Futures 132 (2021) 102816

Contents lists available at ScienceDirect

Futures

journal homepage: www.elsevier.com/locate/futures

The middle powers roar: Exploring a minilateral solar geoengineering deployment scenario

Zachary Dove [a], Joshua Horton [b], Katharine Ricke [c,*]

[a] University of California, Santa Cruz, 1156 High Street, Santa Cruz, CA, 95064, USA
[b] Harvard University, 24 Oxford Street, Hoffman Lab Room 132B, Cambridge, MA, 02138, USA
[c] University of California, San Diego, 9500 Gilman Dr. La Jolla, CA, 92093-0519, USA

ARTICLE INFO

Keywords:
Scenarios
Climate change
Geoengineering
Solar geoengineering
Emergency framing

ABSTRACT

The prospect of solar geoengineering, which would entail reflecting a small fraction of incoming sunlight back to space to cool the planet, has been slowly but steadily rising on the climate policy agenda. Early research suggests that solar geoengineering could substantially reduce climate risks, but its development and potential use would be accompanied by an array of ecological and sociopolitical risks and governance challenges. Here we reflect on our participation in a solar geoengineering governance scenario exercise conducted at the 2019 International Summer School on Geoengineering Governance. In the scenario with which we engaged, a group of 'middle powers' intend to force the issue of solar geoengineering onto the international agenda after decades of deadlock and in the face of intensifying climate impacts. As participants in this exercise, we confronted a range of problems and issues we judged likely to arise. In this article, we discuss a number of these, including the manner in which political considerations are likely to influence the physical and technical aspects of deployment schemes, as well as ways in which emergency framing may undermine political legitimacy. These and other aspects of possible future deployment of solar geoengineering warrant additional targeted scenario analysis.

1. Introduction and background

The prospect of solar geoengineering has been slowly but steadily rising on the climate policy agenda. This technological intervention would entail reflecting a small fraction of incoming sunlight back to space to limit some of the most damaging impacts of climate change. The most studied method would involve dispersing reflective aerosol particles in the upper atmosphere using aircraft or some other delivery mechanism. Although preliminary research suggests that moderate amounts of solar geoengineering could substantially reduce climate risks related to global warming, it would also introduce new risks and challenges. Importantly, solar geoengineering would not address the underlying problem of excessive greenhouse gas concentrations in the atmosphere (National Research Council, 2015). Therefore, it is not a long-term substitute for emissions reductions and adaptation. Associated environmental risks may include altered hydrological cycles and delayed recovery of the ozone layer (Pitari et al., 2014). It may also involve sociopolitical risks such as disagreements over whether and how to implement the technology; the potential for unilateral action, international instability, and even conflict; and reduced incentives to mitigate emissions. These and other challenges underline the need for effective and equitable governance of solar geoengineering across multiple scales. However, no existing governance institution has

* Corresponding author at: 9500 Gilman Dr. #0519 La Jolla, CA, 92093-0519, USA.
E-mail address: kricke@ucsd.edu (K. Ricke).

https://doi.org/10.1016/j.futures.2021.102816
Received 15 February 2021; Received in revised form 14 July 2021; Accepted 15 July 2021
Available online 19 July 2021
0016-3287/

the authority or capacity to meet these challenges (Jinnah, 2018). Many questions remain about alternative forms of governance, the likely preferences and behaviors of relevant actors, and future scientific and technological developments.[1]

In this article, we summarize and reflect on our participation in a solar geoengineering governance scenario exercise conducted over three days at the 2019 International Summer School on Geoengineering Governance. The summer school brought together an international group of geoengineering experts with graduate students, early-career researchers, and professionals to "facilitate intensive, collaborative explorations of the societal, political, governance, and ethical aspects of geoengineering" (UCLA School of Law, 2019).

The scenario exercise involved eight groups engaging with four distinct hypothetical futures in which solar geoengineering is deployed, or at least proposed to be used. Two separate participant groups were assigned to each scenario. We participated in the scenario titled "the Middle Powers Roar" (discussed below) as members of the "Bear" group and the "Bighorn Sheep" group. Bear and Bighorn Sheep were composed of 15 participants in total, 5 females and 10 males, representing 7 nationalities. The participants in these groups were from the academic, non-governmental organization, and government sectors. Our aim here is to reflect on findings from this exercise and consider the potential for scenario exercises to anticipate future governance needs.

