



Reflections on a hypothetical decentralized grassroots deployment solar geoengineering scenario

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ABSTRACT

What if solar geoengineering were enacted not through careful intergovernmental deliberations or the actions of a rogue state, but by millions of private citizens taking matters into their own hands? This thought experiment—the subject of a scenario exercise at the Sixth International Geoengineering Governance Summer School—produced a range of critical reflections on international responses to such grassroots deployment as participant teams developed and critiqued governance proposals. Consideration of decentralized solar geoengineering, while unlikely, provides compelling insights for the governance of both irregular and more conventional geoengineering scenarios. Participants stressed that concerns with the collecting and reporting of data, hemispheric imbalances, and multidirectional questions of legitimacy are likely to arise in such contexts. Grassroots activity could further serve to galvanize wider state-led deliberations around geoengineering governance, forcing—but not necessarily deciding—the question of whether and how solar geoengineering should be implemented.

1. Introduction

The prospect of a rogue actor unilaterally deploying solar geoengineering has haunted discussions of climate engineering governance. But what if the rogue actor were not a lone superpower, a desperate developing nation, or even a well-intentioned billionaire, but your next-door neighbor, acting in concert with millions of other people around the globe? This is the situation envisioned in the Decentralized Grassroots Deployment scenario from the scenario exercise at the Sixth International Geoengineering Governance Summer School in Banff, Alberta, in August 2019.

The Summer School examined the governance of two distinct approaches to responding to climate change: solar geoengineering, also known as solar radiation management (SRM), and carbon dioxide removal (CDR). Solar geoengineering consists of reflecting a small fraction of incoming sunlight back into space, thereby partially and temporarily offsetting some of the effects of humanity's greenhouse gas emissions. Proposed methods include the injection of aerosols or aerosol precursors into the upper atmosphere ("stratospheric aerosol injection") and the spraying of fine salt particles into the lower atmosphere over the ocean to increase cloud

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albedo (“marine cloud brightening”). CDR consists of removing carbon dioxide from the atmosphere and sequestering it, thereby decreasing concentrations of the primary greenhouse gas driving global warming. These two approaches are sometimes discussed jointly under the heading of geoengineering or climate engineering. The Decentralized Grassroots Deployment scenario focused exclusively on solar geoengineering.

While preliminary research suggests that solar geoengineering might be able to reduce overall climate risk, the prospect of intentionally tinkering with the Earth’s energy balance provokes intense controversy, especially surrounding how solar geoengineering might be implemented, with what aims, and under what kinds of dedicated governance regimes, if any. Commentators have expressed concerns over the potential for adverse side effects, disagreement over how and whether to deploy solar geoengineering, the possibility of unilateral or “minilateral” deployment, international conflict over deployment, and the undermining of efforts to reduce emissions, among other issues. These concerns point to an acute need for governance specific to solar geoengineering.¹

The Banff Scenario Exercise encouraged Summer School participants to think critically about the future governance of geoengineering by proposing four hypothetical but plausible scenarios that created challenges for geoengineering governance. All four scenarios begin in 2040 and use similar background conditions in which the international community is making progress on curbing greenhouse gas emissions but climate change is proceeding more rapidly than anticipated, as detailed in the introduction to this special issue (Parson & Reynolds, 2021) and the online supplementary materials. Over three days, two groups worked in parallel on each scenario, following a prescribed format. First, each group offered an initial governance proposal to the challenging event. Second, each group critiqued the proposal of its sister group by developing a “stress test” that imagined events that could expose problems with the initial proposal. Finally, each group modified or amended its proposal in light of the critiques and stress test and, in some cases, integrated its revised proposal with that of the other group. This paper discusses the proposals, critiques, and responses of the two groups working on one of the four scenarios. In Sections 2 and 3 we summarize the scenario and the groups’ interpretations of it. Section 4 offers each group’s initial proposal, and Section 5 describes their mutual critiques and revised proposals. In Sections 6 and 7 we reflect on the scenario exercise and its implications on geoengineering governance.

