from the Global South, concluded that capacity building is needed to 'institutionalize inclusion' of the Global South in SG research and governance (Winickoff et al. 2015). Capacity building must therefore be a key topic of concern for those who believe that a wider array of countries and communities, and in particular those that are most vulnerable to climate impacts, need to be included in decision-making surrounding climate intervention technologies.

As with any form of international cooperation, great care must be taken by all parties involved to address differences in power and resources between and within North and South to avoid reproducing relationships and interactions dominated by Global North ideas and interests. The failure of the classic capacity building model to do so is a primary impetus behind the development of the new model. In contrast, the new model aims to rapidly transfer ownership of capacity building efforts to the Global South so that governance capacity building (GCB) is ultimately an endogenous and

Global South led effort, and the role and potential influence of Global North capacity building providers is diminished over time (Khan et al. 2018). To wit, GCB, driven by the new model of capacity building, is needed to enable the development of Global South-led SG capacity building initiatives. Waiting for bottom-up Global South-led SG capacity building initiatives to develop on their own would be problematic because it is unlikely that this would occur in a sufficient time frame given the near-term urgency to govern SG. Failing to start the GCB process early - even if initially catalyzed by the Global North funders or organizations - risks leaving the Global South without sufficient capacity to engage in critical decision-making on the horizon regarding research and possibly deployment. Governance capacities should be built prior to when they are needed, and some governance capacities are needed now, whereas other governance capacities may be needed in the very near future. Given significant time and resource costs associated with capacity building efforts, capacity building should begin well in advance of when specific capacities are needed.

Building capacity to govern SG does not mean communities and countries must adopt any particular position or policy with respect to SG. To the contrary, capacity building efforts should be agnostic about the eventual positions communities and countries take with respect to SG research or deployment - each country should be empowered to decide for themselves whether they will, for example, support an international agreement that restricts or enables research including outdoor field experiments. Capacity building initiatives funded or initiated by the Global North must take steps to limit any potential influence they may have over how their partners in the

Global South think about SG. But regardless of whether populations ultimately prefer a more restrictive or enabling form of SG governance, GCB is needed to design and implement both, and similar forms of capacity are needed to both deter and authorize research and deployment activity (Parson 2017).

Capacity building in the solar geoengineering governance literature

A growing body of literature explores governance issues and challenges related to SG, as well as proposals for why and how its research and deployment should be governed (see Reynolds 2019; Morrow 2017). How is capacity building understood in this literature? We identified and selected relevant literature using a ProQuest search to identify all articles in the SG governance literature that discuss capacity building, including those that use different terminology used to refer to both SG and capacity building. We initially used the following search term: ("solar geoengineering" OR “solar radiation management” OR "solar radiation modification" OR "stratospheric aerosol injection" OR "marine cloud brightening" OR "climate intervention") AND ("capacity building" OR "capacity strengthening" OR "capacity development") for all publication dates, restricting our search to scholarly journals. This search yields 50 articles, however only seven focus on SG (Horton and Koremenos 2020; Delina 2021; Delina 2020; Sugiyama et al. 2017; Reynolds and Parson 2020; Winickoff et al. 2015; and Carr and Yung 2018). To broaden our search to capture literature that discusses capacity - though not necessarily how to build it - and at the same time to attempt to

restrict the results to the governance literature - we then used the following search term: ("solar geoengineering" OR “solar radiation management” OR "solar radiation modification" OR "stratospheric aerosol injection" OR "marine cloud brightening" OR "climate intervention") AND ("capacity building" OR "capacity strengthening" OR "capacity development" OR capacity OR capacities OR capability OR capabilities) AND (governance OR govern). However, this search yielded 424 results, and the vast majority of papers either did not focus on SG or used ‘capacity’ in non-relevant ways, for example to refer to the capacity of SG to reduce surface temperatures. Many articles also discuss what capacities would be required to deploy SG from a mostly technical perspective.[91] Nonetheless, we reviewed a sample of these articles to further identify articles that discuss various forms of capacities needed to govern SG and how to build or transfer them. We also searched for mentions of capacity building or capacity development in authoritative assessments and governance reports on SG based on the author’s familiarity with the issue area (e.g., NASEM 2021; Chhetri et al. 2018; The Royal Society 2009).

We identified only 12 articles that discuss capacity building in the SG context. Of these articles, capacity building is not the focus of the papers, and the majority of those papers mention it only tangentially. No papers in the SG governance literature treat capacity building as an important line of inquiry deserving of focused attention. Where it is discussed, the focus has been on scientific capacity building, and the need

[91] Deployment, governance, and scientific capacity overlap and interact with each other. However, a full exploration of the relationship between these forms of capacity is beyond the scope of this article.

to build a broader array of governance capacities has not been addressed. That the need for governance capacity building (GCB) has been largely neglected in this literature is curious because the literature generally agrees that sufficient capacity to govern SG effectively is currently lacking. While there is considerable attention in the literature towards proposing different possible or desirable forms of SG governance, there has been little interest in exploring the capacity needs specific to those governance arrangements, and virtually no attention towards discussing what sort of capacity building would be required to meet those needs.

We found that five articles address the need for capacity building but in terms of scientific capacity or expertise. For example, Horton and Koremenos (2019) usefully demonstrate that the Solar Radiation Management Governance Initiative's (SRMGI) "scientific capacity building" is a significant governance activity occurring in the SG field, alongside other governance activities such as lobbying or disseminating knowledge. However, conceptualizing capacity building primarily as a governance activity distinct from, for example, lobbying or disseminating knowledge, limits our ability to understand the need for capacity building underlying a wider range of governance efforts and activities. Capacity building may be needed to, for example, enable effective lobbying or knowledge dissemination activities in the first place.

Scientific capacity building has also been discussed as desirable in the context of broadening SG research and assessment activities. For Sugiyama et al. (2017), "capacity building can more specifically indicate the activities that stimulate the technical capacities for local scientists in the Asia-Pacific to participate in an

international research program of impact analysis of climate engineering" (p. 5). For Delina (2020), capacity building is needed to create interdisciplinary expertise on geoengineering in Southeast Asia (see also Delina 2021). Hubert's (2021) code of conduct also calls for capacity building "to assist and strengthen the capabilities and capacities of those in developing countries to participate in geoengineering research and to support decision-making through, *inter alia*, joint programmes to provide education and training of scientific and technical personnel" (p. 91). Scientific capacity building builds vital governance capacities, especially to the extent that scientists are expected to self-regulate under an Asilomar paradigm of governance (see e.g., McLaren and Corry 2021). However, the focus on scientific expertise, technical capacities, participation in research, and scientific and technical training provides a limited model for GCB as vital non-scientific and non-technical capacities are neglected.