The scenario exercise involved three steps.[2] First, after being assigned the Middle Powers Roar scenario, Bear and Bighorn Sheep worked independently but in parallel to develop the specifics of hypothetical combined deployment schemes/governance arrangements ('proposals') meant to address the particular (identical) challenges with which they were confronted. Second, Bear critiqued Bighorn Sheep's proposal, and Bighorn Sheep commented on Bear's proposal. Third, each group responded by modifying its respective proposal. Unlike the other cases reviewed in this special issue, in our case, Bear and Bighorn Sheep decided to merge groups at this stage to craft a joint, revised governance proposal. This joint revised proposal built on Bear's initial proposal.

This article proceeds as follows. We begin by laying out the major elements of the Middle Powers Roar scenario then separately describe the initial proposals advanced by Bear and Bighorn Sheep. Next, we summarize their mutual critiques, followed by a description of their joint revised governance proposal. We then discuss key insights from the exercise and conclude by offering recommendations for further research.

2. The middle powers roar: major elements of the scenario

The scenario takes place starting in the year 2040.[3] Between now (2020) and then there has been no major transformation in the broad characteristics of world politics and no revolutionary or transformative change in the basic structure or character of government in major world powers. There has been moderate progress in international climate cooperation under the United Nations Framework Convention on Climate Change (UNFCCC). World emissions peaked in the mid-2030s and have declined consistently for five years. However, global heating surpassed 1.5 degrees Celsius (°C) above pre-industrial in the mid-2020s, slowed for a decade, then surged in the past few years to over 2.2 °C. As a result, many countries, not just the least developed, are experiencing serious environmental disruptions and political stresses.

Against this background, a group of rich "middle powers" – including Canada, the Nordic countries (Denmark, Finland, Iceland, Norway, and Sweden), the Netherlands, France, New Zealand, and Japan – intend to force the issue of solar geoengineering onto the international agenda after unsuccessfully advocating for expanded research and governance consultations for 20 years. International deadlock and passivity on solar geoengineering thus far have left these countries frustrated. Now, the intensity of climate impacts has pressed them to move forward with implementing some level of solar geoengineering, even in the absence of agreement from the great powers.

Accordingly, the heads of government of these ten countries have agreed on three overall aims. First, they want to establish an effective and well-governed solar geoengineering deployment program. While these middle powers are willing to proceed without the consent or participation of other states, they are also prepared to make concessions to gain broader support in both the implementation strategy and the related governance arrangements. Second, they want to encourage, not obstruct, recent progress in global climate policy, in particular success in entering a global downward emissions trajectory following an apparent peak in the mid-2030s. Finally, they want to avoid escalating disagreements with other governments over their solar geoengineering program, especially to the level of military conflict.

To achieve these aims, the leaders of the middle powers created a task force composed of senior officials and advisors charged with crafting a strategic plan to launch solar geoengineering down a constructive path—our scenario group role-played this task force. Importantly, the Middle Powers Roar scenario is distinct from the other three scenarios in that our groups were asked to design and communicate a proposal for deployment, whereas the other scenario groups were tasked with elaborating a governance response to a deployment undertaken by others.

[1] See Section 2 ('Geoengineering') of the introductory article to this special issue for a detailed discussion of the current knowledge base and prominent debates surrounding solar geoengineering.

[2] See Section 5 ('The July 2019 Scenario Exercise') of the introductory article to this special issue (Parson and Reynolds, 2021) for a detailed discussion of the scenario exercise process.

[3] The complete text of all four scenarios and related material distributed to participants is available in the supplementary online material.

3. Initial proposals

The groups had to deal first and foremost with multiple issues and decisions relating to the intensity and scale of the initial program, when to announce the program publicly, whether to seek more partners before or after the initial deployment, how the program would be framed and justified, how the program would address concerns over potential 'moral hazard'[4], and how the program would be governed. This section sketches the main elements of how each group dealt with these issues. The common elements of the groups' proposals were few: both groups decided to create a new multinational body to govern solar geoengineering's use and to seek the support of other countries. Beyond this, the two proposals diverged in important ways, including the stated purpose of the deployment; the scale, scope, and timing of the deployment; the strategy for gaining broad support; and the design of the multinational governing body.

3.1. Bighorn sheep

The Bighorn Sheep group decided to characterize the deployment program as a scientific research project. Its members planned to proceed immediately with large-scale testing of stratospheric aerosol injections. Citing existing international protections for scientific inquiry, these states would initiate tests with negligible environmental effects on a minilateral basis for one to two years. They would build support for the program by offering to make technical adjustments, providing financial support and political protection to smaller nations, and considering posting environmental bonds or establishing a fund to compensate parties harmed by the research.