2. The decentralized grassroots deployment scenario

Two scenario groups, “Elk” and “Mountain Goat,” were selected for the exercise. They were jointly composed of fourteen participants (four women and ten men), drawn from both the academic and NGO sectors. They were selected as an interdisciplinary group, with specializations in international relations, physics, engineering, climate policy, and cultural studies. Together they included members from Canada, Germany, Pakistan, the United Kingdom, and the United States.

Each group received identical prompts explaining the scenario, entitled “Decentralized Grassroots Deployment.”² The complete text of all four scenarios and related material distributed to participants is available in the supplementary online material, but here we summarize their particular prompt.

A “Geohackers’ Guild” emerges in 2035, encouraging hobbyists and concerned citizens worldwide to launch small amounts of reflective material into the stratosphere using weather balloons, small drones, autonomous aircraft, and other means. Through online recruitment and coordination, the movement grows rapidly, with support from some wealthy technology entrepreneurs and philanthropists. Small firms pop up in various countries to supply materials and launch devices, and instructions circulate freely on the internet. A leading technology firm, whose CEO has adopted the movement as a passion project, launches a blockchain-based platform to coordinate the timing and launches of material. Not everyone is following the platform’s guidance, however, and splinter factions of the Geohackers’ Guild are advocating different intervention strategies in increasingly bitter online disputes.

By 2040, the highly decentralized Guild boasts a large membership in countries around the world, but the total number of “geohackers” remains uncertain, as does the total amount of material being injected into the stratosphere. One widely cited but uncertain estimate puts the size of the deployment at 500,000 tons of sulfur in the past year—about one-fifteenth of the amount injected into the stratosphere by Mount Pinatubo’s eruption in 1991. Some scientists estimate that the aerosols are currently exerting a cooling effect of -0.5 Wm^{-2} , roughly comparable to the cooling effect of sulfate aerosols in the lower atmosphere in the early 21st century³. Based on estimates of the movement’s current growth rates, some commentators are suggesting the forcing could reach -2 Wm^{-2} by midcentury, enough to offset most of the warming effect of anthropogenic carbon dioxide at the time.

Various international, national, and nongovernmental entities agree to convene an ad hoc advisory group. They task the group with preparing a report and recommendations, which these sponsoring organizations would circulate among relevant governmental, inter-governmental, and nongovernmental organizations. Specifically, they ask the group to expound on whether the Geohackers’ Guild’s activities constitute a problem and, if so, of what sort and for whom; what the objectives of any response to the Guild should pursue; and who should respond and how.

¹ For more information about the science and governance of solar geoengineering, see: Flegal et al., 2019; Chhetri et al., 2018; Irvine et al., 2016; National Academies of Sciences, Engineering, and Medicine, 2021; Parson & Reynolds, 2021; Reynolds, 2019.

² This scenario resembles the one imagined by Reynolds and Wagner (2019).

³ Wm^{-2} is watts per square meter, a unit of radiative forcing, which is a change in the planet’s net balance of energy. Greenhouse gases cause positive radiative forcing and solar geoengineering could cause a negative one.