Several articles do address a broader range of governance capacities. Reynolds and Parson (2020) consider multiple forms of non-state governance based in part on various types of actors' capacity, but they are concerned here with existing capacity, rather than the need to build this capacity. They also argue that non-state governance can "provide early considerations, guidance, and capacity building toward the more extensive, robust, and legalized governance that will be warranted" (p. 338). Reynolds and Parson (2020) usefully acknowledge the need for GCB; however, they understand this as a secondary benefit of non-state governance in terms of its ability to build capacity for future state-led governance arrangements. The need for capacity building

in the near term to enable the forms of non-state governance they are proposing is not addressed.

Several exceptions also provide early and valuable explorations of needed governance capacities and pathways to build them. These include Parson (2017), who addresses the need to determine what capacities are needed to govern SG and how they should be built, and Chhetri et al. (2018), who underscore the need to govern SG in the near term, identify several needed capacities, and provide recommendations to govern SG, including by building relevant capacities (see also NASEM 2021; Aganaba-Jeanty 2019). Parson (2017) argues that "international exploration of associated governance challenges, needed capabilities and ways to develop these must start promptly" (p. 4), and calls for a World Commission on Climate Engineering to discuss, for example, "what international capacity and authority would be needed to make informed, prudent, legitimate decisions regarding proposed large-scale interventions" and "what feasible near-term steps could start moving international processes toward developing them?" (p. 3). Additionally, Foley et al. (2018) discuss the need to build anticipatory governance capacities related to foresight, engagement, and integration to responsibly govern SG, where anticipatory governance "refers most directly to building the capacity to manage emerging technologies while such management is still possible."

Other scholars tangentially and briefly mention capacity building as a potential outcome of a multitude of governance mechanisms. These include, for example, public participation (Flegal et al., 2019); a multi-stakeholder dialogue (Conca 2019); establishment of a dedicated network of researchers and stakeholders (Sugiyama et al.

2017); and establishment of an 'interdisciplinary knowledge community' (Delina 2020). While these governance mechanisms may indeed build capacity, understanding capacity building primarily as a follow-on or secondary goal is limiting. Capacity building must also be understood as a necessary prerequisite for establishing these and other governance mechanisms. More work is needed to consider what forms of capacity are needed to organize and participate in, for example, a multi-stakeholder dialogue on SG.

The SG governance literature can better address the importance of capacity building by recognizing the multi-faceted and foundational role capacity building plays within a governance system. Some see capacity building as both a discrete governance activity (Horton and Koremenos 2019) and an end that governance activities contribute to (e.g., Sugiyama et al. 2017). We suggest that it is both a means and end. Conceptualizing capacity building as a central governance process could yield important analytical insights into, for example, how power, authority, and agency is constituted, distributed, and transformed through the capacity building process.

Finally, another key gap relates to an area of the literature that advocates ending SG research and development altogether on sociopolitical grounds including through the adoption of a non-use agreement (e.g., Stephens and Surprise 2020; Biermann et al. 2022). This literature voices very real concerns about the lack of inclusion of the Global South in SG research, discussion, and governance (e.g., Biermann and Möller 2019). However, perspectives from the Global South affirm that capacity building is needed to 'institutionalize' that inclusion (e.g., Winickoff et al. 2015; African Academy of

Sciences and SRMGI 2013), and yet there has been little attention in the SG critical literature towards *how* capacity building could be leveraged to redress exclusions and inequities, including by building capacity in climate vulnerable communities and countries to govern SG. There has also been no effort to identify capacities required to negotiate, implement, and enforce a non-use agreement for SG that would prohibit its development and deployment and to imagine the sort of capacity building initiatives that could help ensure its effectiveness (e.g., Biermann et al. 2022; Gupta et al. 2024).[92]

Existing capacity building efforts focused on solar geoengineering

How well do existing capacity building efforts on SG conform to the core ideas behind governance capacity building (GCB) and the new model of capacity building? Existing efforts to build capacity on climate intervention technologies are conducted on an ad hoc basis, generally focus on building scientific expertise, and have largely neglected building governance related capacities in civil society. This section details the most significant capacity building efforts on SG to date. Based on our understanding of the SG landscape, we looked at all organizations in the issue area working on capacity building related activities and reviewed their missions and activities using publicly available website material to assess how well they practice GCB using the new capacity building model. Whereas some of these efforts explicitly call their activities capacity

[92] Gupta et al. (2024) identify precedents and key lessons from international law for a prohibitory SG non-use agreement. This is a helpful step, but still falls short of identifying what specific governance capacities are needed and where, how they could be built, and by whom.

building, others do not. We include here efforts that have the impact of increasing a target population's ability to engage in scientific research or governance discussions surrounding SG through some sort of information provision or training activities. Capacity building efforts focused on SG began not long after Nobel-prize winner Paul Crutzen broke the taboo on SG research in 2006 (Crutzen 2006).

The largest and most sustained effort so far to build capacity on SG has been spearheaded by The Degrees Initiative, led by Andy Parker, which was previously known as Solar Radiation Management Governance Initiative (SRMGI). SRMGI was launched in March 2010 as an organized joint effort by the Royal Society, the United Kingdom's academy of science; Environmental Defense Fund (EDF), an environmental NGO based in the United States; and The World Academy of Sciences (TWAS), an international organization serving as the academy of sciences for the developing world and based in Italy. SRMGI initially "aimed to foster an interdisciplinary and international discussion to develop ideas on how SRM research could appropriately be governed, appropriately scrutinized and carried out responsibly" (SRMGI 2011, p. 12). In the longer term, SRMGI aimed "to build a diverse community of well-informed international stakeholders engaged and able to contribute to" ongoing debates surrounding SG research and its governance (SRMGI 2011, p. 12).

SRMGI began to document different perspectives of SG research governance in order to 'open up' discussions on governance rather than 'close down' on specific recommendations (SRMGI 2011). This was "done by assembling a working group and a range of international partner NGOs, and by producing background papers on SRM

research governance, hosting an international conference, and by publishing [a] report of the process" (SRMGI 2011, p. 12). These early background papers were produced by a working group of experts, 27 members from 17 different countries. Papers were solicited by a public call for submissions, and through invited input from experts from a range of stakeholder NGOs, primarily from the Global North but with some from the Global South (see Appendix 1 in SRMGI 2011). The papers covered a range of topics: mechanics of SG governance; international dimensions; thresholds and categories of research; and goals and concerns regarding research.