To govern this testing, a multinational research "Consortium" would be created. It would initially consist of representatives of the middle powers, but any country that diplomatically and financially supported the Consortium's mission to initiate large-scale tests of solar geoengineering would be allowed to join. Subsequent deployment would be carried out either by independent contractors or by the air forces of member states. The Consortium would monitor the dispersion and chemistry of stratospheric aerosols across a wide range of latitudes, with data made public.

Participating governments would pair a public announcement of their plans for testing with co-sponsorship of a resolution introduced to the United Nations General Assembly (UNGA) calling upon member states to cooperate on the development of a large-scale study of solar geoengineering. To pass the resolution, the middle powers would seek the support of vulnerable developing states and at least one larger emerging power, potentially China or India. A decision to fully deploy would depend both on the results of the initial tests and on the deliberations of the UNGA.

3.2. Bear

The Bear group spent considerable time grappling with the question of how to simultaneously initiate a minilateral solar geoengineering deployment and generate broad support. The group designed a comprehensive approach to managing anthropogenic climate change. Invoking the language of catastrophe and emergency, heads of government of these middle powers formally announced the Beginning Earth Atmosphere Rescue (BEAR) initiative. Under the initiative, all member countries (also referred to as 'the BEAR states') promised to cut gross greenhouse gas emissions to 80 percent below 1990 levels within ten years, i.e., by 2050. Although the distribution of mitigation commitments among member countries raises considerable challenges, the group nevertheless made drastic emissions reduction a central part of this initiative to demonstrate dedication to avoiding the moral hazard problem and enhance the legitimacy of the program. This way, members of the initiative could not reasonably be accused of using solar geoengineering to avoid their responsibility to reduce climate impacts. Moreover, the BEAR states intended to undertake carbon dioxide removal (CDR) efforts sufficient to take each country's net emissions "well below zero" over the same timeframe. If states were to fall short of fulfilling their 80 percent emissions reduction obligations, they pledged to compensate through secure, verifiable, and long-term CDR.

Most controversially, the BEAR states committed to embark on a regional deployment of solar geoengineering at high northern latitudes (the Arctic) at the beginning of boreal spring. The program would initially release 10 kilotons per day of sulfate aerosol precursor into the stratosphere at a minimum 74 degrees latitude[5] throughout the boreal spring and summer. The aerosol precursor would be delivered by high-altitude aircraft departing from BEAR state territories. The Arctic was strategically selected based on its unique role in the global climate system, the vulnerabilities of its ecosystems and peoples and, perhaps most importantly, a concentration of BEAR states along the Arctic circle. While the effects of this deployment would not be entirely contained to the Arctic, the program is not intended to stabilize global temperatures, and the cooling would be most pronounced at high northern latitudes. As the world's first deployment of stratospheric solar geoengineering, this regional program would be carefully researched to learn important information about the climate response to radiation perturbations, as well as any other environmental or social impacts. In situ and remote monitoring protocols would be implemented to measure the chemical, physical and radiative properties and consequences of the released reflective particles. In addition, a ten-year time horizon was set for this Arctic geoengineering program, with the announced expectation that at this point, the program will be reformulated with broader global objectives and participation.

[4] The 'moral hazard' problem, in short, suggests that attention towards solar geoengineering will reduce the perceived urgency of traditional forms of mitigation, notably emissions reduction.

[5] The proposed amount of material to be released was calibrated roughly according to the Arctic simulations of Robock, Oman, and Stenchikov (2008).

To govern these actions, as well as monitor progress on meeting mitigation and CDR commitments, the BEAR states unveiled a three-part institutional structure, independent of the existing climate regime. First, the "Council of Nations for a Livable Climate", composed initially of heads of government of the BEAR states, would function as a high-level political body with ultimate decision-making authority over the intervention. The Council also has the authority both to scrutinize the mitigation and CDR commitments of member states and to verify their fulfillment. Second, the "Climate Restoration Operating Authority" would be responsible for the physical implementation of the program, including operating an extensive system to monitor the release of precursors, aerosol radiative and climate effects and environmental impacts. The Authority will review the outputs of the global stocktake mechanism under the UNFCCC to examine progress on global mitigation and CDR goals. Finally, the "Climate Restoration Scientific Advisory Body" would provide technical advice to the other two bodies, including on deployment and monitoring methods, impacts and risks, relevant scientific and technological developments, and how to phase out the intervention. This advisory body is comprised of distinguished climate, environmental, and social scientists.