3. Group interpretations of the scenario

The two groups assigned to this scenario both initially struggled to define the geophysical and political presumptions contained within the prompt. Doubts about the plausible scale of deployments and the possibility of effective state suppression were discussed, though both groups ultimately decided to suspend such disbeliefs to better consider the scenario in good faith. This led to a series of secondary assumptions, defined by the groups and not the scenario planners, regarding the speculative dynamics and parameters for consideration. Importantly, both groups chose to accept that the Geohackers' Guild was a genuine grassroots effort (and not, say, a front for more covert state efforts) and that the estimates on the potential growth of deployment rates were credible. The Geohackers' efforts were thus presumed to be more than symbolic and likely outside the control of a single nation state. This, in turn, suggested to several participants that, in addition to questions of formal governance regimes, several important social factors merited consideration. If framed more as a social movement than a classical state actor or insurgent force, the Geohackers' Guild could be approached as a loose federation of actors, tactics, and symbols struggling to achieve its stated goals and—importantly—to sustain itself over time, facing challenges in both resource mobilization and internal principles and practice of unity. The participation dynamics of such movements are hard to predict and subject to periods of intensive mobilization and demobilization with important practical effects on questions of governance. On the one hand, existing divisions in the movement might easily deepen, resulting in internal conflicts that inhibit the growth of the movement as a collective project. The potential for the Geohackers' Guild to fracture or to abruptly wane therefore seemed as credible as its potential scales of deployment, bringing the specter of termination shock (Jones et al., 2013; Parker & Irvine, 2018) into the scenario. On the other hand, the movement might gain internal coherence and greater appeal if subject to external sanctions. Elk in particular presumed that state efforts to suppress the Geohackers could potentially backfire, galvanizing broader public support and paradoxically sustaining the movement they sought to discourage. An arms-length engagement with the social movement therefore broadly seemed the most prudent approach for the group to consider.

Finally, these questions of politics and public opinion also entered into the ways in which both groups roughly sought to define their speculative positions within an advisory committee and in relation to an imagined international civil society community. Neither Elk nor Mountain Goat believed that the ad hoc advisory group described in the prompt had the political legitimacy or authority to make relevant decisions themselves. Some participants noted that this would be particularly problematic if the demographics of the ad hoc advisory group mirrored those of the Elk and Mountain Goat teams themselves—largely but not exclusively white, male, and North American. Overall, both groups concluded that the ad hoc advisors should largely seek to establish the parameters in which informed, political discussions could be held, without themselves overly determining those discussions in advance, or indeed, issuing statements for or against geoengineering in general.

4. Proposed governance response

The two groups developed remarkably similar individual initial proposals and ultimately merged them into a single revised proposal for presentation to the rest of the Summer School. Given the substantial overlap in the initial governance proposals, here we present their combined proposal as a single set of recommendations and then discuss the unique aspects of their individual initial proposals. In brief, the combined Elk and Goat groups recommended the following three tenets.

1. Relevant actors should move quickly to improve monitoring capabilities and resolve uncertainties about the deployment and its effects by taking the following steps:
 - a. Establish reporting protocols and mandates for states to gather data on launches within their territories, either through some existing international legal instruments or through amendments to them;
 - b. Create mechanisms by which individuals, non-state actors, and suppliers could anonymously report their own activities, enabling better tracking of launches and supply chains;
 - c. Improve monitoring of atmospheric conditions by enhancing states' remote sensing capabilities;
 - d. Commission reports on potential imbalances between deployments in the Northern and Southern hemispheres and the risks such imbalances could create; and
 - e. Make monitoring and research results accessible in a transparent way.
2. Assuming that grassroots deployment does scale rapidly, states should prepare contingency plans to minimize the risk of termination shock by sustaining deployment of solar geoengineering in the event that public participation in the Geohackers' Guild declines precipitously.
3. At least until better monitoring and governance mechanisms are in place, and/or until the grassroots deployments significantly increase in magnitude, there is no need for the international community to take any immediate action to accelerate, stop, or otherwise interfere with the actions of the Geohackers' Guild and its members.

Both groups articulated similar rationales for all three of these recommendations, reflecting an overlapping understanding of the nature of the problem that such a decentralized deployment posed. Specifically, both groups asserted that without better information, societies could not make good decisions about solar geoengineering. They also agreed that the potential growth of decentralized deployment created a non-negligible risk of termination shock, which states must be prepared to prevent. The two groups developed different plans for guarding against termination shock: Elk proposed that states develop the technical capacity to deploy a centralized solar geoengineering program, whereas Mountain Goat suggested that, at least in the short term, states need only develop plans to sustain the existing deployment by purchasing and deploying the small-scale devices currently used by the Geohackers' Guild. Finally,

both groups believed that the presumptively significant practical difficulty of stopping the Geohackers' Guild, along with the uncertainties of both how the Guild would respond, meant that attempts to accelerate, stop, or otherwise control the deployment would be unproductive at best and lead to potentially dangerous climate volatility at worst. For example, partial or temporary disruptions of the Guild's activities could conceivably lead to rapid and repeated changes in the intensity of solar geoengineering or to temporarily stronger deployment in one hemisphere or the other (Haywood et al., 2013; Jones et al., 2017; MacMartin et al., 2019).