SRMGI was to be phased out in 2011 but Parker switched its focus to capacity building in the Global South and reached out to local partner organizations to start running workshops in Southern countries, initially in India, China and Pakistan. From then on, SRMGI's initial capacity building strategy revolved around workshops in Southern countries for educating, deliberating, and gathering perspectives primarily from climate experts from the Global South. All workshops were convened in partnership with local partner organizations.[93] By working with local partner organizations, SRMGI's activities demonstrated the potential to implement the 'new' capacity building model in the SG issue area. However, it is not clear what role these local partners played in shaping the process or aims of the workshops, leaving it difficult to assess to what extent these workshops or the broader strategy were led by

[93] For a full list of workshop partners, see: The Degrees Initiative (n.d.a.).

recipients in the Global South. To date the organization has run more than 25 of these events.

In 2018, SRMGI expanded the scope of its work and launched the DECIMALS Fund (Developing Country Impacts Modelling Analysis for SRM). This is the world's first international SG research fund and the first aimed exclusively at developing countries. The launch of the fund reflected a belief that it is not possible to effectively build capacity by running workshops and writing reports, and that enabling research in the Global South was also a necessary component. Importantly, the creation of a SG research fund for scientists in the Global South was an idea often proposed and widely supported by participants at SRMGI's workshops in developing countries. Here SRMGI demonstrated the potential of the 'new' capacity building model by ensuring that recipients have ownership of the capacity building process, in this case by implementing a capacity building method that was widely called for and supported by recipients.

In 2022 SRMGI transformed into the Degrees Initiative to focus on the fund, now called the Degrees Modelling Fund (DMF). The DMF aims to "build developing country capacity to research and evaluate solar geoengineering" by directly funding SG modeling research conducted by developing country scientists. The fund has successfully distributed over $1.8 million in research grants across 26 modeling projects in 21 developing countries (The Degrees Initiative n.d.b). Funding comes from philanthropic organizations based in Northern countries, currently from Open Philanthropy (The Degrees Initiative n.d.c.). Degrees publishes an open call for

proposals to solicit new research projects and uses an independent peer review process to select which projects will be funded. Underlining the potential to give Southern countries ownership of the capacity building process, "[a]pplicants are free to define their own research questions and methods for answering them - the Degrees Initiative does not tell teams what to study or how to do it" (The Degrees Initiative n.d.b.). At the same time, because the funding originates in the Global North, the real or perceived risk that there is a Northern bias in funding decisions could undermine the credibility of the researchers, by creating the perception that researchers' perspectives on SG have been inappropriately shaped by Northern experts and practitioners.[94] Based on personal author experience, the peers that evaluate research proposals and make funding decisions are not as diverse or inclusive as the recipients of the funds, suggesting a greater need to transfer ownership to the Global South by initiating joint research funding decision-making.

Reflecting on the fact that SG expertise has generally developed where climate experts have received funding to work on SG for extended periods – typically through research support – the Degrees Initiative has primarily focused on building capacity surrounding SG expertise through funding scientific research. They argue that creating SG experts across the Global South will "ensur[e] informed and confident

[94] We acknowledge the possibility that the perspectives of Southern researchers involved in the Degrees Initiatives' activities are shaped throughout their interactions with the organization and with the Northern SG experts they collaborate with. At the same time, we are not aware of this occurring in an inappropriate or coercive manner, and we do not believe that Southern researchers are necessarily conditioned through their involvement in these activities to think about SG in a particular way. We suggest that Southern researchers have the agency to form their own opinions on the matter even when they learn about it alongside Northern experts.

representation from developing countries" at SG governance activities (The Degrees Initiative n.d.c.). The organization's approach states: The Degrees Initiative builds "the capacity of developing countries to evaluate SRM" by "Bringing climate experts from the Global South into the SRM conversation"; "Supporting the creation of Global South SRM expertise through the Degrees Modelling Fund"; and through "activities that build an international community of experts" (The Degrees Initiative n.d.c.). Recently, the Degrees Initiative created a second fund dedicated to social scientific research. According to the Initiative, the Degrees Socio-Political Fund "marks a major expansion of Degrees' work, becoming the first-ever fund aimed exclusively at researchers in the Global South to study the social and political dimensions of [SG]" (The Degrees Initiative n.d.d.). Seven research projects were selected for funding by an independent grants committee and the research teams will further plan their projects during a research planning workshop alongside Northern research collaborators (The Degrees Initiative 2024).

The Degrees Initiative is fulfilling a critical need to build SG expertise in the Global South, and this will go a long way towards enabling effective and inclusive governance. At the same time, its current focus on building scientific and research related capacities in scientists and other researchers addresses only one limited set of needed governance capacities, and in only one type of actor. The addition of a social science research fund is a welcome first step to broadening the type of expertise that is valued. At the same time, the focus remains on building expertise and scientific or research capacity. From a comprehensive GCB perspective, which emphasizes the need

to build a range of governance capacities across diverse actor types, this alone is insufficient. Degrees' capacity building efforts therefore largely focuses on building an international community of SG experts to enable informed and global participation ('why'), by providing research funding and hosting workshops ('how') for developing country scientists and researchers ('who').

In contrast to the Degrees Initiative's scientific capacity building efforts, C2G (the Carnegie Climate Governance Initiative) focused its efforts on raising awareness and convening discussions among policymakers and their advisors and other key actors (C2G 2022). C2G, an initiative of the Carnegie Council for Ethics in International Affairs, was created as an intentionally time-bound initiative and ceased operations at the end of 2023, aiming to transfer its expertise, products, and practices into intergovernmental and non-governmental organizations before it dissolved (C2G 2022). C2G aimed to "catalyse the creation of effective governance for climate-altering techniques, in particular for [SG] and large-scale [carbon dioxide removal]." While C2G did aim only to catalyze governance, from the perspective of the new capacity building model, which emphasizes the long-term nature of the capacity building process, a short-term time-bound initiative is inherently limiting and may fail to produce capacity that remains with recipients over long periods of time. C2G was led by Janos Pasztor, who has held many high-level positions in global environmental politics, most recently as UN Assistant Secretary-General for Climate Change. Funding came from several philanthropic organizations based in Northern countries, which

again raises questions about power relations between C2G and policymakers particularly in Southern countries (C2G n.d.a).