Within ten years of initiating BEAR, the Council would begin the process of developing a global solar geoengineering program, called the Partnership for Earth Atmosphere Restoration (PEAR). The function of PEAR would be to expand these regional operations to counteract a more substantial fraction of anthropogenic warming and be designed and implemented based on the knowledge acquired through BEAR. By default, this global program will aim to increase globally averaged negative radiative forcing by 0.1 W per square meter (W/m^2) per year beyond BEAR program levels, increasing this rate of intensification as necessary to keep net global anthropogenic radiative forcing below 4.5 W/m^2. BEAR member states would urge *all* governments to join the PEAR successor initiative.

In exchange for making emissions reduction and carbon removal commitments comparable to those of the original BEAR members, new members would be granted some degree of control over this global deployment program. All states participating in PEAR, including the newcomers, will have equal voting power in the Council. However, until the Climate Restoration Operating Authority, in consultation with the Climate Restoration Scientific Advisory Body, concludes that solar geoengineering is no longer necessary to protect human or environmental well-being, some aspects of PEAR will be non-negotiable, including the initiation of a global program. Bear did not further elaborate on how control would be shared with new members in exchange for their cooperation.

Members of Bear internally considered Russia to be the state most likely to oppose the regional solar geoengineering under BEAR or the global deployment under PEAR.[6] While, as an Arctic nation, Russia will experience serious impacts from climate change, Russia also stands to potentially benefit from northern shipping routes newly opened by sea ice loss in the Arctic (Melia, Haines, & Hawkins, 2016) and therefore may oppose any attempt to reverse seasonal ice losses. Climate change may also increase prospects for oil and gas exploration in the Arctic and is projected to improve agricultural productivity in central Siberia (Tchebakova, Parfenova, Lysanova, & Soja, 2011).[7] While the relatively modest forcings associated with BEAR would not necessarily be large enough to nullify these economic opportunities, those from the larger PEAR intervention may be sufficient to do so. Bear considered opening back-channel negotiations with Russia to prevent active opposition to the initiatives. For example, the BEAR states might quietly signal some willingness to reduce the program's intensity as needed to preserve some Arctic shipping routes. Additionally, the group considered offering financial compensation for the loss of shipping routes. However, despite the internal discussion, Russia was not mentioned in the initial formal proposal.

4. Critiques and the revised proposal

After the scenario groups produced their initial proposals, each was critiqued by the other group.

4.1. Bear critique of bighorn sheep

Bear provided critiques of Bighorn Sheep's proposal in two parts. The first part includes general comments prepared by members of Bear acting as a hypothetical International Scientific and Legal Expert Working Group. The second part simulates a response by nations opposed to Bighorn Sheep's proposal.

First, the Expert Working Group said that Bighorn Sheep's proposal was ambiguous regarding the nature of the proposed intervention. The program was characterized as "large scale testing of solar geoengineering injections," however, the boundary between large-scale testing and deployment is fuzzy. To be effective, a large-scale test would need to generate a detectable climate signal above the background noise of natural variability; in functional terms, this would be indistinguishable from deployment. Given that the task assigned by heads of government was to deploy the technology, this suggests that Bighorn Sheep intend to implement solar geoengineering under the guise of research. Such a strategy could undermine future prospects for wider cooperation.

Additionally, the proposal makes no commitment to further mitigation action. Absent further commitments to reduce their emissions or expand CDR, the proposal appears to be a cover or justification for continued lack of adequate mitigation, thereby validating one of the most serious critiques leveled against solar geoengineering. Moreover, the middle powers offer funds for other

[6] Bear assumed this without considering which other states are likely to oppose the program. Future scenario work should more carefully anticipate state and non-state actor interests, reactions and positions with respect to solar geoengineering. When possible, actor interests should be treated as empirical questions, although currently few actors have articulated positions on solar geoengineering.

[7] At the same time, climate change also threatens to weaken existing infrastructure in Arctic and subarctic regions—for example, thawing permafrost may cause land subsidence and damage transport networks—so that net benefits for countries like Russia are uncertain.

countries to develop their own solar geoengineering capabilities but not to develop their own enhanced mitigation or CDR technologies. All of this together suggests the middle powers are failing to address the core problem of excess atmospheric carbon.