In addition to the three overlapping proposals, Mountain Goat added a fourth recommendation:

4. The international community should immediately begin negotiating an international legal instrument, either a new treaty or an amendment to an existing treaty, "through which nation states can collectively decide whether deployment should continue and if so, what its objectives should be and how it should be regulated."

Elk, by contrast, asserted that legal governance of that sort could or even should wait until the international community had a better understanding of the situation. This reflects the sharpest divergence in the groups' respective views of the problem: Elk saw the problem as one of building capacity to understand and manage physical risks, such as hemispheric imbalance and termination shock, while Mountain Goat (despite some internal contestation) emphasized the problem that the Geohackers' Guild lacked the normative political legitimacy to intervene in the climate on behalf of the global public (Callies, 2018, 2019). Such directions are not inherently incompatible, but nevertheless represent different horizons of concern (and, perhaps, tolerance for potential public controversy).

Notably, neither group took it upon themselves, in their role as the ad hoc advisory group, to recommend specific objectives that states and other actors should pursue with respect to solar geoengineering in general or the Geohackers' Guild in particular, despite the scenario prompt's explicit call to do so. Both groups regarded such recommendations as beyond the appropriate mandate of the participants' ad hoc committees, situated as they were outside of clear, existing structures of governance and accountability. Many Mountain Goat members argued that it would be hypocritical to argue that the Geohackers' Guild lacked the political legitimacy to make decisions about geoengineering while simultaneously making that decision themselves (although the scenario groups' roles were described as advisory and not authoritative). Likewise, Elk declined to make a recommendation on geoengineering objectives out of concern for political neutrality; as states would inevitably develop differing opinions about the "best" way to deploy geoengineering, it would be unwise for the committee to "take sides" before the teams had even formed, especially since a wide range of diverging opinions could be expected within the international community and grassroots communities. These decisions were tied to the groups' internal discussions about the social legitimacy of the ad hoc advisors and the social movement dynamics of the Geohackers. In either case, the groups combined both pragmatic diplomatic concerns and political commitments to governance norms to in part refuse the full advisory mandate of the ad hoc committee. The implications of this are discussed later in this paper in Section 7.

5. Critiques, challenges, and responses

The governance proposals described above emerged from the process sketched in the introduction, which involved a series of challenges to the initial governance proposals. In this section we describe the development of the related stress tests and final proposal through that process.

5.1. Initial proposals

Elk and Mountain Goat teams met separately to discuss the scenario prompt. Over two sessions, each team sketched answers to the questions posed by their imaginary sponsors. Both teams' proposals covered Recommendations 1–3 above; Elk focused on the details of monitoring and reporting and created the detailed outline provided in Recommendation 1, while Mountain Goat focused on the political ramifications of the scenario and added Recommendation 4. Thus, the main components of both groups' final proposals emerged early in the process.

5.2. Stress test

After submitting their initial proposals, each group read the other's proposal and imagined complications which would cause the other team's initial proposal to struggle or fail, a process referred to as the "stress test."⁴ Interestingly, neither group felt that responding to the stress test imposed by the other group would require significant changes to its own proposal. Additionally, although both groups forwarded very similar initial proposals, their stress tests differed remarkably, exposing underlying differences both in how they interpreted the exercise and their assumptions about global power balances and shifting social formations. Table 1 summarizes the major events confronting each group's proposal in the stress test, as well as the relevant group's response to each event.