C2G aimed to catalyze governance, in part, by raising awareness among "[p]olicymakers and their advisors, and other key actors" to "learn about new approaches, their implications, and why they need to be governed" (C2G 2022). C2G produced a range of information material including briefs and reports, blogs, infographics, and videos to "to raise awareness, build understanding and stimulate discussion in support of its mission" (C2G n.d.b.) These materials include, for example, information on solar and geoengineering and carbon removal methods, key governance issues associated with particular methods, technical analysis, and insight into specific themes, such as the relationship of geoengineering to the Sustainable Development Goals. The initiative also hosted a series of online events "designed to catalyse learning about climate-altering approaches and their governance", including formal webinars and informal chats with question and answer opportunities (C2G Learn), one-to-one interviews (C2G Talk), and moderated in-depth conversations (C2G Discuss) (C2G n.d.c). Information and recordings of 49 of these online events can still be found on C2G's website.

In addition to raising awareness, C2G also convened key actors with the aim to discuss and develop "shared understanding and collaborative approaches to governance" (C2G 2022). C2G targeted policymakers and their advisors, including those in intergovernmental organizations such as UNEA and the UNFCCC, "key relevant government positions" in national governments, and non-state actors,

including “key civil society organizations” and “influential individuals from the international policy world, academia, and media” (C2G 2022). Although C2G did not explicitly aim to build capacity, their activities did contribute to overall capacity building efforts. While C2G restricted its focus to those actors it considers ‘key’ to catalyzing governance discussions, C2G took important first steps towards GCB by focusing on multiple types of state and non-state actors that can be expected to play important roles in governing SG. However, the focus on ‘key actors’ who are already influential suggests that this effort fails to build capacity with the people most in need of SG capacity building, including those from marginalized and vulnerable communities. Additionally, it’s unclear how effective C2G’s efforts to raise awareness and develop shared understanding among key actors were. Part of the reason why a Swiss resolution on SG failed at UNEA-4 in 2019 was because there was a limited understanding of what SG was - awareness of SG did not reach many countries and their officials (Jinnah and Nicholson 2019). C2G’s capacity building activities therefore largely focus on catalyzing effective forms of governance (‘why’) by raising awareness among and convening (‘how’) policymakers, their advisors, and other actors in influential roles (‘who’).

Other international workshops and conferences have also been held in recent years. For example, a 2014 workshop in Fiji hosted by the Institute for Advanced Sustainability Studies (IASS) and the Pacific Centre for Environment and Sustainable Development at the University of the South Pacific aimed to “*inform Pacific stakeholders about the current state of the scientific, political and ethical debate on*

climate engineering and to provide a platform for discussion and exchange of views between science and policy communities as well as among the Pacific island countries" (Beyerl and Maas 2014, p. 7, emphasis added). In its short-term transfer of knowledge developed by international consultants, this workshop was more in line with the "classic" model.

Other 'classic' and research-oriented capacity building activities include discrete trainings and presentations. For example, several geoengineering focused short-term 'schools' have been organized with the aim of enhancing interdisciplinary research capacity among scholars. The Emmett Institute on Climate Change and the Environment at the UCLA School of Law has hosted six such events, mostly recently in 2019, in partnership with the Forum for Climate Engineering Assessment, SRMGI, the Harvard Solar Geoengineering Research Program, and C2G. The week-long school held in 2019 aimed to "bring together an international group of leading experts with post-graduate students, early-career researchers, and professionals seeking to develop expertise in the field … [and to] facilitate intensive, collaborative explorations of the societal, political, governance, and ethical aspects of geoengineering" (UCLA Law n.d.). Moreover, research presentations related to SG have also been held within several academic conferences, such as at meetings of the American Geophysical Union (AGU) and the International Studies Association.[95] These efforts contribute to overall capacity building efforts within the research community because they develop individuals'

[95] For example, the Fall 2022 Meeting of the AGU hosted several solar geoengineering related events, such as "Advances in Solar Radiation Modification (SRM) Research". See for example Visioni et al. (2022).

capacities to understand SG and related issues and challenges. However, they demonstrate how entrenched the classic capacity building model is because they are short-term and largely uncoordinated.

To summarize, capacity building efforts surrounding SG have had a diverse mix of target recipients (i.e. scientists, government actors, and influential actors in civil society ('who')) and approaches (i.e. funding research, raising awareness, and convening discussion) ('how')). Although these efforts have included the aim of catalyzing governance and governance related discussion ('why'), this has been done primarily through short-term efforts to develop basic SG literacy and by funding scientific research.. There remains a significant need for more GCB among a wider set of civil society that is more representative of the diversity across marginalized and climate vulnerable communities. This is true for other emerging climate intervention technologies as well.

A Critical Evaluation of Existing Solar Geoengineering Capacity Building Efforts

Overall, existing capacity building efforts on SG show several promising developments and future prospects, including as related to working with and taking direction from researchers and other actors in the Global South. However, these efforts remain overall ad-hoc and fragmented, with individual initiatives targeting specific target populations for capacity building but without apparent multi-sectoral coordination and collaboration. Much of the focus has remained on building SG expertise and basic

literacy among scientists, researchers, policymakers and other influential actors. Additionally, with the exception of the Degrees Initiative, all efforts are short-term, undermining the need to initiate long-term processes that develop and sustain capacity over long periods of time. Most of these efforts also generally suffer from a lack of diversity of staff. This lack of diversity, together with funding coming primarily from philanthropic bodies in the Global North, raises the need to consider more seriously how ownership over the capacity building processes and outcomes can be transferred to the Global South. The existing field therefore has a ways to go to fully implement comprehensive GCB initiatives in line with the new capacity building model.

Where do we go from here?

Governance capacity building (GCB) is needed to establish effective and inclusive governance of climate intervention technologies. We have demonstrated here the critical importance of initiating in the near term a comprehensive GCB program using the new capacity building model as a guide in order to enable climate vulnerable communities and countries to govern SG and climate intervention technologies more broadly. Centrally, this means that capacity building programs are needed to build a wide range of governance capacities - including but stretching beyond scientific capacity and expertise - within a wide range of actors and sectors of society. These efforts must also focus on strengthening existing capacities in climate vulnerable communities and countries by transferring ownership of the capacity building process

and products to these populations. By falling short on these insights, we also demonstrated that gaps and limitations in how capacity building is understood in the SG literature and implemented in practice can stifle the potential of capacity building to enable inclusive and effective governance in this issue area. We close with a discussion on where we go from here to build a successful GCB program.