The Working Group also criticized the proposal for simultaneously initiating a large-scale test of solar geoengineering and asking members of the UNGA to endorse and cooperate on a continuous deployment program. If international endorsement and cooperation are important, why not seek it at the outset? The answer would seem to be that consent from other countries is a secondary concern, subordinate to the middle powers' primary interest in action.

The proposal also failed to specify any conditions that might apply to other countries wishing to join the coalition. This introduces the possibility that states opposed to deployment might become members of the governing authority in order to subvert its aims (akin to what happened to the International Whaling Commission when states opposed to whaling joined in order to halt the activity it was set up to manage). It also gives up the opportunity to leverage membership to enhance mitigation by requiring emissions cuts or CDR as a condition of ongoing participation in the program.

In the second part of the critique of Bighorn Sheep's proposal, the Bear group imagined itself as "the Opposition," a group of like-minded nations initially convened by the Russian Federation. These countries profoundly object to Bighorn Sheep's proposal because it would attempt to control the global climate on behalf of a small, unrepresentative group of countries. If Bighorn Sheep countries were to proceed as planned, the Opposition would resist, in two ways.

First, Opposition states will introduce a separate resolution to the UNGA characterizing Bighorn Sheep's proposal as "an international geoengineering coup" and their attempt to pass a supporting resolution as "a sham." In addition to calling on member states to oppose Bighorn Sheep's UNGA resolution, the Opposition resolution would also include a general condemnation of solar geoengineering as violating the spirit of peaceful international cooperation and the customary legal norm of not polluting the territory of another sovereign nation.

Second, the Opposition will oppose the proposed program as a contravention of the Environmental Modification Convention of 1977 (ENMOD), which bans hostile or military use of environmental modification techniques. Specifically, the Opposition will contend that, under the terms of ENMOD, if Bighorn Sheep countries were to use their (military) air forces to deploy solar geoengineering, they would be in violation of Article 1, Para 2, which prohibits military use of environmental modification techniques. Further, if these countries were to attempt to persuade, coerce, or encourage other nations to provide assistance to their program, they would also be in violation of Article 1, Para 2, which prohibits the same.[8]

4.2. *Bighorn sheep critique of bear*

Bighorn Sheep provided several critiques of Bear's initial proposal. First, the former noted that Russia might object to an Arctic regional deployment given the country's interest in an ice-free Arctic and the benefits of climate warming for Russia's agricultural sector. Bighorn Sheep declared that Russia expressed its intent to shoot down any aircraft engaged in solar geoengineering activities, including those operating over international waters, in order to stop what it called "dangerous meddling in the climate system."

Additionally, Bear's proposal would entail minilateral initiation of a solar geoengineering deployment program, which seems to contradict language in the proposal relating to democratic legitimacy and international cooperation. The BEAR states do not have the political or moral authority to act for the world on this issue—even by their own declared standards.

Bighorn Sheep also did not think Bear's proposal adequately addressed the moral hazard problem. The fact that membership in PEAR is contingent on using solar geoengineering and CDR was criticized for further reducing the international commitment to mitigation.

Moreover, Bighorn Sheep raised several technical issues with Bear's proposal. The deployment would be based on an incomplete understanding of stratospheric chemistry and circulation of aerosols on a global scale, including potential ozone depletion. Bear also failed to account for other negative impacts of solar geoengineering, such as stratospheric heating or acid rain.

Bear's proposal was further criticized for failing to specify how the initiative would respond to unintended – or possibly unrelated – climatological outcomes such as a devastating weather event, or to unforeseen complications such as a large volcanic eruption or a nuclear conflict occurring during the deployment period. Bear failed to specify who would be responsible for harm caused or exacerbated by solar geoengineering.

Finally, Bear's proposal was criticized for not addressing the chance of termination shock resulting from a collapse of PEAR. Abrupt cessation of global deployment could result in temperature increases much more rapid and more destructive than would have taken place in the absence of solar geoengineering (Matthews & Caldeira, 2007).

4.3. *Joint revised proposal*

At this point in the scenario exercise, members of both Bear and Bighorn Sheep decided to merge to develop a joint revised governance proposal based primarily on Bear's initial proposal, which they revised in four key ways to address the most significant limitations and weaknesses raised in the critique.