⁴ Elk, as per the scenario exercise prompt, also offered general criticisms of Mountain Goat's proposal. As Mountain Goat believed that these criticisms largely depended on misunderstandings of Mountain Goat's intended recommendations, rehashing them here would be unilluminating. We reflect on the significance of these criticisms and misunderstandings later in this paper.

Table 1

Stress tests.

Stress Test of Elk's Proposal	
Stress Test Event	Elk Response to the Stress Test Event
Reporting mandates lead to different deployment rates in different countries, resulting in growing hemispheric imbalances that exacerbate the physical risks from the Geohackers Guild's deployment.	Elk's efforts to ensure high-quality data will likely play a significant role in identifying and responding to this problem. However, while multiple, reasonable responses to this imbalance are conceivable, choosing the correct one is largely outside of the group's purview. As with the initial proposal, Elk define their role as informing and advising the international community, rather than deciding on the "correct response."
Personal allegations against the CEO behind the blockchain-based deployment coordination mechanism prompt activists to flood the blockchain with false reports. As a result, others come to regard that coordination mechanism as unreliable and abandon it, but no single alternative emerges. Instead, competing factions begin deploying in pursuit of incompatible objectives.	Here again Elk's strategy benefits from multiple, redundant forms of reporting and observation (including global remote sensing data, as well as reports from suppliers and states). With sufficient alternative information streams, the loss of blockchain reporting and coordination can be weathered. This stress test is ultimately similar to the first event in that it can also be detected through improved data collection strategies, giving the international community the ability to respond appropriately.
Based on the results of a paper from the 2020s on the macroeconomic impacts of geoengineering (Harding et al., 2020), ^a one faction of the splintered Geohackers' Guild begins accelerating deployment with the ambitious aim of lowering global mean temperature well below the preindustrial average, with even sharper declines targeted in equatorial zones. Tropical governments tacitly support the actions of these "Tropical Supercoolers."	Elk found this development to be the most concerning, though perhaps also the most improbable. Several questionable assumptions are built into this future turn, including assumptions on the part of the Supercoolers about the link between temperature and economic growth absent a longer global history of imperialism, and assumptions by Mountain Goat concerning the degree of solar geoengineering deployment that is possible by non-state actors, as well as the cultural desirability of massive climatic upheaval within these communities. However, if the Supercoolers have indeed mounted a credible geophysical threat to the distribution of global resources, then it seems incumbent upon Global North powers to meet them at the bargaining table.
As the variety of substances released into the stratosphere increases, unexpected interactions between them cause a rapid, unprecedented decline in stratospheric ozone and a rise in tropospheric particulate matter, presenting serious public health threats.	Elk was confident that these concerns could be addressed through educational outreach, identifying the most problematic substances to grassroots deployers, coordinated with a neutral party such as the World Health Organization. The group's carefully neutral stance in the early days of deployment may well pay dividends here, ensuring that its recommendations are seen to be offered in good faith and with legitimate concern and urgency.
Stress Test of Mountain Goat's Proposal	
Stress Test Event	Mountain Goat Response to the Stress Test Event
The release of the committee's report sparks protests and riots as diverse audiences interpret the call for international negotiations on solar geoengineering as an endorsement of deployment.	These protests reflect a misunderstanding of the committee's recommendation regarding international negotiations, given that such negotiations are explicitly designed to enable collective decision-making about, <i>inter alia</i> , whether deployment should continue. The prospect of such a response highlights the need for good communication but does not point to a substantive problem with the proposal.
Russia walks out of international negotiations about solar geoengineering, insisting that the approach harms its national interests and warning that Russia will regard any state deployment of solar geoengineering as an act of war and respond accordingly.	After reviewing a list of other actions that Russia has recently decried as "an act of war," Mountain Goat strongly doubted that Russia will go to war over solar geoengineering and regard its non-participation as a regrettable act of political theater that does not undermine the broader push for politically legitimate international decision-making about solar geoengineering. Russia would be welcome to rejoin negotiations and argue for the phasing out of deployment.
Sophisticated cyberattacks, perhaps with Russian backing, target large corporations associated with the deployment of stratospheric aerosols.	Mountain Goat did not regard this as a particularly important reason to revise their governance proposal, given that such activities would likely continue unless the international community somehow shut down the Geohackers' Guild; Mountain Goat deferred decisions about whether and how to do that to the international community.