First, the scholarship on SG governance can better support existing and future capacity building efforts by treating it as an important line of inquiry deserving of focused attention. To do so, the literature must rethink existing framings of capacity building as a governance objective that other mechanisms merely contribute to. Rather, capacity building should be understood as a necessary prerequisite for establishing a wide variety of effective climate intervention governance mechanisms and ultimately achieving a range of diverse goals or functions that stretch across the entire governance process. Scholarship can therefore support efforts to identify a full range of governance capacities that are needed to govern SG in different ways, including as related to specific governance proposals and mechanisms. Researchers can also support practical efforts to develop GCB strategies and best practices by identifying lessons from other issue areas and by developing innovative assessment methodologies. Moreover, by investigating cross-cultural perspectives on SG and its governance, public perspectives researchers are well positioned to support efforts to identify capacity gaps and needs and to help determine the most appropriate ways to build capacity within local contexts, all of which can help inform decisions about how to distribute resources to best support capacity building efforts.

In practice, a new organization is also needed that can spearhead a broader and more inclusive GCB program for SG, thereby filling important gaps in existing capacity building efforts. The Alliance for Just Deliberation on Solar Geoengineering (DSG) was founded in April 2023 by Shuchi Talati with the aim of working towards just and inclusive deliberation on SG.[96] The organization does so by building capacity in climate vulnerable communities and countries to engage in and lead deliberations on SG. In contrast to other capacity building efforts, DSG focuses on building capacity primarily in civil society, including but not limited to non-governmental organizations and universities, as well as in policymakers in climate vulnerable countries. DSG's work currently focuses on meeting with civil society organizations in several target countries and learning about their needs, awareness, and perspectives on SG as part of a trust-building process and subsequently partnering with some of these organizations to expand activities to build a range of governance related capacities in civil society and policymakers across many national and local contexts. DSG is developing an iterative capacity building strategy, inspired by the new model of capacity building, that revolves around a series of modular learning projects that can be tailored through joint decision-making with local partners to meet local capacity needs and circumstances. Importantly, DSG aims to empower its local partners and communities to form their own opinions and positions on SG; it does not advocate for or against SG. We believe DSG's approach is an imperfect but important first step towards improving capacity

[96] The authors recognize affiliations with The Alliance for Just Deliberation on Solar Geoengineering (DSG). Shuchi Talati is the Founder and Executive Director of DSG; Zachary Dove is a Research Fellow at DSG; and Sikina Jinnah is an external collaborator.

building in the issue area. Here we discuss some aspects of how DSG is aiming to implement our recommendations for developing successful GCB programs.

DSG and any other capacity building initiatives for climate intervention are likely to face multiple challenges. These challenges are not specific to these technologies; still, capacity building surrounding these technologies may present novel challenges due to the controversial and scientifically complex nature of climate intervention. As the following practice-oriented recommendations designed to address these challenges follow from general lessons in the capacity building literature, they likely apply as well to GCB programs surrounding broader classes of emerging technologies, including artificial intelligence (AI), human genome editing (HGE), and nanotechnology. DSG aims to use these recommendations as a starting point for working alongside other SG capacity building initiatives to improve how capacity building is practiced in the issue area.

The first recommendation for improving existing SG capacity building efforts in practice relates to a widely agreed element of what makes capacity building successful. According to Khan et al., "Whatever way capacity building is conceptualized, there is an agreement in the literature that the key to success is ownership [by recipients] of the process and products" (2020, p. 501-502). Perspectives on capacity building from Southern countries also emphasize the need for partnership between recipient and donor to balance power relations (Hagelsteen et al. 2021). In other words, capacity building should ideally be led by recipient countries or communities and should be 'demand-driven' rather than donor or 'supply-driven'

(Godfrey et al. 2002; Khan et al. 2018). This is important because it ensures that capacity building efforts address the specific capacity needs identified as most important by the recipients and that decision-making and responsibility, and ultimately capacity, remains with the recipients.

However, the early stages of a GCB program catalyzed, for example by NGOs from Northern countries, is unlikely to be sufficiently 'owned' or driven by Southern countries. This includes DSG's efforts so far. This is in part because immediate socio-economic priorities may take precedence over climate change capacity building (Pandey and Kumar 2018). Yet additionally, capacity building efforts take place within a context characterized by unequal distributions of resources, including money, knowledge, and technology (Khan et al. 2018). In this context, NGOs from the Global North such as DSG will be providing and coordinating, albeit increasingly with Southern SG expertise, the resources needed to initiate a capacity building program. Funding from democracy-oriented philanthropic bodies in the Global North is not intrinsically problematic, however, important questions of power and partnership arise when considering who makes decisions about how resources will be used (Khan et al. 2018).[97] As such, achieving genuine partnership with capacity building recipients in the Global South becomes challenging and the task is to figure out how to transfer ownership to these recipients. A genuine partnership entails recipient communities and

[97] We suggest moreover that the Global North may be morally obligated to fund governance capacity building work in the Global South, possibly under a climate debt or adaptation finance framework.

countries “setting the [capacity building] agenda from the outset and remaining in control throughout” (Khan et al. 2018, p. 101; Brohman 1996).

Silver bullet solutions do not exist but several paths forward seem promising. The risk of insufficient ownership by recipient countries can be mitigated by developing genuine relationships with local partners in participating countries early in the capacity building process including by practicing joint decision-making and by investing resources to build their own capacity to demand, coordinate, and lead capacity building efforts. This could be done, for example by developing a local ‘legacy partner’ that would closely follow the entirety of the capacity building process and would continuously build its own capacity to advance capacity building efforts in the long term. The International Institute for Environment and Development (IIED) is developing the idea to ensure long-term capacity building by working with a local partner institution to “follow the process and capture lessons learned, with a focus on building the capacity of individuals and relevant institutions through 'learning-by-doing'” (IIED n.d.a.). Khan et al. (2018) argue that Global South universities are particularly suited for this role because they tend to exist for long periods of time, they have existing expertise, and they are well positioned to train young people for positions in a variety of sectors.

Initiating joint decision-making to the greatest practical extent is also needed to create meaningful partnerships and transfer ownership of SG capacity building programs to the Global South. This means local partners would have an equal if not leading role in deciding what SG governance capacities need building or strengthening,

how to best do so, and how to use money, expertise, and other resources towards this end. DSG is initiating joint decision-making in program and workshop planning by working with individuals from partner organizations in the design and implementation of SG capacity building activities. In practice, this can look like co-creating agendas and activities, highlighting local experts and speakers, and jointly deciding outcomes and next steps. Evidence from other issue areas also shows that partner institutions in participating countries can play a central role in shaping how external capacity building projects are implemented (Biedenkopf et al. 2017).