First, more cooperative language was added to emphasize the middle powers' commitment to act alongside the rest of the world. For example, in discussing the global program, PEAR, it was emphasized that the middle powers are urging the rest of the world to join

[8] These arguments are problematic insofar as ENMOD applies only to environmental modifications for "hostile" (war-related) purposes.

in designing the program and that the proposed governance systems and deployment program will be open to negotiation and modification. These changes were made to signal a willingness to collaborate, in response to Bighorn Sheep's criticism that the world may perceive a minilateral deployment as conflicting with the stated desire for cooperation.

Second, institutional changes were made to the proposed governance systems. In response to Bighorn Sheep's criticism that Bear had not addressed the question of compensation, the Council will establish a financial mechanism to compensate for damages resulting from the intervention (the precise nature of this mechanism was left unspecified). Further, the Climate Restoration Operating Authority is explicitly subordinated to the Council to clarify their institutional relationship. The Authority will be primarily responsible for developing a protocol for addressing issues of compensation for negative climate outcomes subsequent to initiation of atmospheric interventions, in consultation with the Climate Restoration Scientific Advisory Body. The Authority will also be required to consult with states and communities that allege to be harmed.[9]

Third, in response to Bighorn Sheep's criticism about moral hazard, PEAR membership requirements were changed so that prospective members must meet their emission reduction commitments in order to have a say on issues related to both solar geoengineering and CDR.

Finally, an added footnote explicitly addressed the group's discussion of Russia's geopolitical interests in the Arctic and ongoing diplomacy regarding Russia's participation in the design of the program. The combined Bear/Bighorn Sheep group acknowledged the potential for Russian opposition to the program and initiated backdoor diplomatic conversations with Russia to invite participation or, failing that, secure a commitment not to interfere. A similar strategy could be used to elicit, at a minimum, acquiescence to the program from other great powers.

5. Discussion

We discuss here several aspects of the Middle Powers Roar scenario, including the underappreciated significance of political factors in future decisions about solar geoengineering deployment, as well as how the scenario brings to the fore a tension between emergency action and political legitimacy, and our group's challenge in responding to that dilemma. We close by synthesizing key lessons from our scenario exercise.

5.1. Physical versus political imperatives in solar geoengineering decision-making

Our engagements with the scenario highlight the possibility, little explored in the literature to date, that solar geoengineering deployments may not be designed primarily with physical outcomes in mind. In Bear's proposal, an Arctic site was selected not just for physical reasons, such as the Arctic's important role in the global climate system, but for strategic political and legal reasons as well. The concentration of BEAR states near the Arctic circle meant that these countries themselves would be primarily affected by the deployment, and solar geoengineering could be conducted from their sovereign territories. Ultimately, the climatic intervention was not designed to optimize physical outcomes, but to minimize political risks.

This must be viewed in the context of the middle powers' prescribed long-term goal of global deployment. Given this ultimate objective, Bear decided on an initial regional action that was approached principally in terms of its likely global reception and the tone and precedent it would set for future efforts toward expansion, rather than its physical impact on the Arctic regional climate. Bighorn Sheep similarly decided on a program with negligible environmental impacts, to attempt to avoid international opposition as well as take advantage of legal protections afforded to scientific research. In general, it is probable that for those who ultimately want to deploy solar geoengineering on a global scale, political considerations will inform their first steps, since sustained global implementation will hinge on international cooperation.

This insight has implications for the type of outcomes associated with such a deployment. These outcomes may look much different than the physical outcomes of the scenarios simulated in climate models to date, which were designed with physical outcomes in mind. For example, making decisions about solar geoengineering based on political considerations, rather than physical outcomes, may increase the likelihood of harmful physical side effects such as a major displacement of the Intertropical Convergence Zone which drives the distribution of precipitation in the tropics (Nalam, Bala, & Modak, 2018), in addition to the social impacts that would follow. On the other hand, interventions driven by political considerations may also lead to less intensive deployments that aim to prioritize physical stability as a means of ensuring social stability.

Overall, the early stages of a global program in particular may be designed to create optimal political conditions for its expansion. This suggests that it is important to engage in some solar geoengineering science in which sociopolitical considerations drive deployment decisions, rather than physical ones. In research design, scholars should consider the possibility that decision makers may prioritize political considerations first and foremost. Research should conceptualize pathways for use of solar geoengineering technology driven by political expedience rather than technocratic deliberation.