^a While Harding et al. (2020) was not published until after the Summer School, one of the paper's co-authors presented its main results at the Summer School, which inspired this element of the stress test.

5.3. Combining the proposals

After discussing their respective "stress tests" separately, representatives of each group met to discuss their corresponding responses. Due to the nature of the original scenario, which both groups found somewhat vague and implausible, the groups had independently suspended doubts about the situation to different degrees, which accounted for much of the differences between the original proposals, stress-tests, and stress test responses. Most importantly, Elk generally presumed that public support for and against geoengineering would be far more volatile, threatening the credibility and efficacy of international efforts to bring the Guild to heel. Mountain Goat, by contrast, emphasized the geophysical harms made possible by uncoordinated and sizable deployments, pointing to the eventual need for greater coordination and control within international regulatory agreements. Given the different assumptions made, each group was largely receptive to criticism from the other; many of the decisions made were deemed reasonable once they were clarified and the underlying thinking behind them was discussed in greater detail. Some of these differences in interpretation are discussed in the following sections. Ultimately the groups concluded that their proposals overlapped significantly, with the differences

largely complementing each other rather than competing: Elk had provided detailed recommendations on monitoring capabilities, whereas Mountain Goat had provided more detail regarding international negotiations. In recognition of this common ground and complementarity, the groups agreed to combine their proposals for presentation to the broader Summer School.

6. Reflections on the process

In reflecting on the scenario exercise, we find that features of the scenario, the teams, and the structure of the exercise affected the process in both positive and negative ways. The Grassroots Decentralized Deployment scenario presented an implausible narrative in a way that highlighted interesting sets of actors and a challenging form of uncertainty. By focusing on atypical, non-state actors, including not only the individuals deploying stratospheric aerosols but also the corporate actors and high-profile individual supporters, the scenario forced both teams to think about aspects of governance that often go unexamined in discussions of solar geoengineering (see also [Belaia, Borth, & Weng, 2021](#)). Similarly, the decentralized deployment forced both teams to think about how the world might monitor solar geoengineering in the absence of an easy centralized accounting of aerosol inputs.

The structure of this exercise, especially its emphasis on storytelling over numbers, compressed timeframe, and somewhat adversarial approach, arguably tilted the process toward certain kinds of outputs. Speculations about the future easily slip into narrative terms. This can be an asset in reasoning through a complex slate of global actors and concerns ([Nikoleris et al., 2017](#)), but it also risks focusing one's thinking too quickly on potential dramatic turns at the expense of careful and plausible accounts of the physical and social sciences of climatic change and geoengineering. The emphasis on narrative seems to have encouraged groups to prioritize drama over realism when identifying potential flaws in the other group's proposal. For instance, Mountain Goat, inspired by economic modeling results presented earlier at the Summer School, designed their stress test to underscore the importance of international governance, which they felt Elk's initial proposal lacked. However, perhaps influenced by the suspension of disbelief about the plausibility of high-intensity decentralized deployment that the original scenario required, they made no attempt to estimate whether a grassroots deployment really could achieve the effect sought by the "Supercoolers," and they simply accepted, for the sake of the narrative, the unpublished results indicating that this would be desirable to tropical actors. Furthermore, the compressed time frame presented a challenge in evaluating the plausibility of dramatic narratives. For instance, when Elk suggested that Russia would threaten to 'respond appropriately' to what they called 'an act of war,' Mountain Goat had limited time to identify other instances in which Russia had condemned something as 'an act of war' and assess how Russia had responded in those cases. In the context of the scenario exercise, it was difficult to assess where threats of military response from particular countries were mere bluster or instead a real danger to international peace and security. While the thought experiments were broadly productive in forcing groups to consider unusual or extreme events and circumstances, both groups' skeptical responses to the stress tests of the proposals written by the other suggest that a slower, more deliberate approach might have revealed more realistic challenges, especially if the exercise had required teams to show quantitatively or contextually that the events they described might be possible.