The second recommendation is for donors and facilitators of capacity building programs to take seriously the need to build their own capacities (Sagar and VanDeveer 2005) to successfully provide capacity building interventions. In other words, there appears to be an acute need for c*apacity building for capacity building.* For example, participants in capacity building processes emphasize that capacity building providers must have the capacity to understand the local context including what work has already been done and where capacity already exists (Hagelsteen et al. 2021). This requires that capacity building efforts develop capacities to learn from mistakes and successes and adapt over time in response to assessments and input, including, crucially, from capacity building recipients. DSG is embracing a 'learning-by-doing' approach to building its own capacities by learning about local context from institutional consultations and partnerships, developing a better understanding of approaches from capacity building experts and facilitators, and hiring diverse staff with a range of geographical and disciplinary expertise.

One critical area where capacity must be built is in how to define and measure success in capacity building efforts. There are currently few assessments of capacity building activities and there is no standard way to define and measure success in this area. A core element of the 'new' capacity building model is the importance of building long term sustainable systems that can continue capacity building efforts in order to effectively address long term problems (Khan et al. 2018). Khan et al. (2018) for example propose that "the main indicators used to judge value for money for climate change capacity building should be whether in-country capacity systems and capacity suppliers have been left behind in each target country" (p. 13). However, donors are likely to want evidence of short term impacts to renew funding.

There are also methodological challenges involved in assessing the effectiveness of capacity building. For example, a rigorous evaluation method would need to separate the impacts from capacity building programs from other interventions and factors in order to demonstrate that it was the capacity building that contributed to beneficial impacts or outcomes. Attribution of causality remains a challenging endeavor in the social sciences and would similarly present challenges for capacity building assessments. To compound this challenge, capacity building efforts can also become structurally complex as more projects, levels, funders, partners, and targeted communities are included in the overall capacity building space. Complex arrangements can generate their own capacity needs, as different actors grapple with their roles and responsibilities within a broader system (Soal and Merrill 2021). In a comprehensive SG GCB program, many types of actors working across multiple levels

will be working together to build a wide array of capacities required to govern different forms of SG research and deployment. Care must be taken to assess the effectiveness of both individual efforts and the capacity building system as a whole, including for different capacities, actor types, and locations.

To address these challenges, NGOs including DSG are developing their own capacities in "impact assessment, value for money and cost-benefit analysis, monitoring mechanisms, performance and process evaluation", or systemic monitoring, evaluation, and learning (IIED n.d.b). For example, sophisticated methodological tools such as the Capacity Building Assessment Matrix developed by the Council on Energy, Environment and Water aims to quantify the progress of capacity building in the Global South (Prasad and Gupta 2019). These tools hold the potential to enable systematic and rigorous assessment of capacity building efforts, which is needed to improve capacity building methods and models over time. Overall, while the new capacity building model looks promising and may enable a more successful phase of capacity building efforts, it is also unproven. Time is needed to assess how successful it is in transgressing the limitations of the classic model and in achieving long-term sustainable impacts. Despite some promising developments, tried-and-true capacity building methods and solutions do not exist, and experimentation and ongoing evaluation and reflexivity is required to develop these.

In sum, initiatives for building governance capacity for emerging climate intervention technologies should build their own capacities related to anticipation, reflexivity, and adaptability to assess whether and how their capacity building efforts

are successful and if not, what and how they can change to build locally-owned and durable capacity systems.

If followed, the path we have outlined here can enhance the potential for governance capacity building to enable inclusive and effective governance of climate intervention. This important work is needed to help ensure that the capacities required to either restrict or enable climate intervention activity are widely available as communities and countries begin or continue to make critical decisions about whether and how research or deployment activity will move forward or not.

Appendix

Supplemental material for Chapter 2: Global Perspectives on Solar Geoengineering: a novel framework for analyzing research in pursuit of effective, inclusive, and just governance

Reproduced from:
Dove, Zachary, Arien Hernandez, Shuchi Talati, and Sikina Jinnah. 2024. "Global Perspectives on Solar Geoengineering: A Novel Framework for Analyzing Research in Pursuit of Effective, Inclusive, and Just Governance." *Energy Research & Social Science* 118 (December):103779. https://doi.org/10.1016/j.erss.2024.103779.

Supplement A: Additional method details

The following supplement presents additional methods details organized by research question.

RQ1: Where is the research being done? Which publics or groups are included?

Participant location

Our analysis of participant location is based on the **number of studies** and **number of participants** for each country. To create **Figure 2.1** in the main article, we first identified studies within our database that provided original data and that aimed to collect perspectives from particular countries. Each of these studies were coded for the location of participants. For example, a survey experiment that includes a participant sample from the United States (e.g., Bolson et al., 2022) occurred in the United States, and deliberative workshops held in the United Kingdom occurred in the United Kingdom (Bellamy et al., 2013). Studies can also elicit SG perspectives in more than one country. For example, Sugiyama et al. (2020) studies SG perceptions across six Asia-Pacific countries.

For all analyses for participant location, we exclude articles that review or analyze data from studies that are published elsewhere to prevent double counting (e.g., Carr and Yung, 2017); studies that did not provide sufficient participant location information (e.g. Merk et al., 2019), and, where data from a single study is published across multiple articles, we count only one (e.g., Sovacool et al., 2002).

For the **number of studies** per country data, workshops that include participants who primarily are from multiple other countries were also excluded (e.g., Winickoff et al. 2015), as were surveys that included a small number of individuals based in a large number of countries (e.g. Baum et al. 2022). Many stakeholder engagement workshops that publish reports of participant perspectives include a small number of individuals from multiple countries. For example, the African Academy of

Sciences and the Solar Radiation Management Governance Initiative (now known as the DEGREES Initiative) held three workshops in Senegal, South Africa, and Ethiopia in 2012 and 2013. However, the workshop report notes that participants at these workshops came from 21 different African countries, and neither the 21 countries nor the number of participants from each country are reported (African Academy of Sciences and SRMGI, 2014). Coding for each of the 21 countries as a location of study would have misleadingly shown more studies of African perspectives than has occurred. We excluded this and similar studies from the number of studies per country data.