Similarly, political considerations will continue to be influential past the early stages of deployment. Further research should explore the potential effects of solar geoengineering on world politics, as climatic interventions may, for example, generate new security risks or exacerbate existing tensions (Horton and Reynolds, 2016). Such consequences may, in turn, prompt actors to modify existing deployments.

[9] This is in part also an attempt to fulfill state's procedural duties under international law regarding activities that pose environmental risks: ensure access to information, participation in decision-making, and access to justice.

5.2. Emergency versus political legitimacy

Our scenario lays bare what may happen in any future contest between emergency action and political legitimacy in the context of solar geoengineering. In the scenario, coalition members have come to believe that urgent action is necessary to avoid significant losses. These countries also possess a strong desire to avoid acting against the wishes of other states. As the scenario exercise unfolded, the choices each group made served to demonstrate that the perceived need to act quickly and decisively inherent in the concept of emergency, on the one hand, and the desire to act on the basis of agreement among affected parties—that is, to act in a manner regarded as politically legitimate—may be in considerable tension.

Initially, Bear pledged to act unilaterally both at the outset and in the medium term, regardless of other states' reactions. Their plans for global deployment invite participation by others but are in no way contingent on it. In their critique of Bear's proposal, Bighorn Sheep highlighted the fact that such a fundamental stance undermines Bear's rhetoric about legitimacy and cooperation. In light of this criticism, the joint group made stylistic changes to its revised proposal but did not alter its substantive commitment to act. In effect, the combined Bear/Bighorn Sheep group accepted (and prioritized) the need to act. The logic of necessity dictated that all other considerations are secondary. Adopting this logic, the joint group ultimately treated legitimacy as aspirational rather than essential.

Confronted with an identical scenario, Bighorn Sheep alternately obscured the nature of their initial deployment and abandoned their charge to implement solar geoengineering. In the former instance, Bighorn Sheep labeled their deployment as "research."[10] In the latter instance, the group ceded decision-making authority over a global program to the UN. Bear criticized them on both fronts. In effect, Bighorn Sheep insisted on a decision that was politically legitimate, even if this meant that no action was taken. Allowing for the prospect of inaction came at the expense of necessity, however, and what had been regarded as an emergency was no longer treated as such.

Framing this scenario in terms of an emergency helps illustrate the dangers of appealing to a crisis as the basis for action. When necessity is invoked (and taken seriously), it invariably carries the potential to override any other ethical or political considerations, regardless of how favorable or desirable they may be. Emergency thinking can breed, at a minimum, hasty and (as exemplified here) hierarchical and exclusive decision-making and, at the extreme, authoritarianism, repression, and abuse (Horton, 2015). Yet not only has emergency framing been typical of some discourses on solar geoengineering, it is increasingly evident in conventional, contemporary climate politics, for example in the language used by Extinction Rebellion and similar movements and the growing trend of local and national declarations of a "climate emergency." Climate change demands urgent action, but as long as people regard other values such as political legitimacy (or democracy or fairness) as important, framing problems as emergencies runs the risk of marginalizing such ideals for the sake of necessity.

6. Conclusion

Exploring the Middle Powers Roar scenario shed light on numerous aspects of hypothetical deployment of solar geoengineering; these insights, in turn, suggest a number of areas ripe for future research. First, most theorizing about deployment schemes to date has assumed that policymakers will base their decisions on the degree to which alternative designs are likely to reduce global or regional climate risk. As this scenario illustrates, however, at least in the initial stages of deployment, climate risk reduction may be subordinate to geopolitical considerations; concerns about how implementation is likely to be viewed by powerful actors will be at least as important as any near-term climate benefits. Researchers interested in the climate impacts of solar geoengineering under plausible real-world conditions should therefore take greater account of how political factors are likely to constrain initial design parameters. Related to this, future scenario exercises should seek to integrate "real-time developments" into the scenario design that prompt participants to alter their climatic interventions in response to sociopolitical developments, for example a great power's declaration to counteract the program by initiating their own climate intervention, a prospect known as 'counter-geoengineering' (Parker, Horton, & Keith, 2018).

Second, the exercise suggests that when emergency framing is used, political legitimacy may be subordinated to expediency, heightening the probability of imprudent decision-making and promoting the advance of less democratic forms of politics. Emergency framing was implicitly built into the Middle Powers Roar scenario, but future scenarios work could take a step back and seek both to identify those conditions under which crisis thinking is more or less likely to arise in climate politics (including solar geoengineering), and to assess which risks are most likely when an emergency frame predominates. Such risks include but are not limited to minilateral deployment. Where risks appear to be significant, researchers might further explore the possibility of constructing political and institutional safeguards to protect against the pathologies associated with emergency modes of action. Additional scenario rounds might then be designed to "stress-test" the adequacy of such safeguards.