Similarly, we excluded from this heatmap several studies that gather perspectives from experts or other individuals from a large number of countries. For example, we excluded Baum et al. (2022), which interviews 125 experts from 21 countries, primarily from the Global North. Again, it would be misleading to code each of the 21 countries as the location of a perspectives study. Similar cases include Mercer's (2014) survey of international experts and Dannenberg and Zitzelsberger's (2019) survey of 723 climate experts from more than 150 countries.

To obtain a more comprehensive understanding of whose perspectives are included in SG perspectives research, we created **Figure 2.2,** based on the **number of participants** per country data. This figure allows us to capture efforts to elicit perspectives from people around the world without overrepresenting the number of times each country was included in SG perspectives study. To create **Figure 2.2**, we

totaled the sample sizes for all participants for each country for all studies that report original data.

Some studies provide incomplete participant location information. For studies that include participants from multiple countries and provide a total sample size but without a country specific sample size, we divide the total sample size by the number of countries to create an estimate for the number of participants from each country (e.g., Winickoff et al. 2015; African Academy of Sciences and SRMGI 2014). Baum et al. (2024) reports surveys in 30 countries totaling 30,284 participants, with at least 1,000 participants from each country; we estimated 1,000 participants for each country.

Additionally, Merk et al. (2019) reports that 52% of the participants in their survey are from German institutions; the rest of the participant locations are not reported. We coded 52% of the total sample size as participants from Germany, and the rest are not included in either analysis of participant location.

For studies with two methods and separate samples for each method, we totaled the number of participants included in both samples. Where the samples overlap, we avoid double-counting. For example, Fenn et al. (2023) note that 56 of 58 participants that participated in their cognitive affective mapping also participated in their survey.

For longitudinal studies with attrition, we code for the original sample size, not accounting for attrition (e.g., Bolsen et al. 2023).

For studies in which not all participants are asked about or provided information about SG (Jobin and Seigrist 2020; Baum et al. 2024), we still include the total sample size for the study, not only those participants that are asked about SG. **Supplementary**

Table A.1 includes the final data for **number of studies** and **number of participants** for each country, which are visualized in **Figure 2.1** and **Figure 2.2** respectively.

Table A.1: Number of studies and number of participants data

Country	**Number of studies**	**Number of Participants**
United States	32	24278
United Kingdom	22	13760
Germany	12	10723
Australia	7	4007
China	7	3299
Japan	6	6473
Switzerland	6	3562
India	5	2113
Sweden	4	1107
Kenya	4	1400
Norway	4	1837
Nigeria	4	1362
Italy	4	1357
Philippines	3	1110
Canada	3	2394
New Zealand	3	1816
Finland	3	64
Singapore	3	2771
Austria	3	1302
Turkey	3	1425
Spain	3	1408
Brazil	3	1229
Portugal	2	202

Dominican Republic	2	1015
Chile	2	1018
South Africa	2	1052
Netherlands	2	1480
Poland	2	1016
Mexico	2	1308
Indonesia	2	1020
Saudi Arabia	2	1016
South Korea	1	504
Solomon Islands	1	33
Bangladesh	1	27
Pakistan	1	348
France	1	1000
Estonia	1	1000
Greece	1	1000
Iran	1	366
Kazakhstan	1	301
Taiwan	1	492
Ireland	1	330
Denmark	1	1002
Argentina	1	211
Russia	1	217
Timor-Leste		2
Fiji		31
Uganda		2
Vietnam		5
Senegal		35
Nepal		2
Ethiopia		35

Samoa		1
Laos		3
Madagascar		3
Malaysia		2
Peru		2
Ghana		2
Belgium		2
Sri Lanka		2
Mongolia		2
Cuba		1
Thailand		1
Brunei Darussalam		1
Albania		1
Djibouti		2
Malawi		2
Ecuador		2
Afghanistan		2
Myanmar		2
Czech Republic		1
Tunisia		2
Mozambique		2
Slovenia		1
Cook Islands		1
Tonga		1
Nauru		1
Vanuatu		1
Tokelau		1
Kiribati		1
Hong Kong		3

Participant Actor Type

Our coding for **participant actor type** visualized in **Figure 2.3** began by recording the actor type as reported by each study. We then simplified the actor types by removing specific qualifiers and descriptors.

For example, faculty, researchers, and experts of varying disciplinary expertise and affiliations were coded as 'Experts'. Similarly, all members of subnational and national government, including policymakers, regulators, and other public officials were coded as 'Government'. Members of NGOs, civil society, scientific associations, or lobbying organizations were coded as 'NGO'. All members of business organizations or workers, tradespersons, and other people identified by their specific occupation were coded as 'Industry'. All members of regional or international organizations were coded as 'International Organization'. We kept 'Youth' and 'University students' as separate types of actors and coded each by how each relevant study labeled the participants.

Studies that aimed to study 'situated publics' or that included a diverse sample of individuals with varying occupations, positionalities, and identities were coded as 'Lay public' because these samples likely resemble how lay publics are actually composed (e.g. Carvalho and Riquito, 2022).

Studies that included a small number of participants of actor types that are different from the primary types of actors studied are coded only for the primary types

of actors studied. For example, Hussain et al.'s (2024) survey was responded to primarily by university students and faculty and is framed as an exploration of 'academic perspectives', however, "[a] few stakeholders in industry, policymakers, NGOs, and the general public also responded" (313). The study was coded as including university students and experts.

We excluded the sample size from Merk and Wagner (2024) because the 340,000 participants included in the social media experiment would clearly skew our results.

Supplementary Table A.2 provides the final data for **participant actor type** and is visualized in **Figure 2.3**.

Table A.2: Participant actor type data

Participant actor type	Number of studies
Lay public	63
Experts	27
Government	14
NGO	13
University students	13
Industry	9
Int'l Org	4
Media	2
Youth	2
Indigenous	1

RQ2: ***Who is producing the research? Where are those researchers based?***

Our analysis of **researcher location** visualized in **Figure 2.4** is based on institutional affiliations as reported in each study. For researchers with more than one institutional affiliation, we used the first listed affiliation. For organizational authors, we coded for the location of the organizational headquarters (e.g., African Academy of Sciences and SRMGI 2014).

Supplementary Table A.3 provides the final data for **researcher location** and is visualized in **Figure 2.4**.

Table A.3: Researcher location data

Country	**Number of Researchers**
United States	109
United Kingdom	88
Germany	59
Denmark	53
Japan	26
New Zealand	11
Norway	10
Switzerland	9
Italy	8
Sweden	7
Singapore	7
Finland	6
Netherlands	6
Canada	6
Portugal	5

China	4
Austria	4
Belgium	3
Hong Kong	3
Russia	3
Argentina	3
India	3
Pakistan	2
France	2
Brazil	2
Spain	2
Ireland	2
Kenya	1
Czech Republic	1
Ethiopia	1
Nigeria	1
Taiwan	1
Mexico	1
Australia	1
Kazakhstan	1
Iran	1
Turkey	1

RQ3: How is research interest in SG perspectives changing over time?

Our analysis of research interest over time is based on the year each study was published, as stated within the study.

Supplementary Table A.4 presents the final data for the year **published** and is visualized in **Figure 2.5.**

Table A.4: Year published data

Year Published	Number of Studies
2009	1
2010	2
2011	7
2012	7
2013	7
2014	5
2015	10
2016	12
2017	10
2018	8
2019	8
2020	6
2021	7
2022	11
2023	15

RQ4: What lines of inquiry are being pursued? What types of questions are being asked?

We coded **line of inquiry** for all studies in our database visualized in **Figure 2.6**, including those that review previous literature and studies that re-analyze previously

reported data because these studies offer new and sometimes unique lines of inquiry and research questions and therefore also produce valuable forms of knowledge about SG perspectives (see e.g., McLaren et al. 2016). We exclude from this analysis two studies that present preliminary results of research that is published later and that do not present additional lines of inquiry or analysis.

To code lines of inquiry, we included statements of research object or focus as stated in each article and we also code for key themes that arise in presentations of results. We first coded for line of inquiry using short quotes that describe which particular aspects of SG perspectives are being investigated.

Importantly, studies can and overwhelmingly do include more than one object of study, and they are not mutually exclusive. Perceptions of *Trust*, for example, is often studied as a *Predictive factor* for *Support*. Our list of lines of inquiry aims to be broadly comprehensive of the major lines of inquiry within the research but not exhaustive of all possible or observed lines of inquiry.

Supplementary Table A.5 provides the final data for **line of inquiry** and is visualized in **Figure 2.6**.

Table A.5: Line of inquiry data

Line of Inquiry	**Frequency**
Support	84
Predictive factors	49
Risk	44
Impact concerns	42

Governance	41
Familiarity	30
Moral Hazard	28
Trust	23
Framing	22
Justice, ethics	19
Benefit	19
Global politics	16
Nature	14
Effectiveness	13
Affect	9
Public engagement	9
Security	8
Capacity	7
Conspiracy	4
Sense-making	3
Free-driver	3

RQ5: How is the research being done? What methods are used?

For our analysis of **methods** used in the literature visualized in **Figure 2.7** we include only articles that present original data and exclude those articles that review or re-analyze previous research. Where results from the same data collection process are published across multiple articles, we count only one (e.g., Sovacool et al., 2022). Where two different methods were used to study perspectives from the same participant sample and where the data from each method were published separately, we count each

method once (e.g., Delina 2021; Sovacool et al., 2002c). 14 studies use multiple methods to elicit SG perspectives, although most studies only use one method.

We coded first for the method as described in the study. We then simplified several codes to enable a more simplified frequency count of methods used. Our simplified coding procedure elides a more complex picture that also includes unique methodologies and mixed-methods research. We coded all group discussion group-based methods, including a citizen's jury (Merk et al. 2019) and 'deliberative public forums' (Nelson et al. 2019) as a 'workshop' because they show considerable similarity to 'deliberative workshops' (e.g., Pidgeon et al. 2013) and to other workshops that are not explicitly claimed to be deliberative (e.g., African Academy of Sciences and Solar Radiation Management Governance Initiative 2013). The only studies coded as 'focus group' were those that used the term. Any survey-based data collection method that introduces any form of treatment effect was coded as a 'survey experiment' even if it was not described as such in the study. Some of these studies describe themselves as 'experiments' however their methods are functionally equivalent to survey experiments whereby participants are presented with information and then answer questions to either state or reveal their preferences (e.g., Raimi et al. 2019). We only coded studies as 'experiment, game' if the article used an experimental method or game in which participants did more than answer questions in response to provided information.

Where studies distinguished between data collection and data analysis methods, we coded only for data collection methods (e.g., Fenn et al. 2023).

We also distilled several unique methodologies to the core data collection methods that were used to gather perspectives:

- ‘Multi-criteria mapping’ (Bellamy et al., 2013) → interview
- ‘Decision pathway survey’ (Gregory et al. 2016) → survey
- ‘Fuzzy cognitive mapping’ (Rothman et al. 2023) → survey; interview
- ‘Group Delphi process’ (Scheer and Renn 2014) → workshop
- ‘Cognitive affected mapping’ (Fenn et al. 2023) → interview

Supplementary Table A.6 presents the final data for research method and is visualized in **Figure 2.7.**

Table A.6: Research method data

Method	**Frequency**
Survey	37
Survey experiment	22
Interview	18
Workshop	15
Focus group	10
Experiment, game	7
Social media analysis	4
Secondary analysis	2
Foresight scenario	1

RQ6: Why is the research being produced? What rationales are given for why SG perspectives are important to know?

We coded research **rationales** for all studies in our database visualized in **Figure 2.8**, including those that review previous literature and studies that re-analyze previously reported data because these studies offer additional and sometimes unique rationales. Research rationales include the rationale and motivation for the study, in the form of stated potential benefits of the research, an explanation of why the study is valuable, or an explanation of why it's important to know what or how people think about SG. Some rationales include an explanation of why it's important to know what particular types of actors or what people from particular parts of the world think about SG. Importantly, rationales are not mutually exclusive, and most studies provide more than one rationale to explain why the particular knowledge the study produces is valuable.

We coded first for the rationale as described in the studies, using short quotes that capture the research rationale. We then grouped similar rationales together and distilled each to a short descriptive label.

Our list of rationales aims to be broadly comprehensive of the major motivations underlying the literature but not exhaustive of all possible or observed rationales.

Supplementary Table A.7 presents the final data for **rationale** and is visualized in **Figure 2.8.**

Table A.7: Research rationale data

Rationale	Frequency
Inform decision-making	85
Inform research	43
Inform discussion	38
Inform communication strategy	32
Public importance assertion	28
Enhance inclusion	23
Inform public engagement	18
Open up	15
Increase public support	12
Democracy	10
Capacity building	8
Expert importance assertion	7
Justice	6
Responsible innovation	6
Moral imperative	4

Supplement B: Full List of Studies included in Analysis (Chapter 2 only)

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