Overall, the scenario exercise illuminates the issues that arise in an imagined world where heightened climate impacts and deadlock on solar geoengineering have pressed the governments of middle powers to plan and initiate minilateral solar geoengineering. The exercise has usefully allowed us to anticipate how such a program might be designed, what questions, issues, and challenges the deploying actors might grapple with, and how other actors might respond. Our lessons for researchers aim to shed

[10] This response raises unresolved questions about what constitutes a geoengineering test. Physical scientists working on geoengineering have generally remarked that if the climate response is detectable, it is deployment, but this may not be the only valid interpretation. Does intent matter as well? The stakes are high in making this determination because scientific research is afforded certain protections under international law.

further light on the social and physical consequences of such actions.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest

The authors report no declarations of interest.

Acknowledgments

The authors would like to thank Edward Parson and Jesse Reynolds for helpful comments on earlier drafts, as well as the organizers and funders of the Sixth International Geoengineering Governance Summer School.

References

Horton, Joshua B. (2015). The emergency framing of solar geoengineering: Time for a different approach. *Anthropocene Review, 2*(2), 147–151.

Horton, Joshua B., & Reynolds, Jesse L. (2016). The international politics of climate engineering: A review and prospectus for international relations. *International Studies Review, 18*(3), 438–461. https://doi.org/10.1093/isr/viv013.

Jinnah, S. (2018). Why govern climate engineering? A preliminary framework for demand-based governance. *International Studies Review, 20*(2), 272–282. https://doi.org/10.1093/isr/viy022.

Matthews, H. D., & Caldeira, K. (2007). Transient climate–carbon simulations of planetary geoengineering. *Proceedings of the National Academy of Sciences, 104*(24), 9949–9954. https://doi.org/10.1073/pnas.0700419104.

Melia, N., Haines, K., & Hawkins, E. (2016). Sea ice decline and 21st century trans-arctic shipping routes. *Geophysical Research Letters, 43*(18), 9720–9728. https://doi.org/10.1002/2016GL069315.

Nalam, A., Bala, G., & Modak, A. (2018). Effects of arctic geoengineering on precipitation in the tropical monsoon regions. *Climate Dynamics, 50*(9–10), 3375–3395. https://doi.org/10.1007/s00382-017-3810-y.

National Research Council. (2015). *Climate intervention: Reflecting sunlight to cool earth*. National Academies Press. Retrieved from https://www.nap.edu/catalog/18988/climate-intervention-reflecting-sunlight-to-cool-earth Accessed January 22, 2021.

Parker, A., Horton, J. B., & Keith, D. W. (2018). Stopping solar geoengineering through technical means: A preliminary assessment of counter-geoengineering. *Earth's Future, 6*(8), 1058–1068. https://doi.org/10.1029/2018EF000864.

Parson, E. A., & Reynolds, J. L. (2021). Solar geoengineering: Scenarios of future governance challenges. *Futures*. https://doi.org/10.1016/j.futures.2021.102806.

Pitari, G., Aquila, V., Kravitz, B., Robock, A., Watanabe, S., Cionni, I., et al. (2014). Stratospheric ozone response to sulfate geoengineering: Results from the Geoengineering Model Intercomparison Project (GeoMIP): GeoMIP ozone response. *Journal of Geophysical Research Atmospheres, 119*(5), 2629–2653. https://doi.org/10.1002/2013JD020566.

Robock, A., Oman, L., & Stenchikov, G. L. (2008). Regional climate responses to geoengineering with tropical and arctic SO_2 injections. *Journal of Geophysical Research Atmospheres, 113*(D16). https://doi.org/10.1029/2008JD010050.

Tchebakova, N. M., Parfenova, E. I., Lysanova, G. I., & Soja, A. J. (2011). Agroclimatic potential across central Siberia in an altered twenty-first century. *Environmental Research Letters, 6*(4), 045207.

UCLA School of Law. (2019). *Sixth international summer school on geoengineering governance*. Retrieved from https://law.ucla.edu/academics/centers/emmett-institute-climate-change-environment/sixth-summer-school-geoengineering. Accessed January 22, 2021.