The compressed time frame for the scenario exercise also led to some unproductive miscommunication between the groups. Because each interpreted the initial prompt slightly differently and misinterpreted certain elements of the other's initial proposal, the groups spent time critiquing ideas that the other group had never intended to advance. More time to draft and interpret proposals might have reduced these miscommunications, as would some time for the groups to discuss the initial prompt and the proposals with each other in person.

The interdisciplinary nature of the teams contributed significantly to the process, mostly positively. The exercise raised a broad range of issues in a number of very different research fields. Only interdisciplinary teams could have had the collective expertise to address all of these issues. As an illustration of the importance of expertise across a range of fields, Elk's greater detail in describing mechanisms for monitoring reflected that team's greater technical experience. Furthermore, because different members of each team viewed the problem and potential solutions through different lenses of expertise, interdisciplinary teams could understand and respond to the problem in a more comprehensive way. That said, working across domains creates challenges, too. Disciplinary divides can also find their way into how we make narrative sense of the future and the points at which those narratives lose their credibility. Within and between the groups participants often experienced debate, tensions, and dismissal about the idiosyncrasies and assumptions intrinsic to different scholarly takes on the interlinked problems of climate governance. One member, for example, might forward a portfolio of international legal treaties and precedents under which the future story of solar geoengineering could be told with legible villains, heroes, and calls to order. For another member, these details might seem wholly irrelevant, given the primacy of social movement dynamics or aerospace engineering in setting the stage for the drama to come. As a whole, however, the diverse nature of teams ultimately proved valuable. Interdisciplinary reflections on the challenges of such socio-technical pathways are essential to mounting sufficiently nuanced accounts of speculative futures. Deliberation and consensus on the starting conditions, however, are essential to successful attempts at worldbuilding, and the compressed timeframe of this exercise made it hard to establish that shared starting point. This concern is felt to an even greater extent when considering scenarios such as a grassroots deployment that confound well-worn frames for deployment and governance. In real-world scenarios, where the make-up of advisory groups would presumably include more civil-society advocates and diverse, international representation, these questions of coordinated speculation will apply all the more so. Conversely, questions of legitimacy and neutrality are likely to be differently experienced by groups with a more narrow mandate to advise on policy or military actions within a given governing body or stakeholder group.

Reflecting on the broader scenario exercise as a whole, instead of just on the Decentralized Grassroots Deployment scenario, one member of Elk team noted that almost every team across all four scenarios pushed to bring governance of solar geoengineering back into the multilateral system that characterizes the post-World War II international order. Looking forward to the coming decades, it could be useful to imagine what solar geoengineering governance might look like if the international order of the mid- to late twenty-

first century looks markedly different. Along this vein, further research is warranted into plausible and perilous forms of international, non-state governance of and by international, non-state actors, both on the questions of social license and group codes of conduct/self-regulation (see [Bernstein, 2011](#); [Hubert, 2017](#); [Lockley et al., 2019](#); [Reynolds, 2019](#) and [Reynolds & Parson, 2020](#) for interesting directions and precedents to this question).

7. Lessons for the governance of solar geoengineering

The groups' cumulative responses to the Decentralized Grassroots Deployment scenario highlight several lessons for the governance of solar geoengineering.

One clear implication of this scenario is that good governance requires good data collection, and that data collection would benefit from multiple, independent channels of monitoring and information gathering, transparently shared with all stakeholders. Most of the recommendations about building monitoring capacity and data collection mechanisms would apply in almost any solar geoengineering deployment scenario. The quality of and access to salient data stand to be key pillars of any effective governance regime.

A second implication is that in the event of significant deployment, states should develop redundant deployment capacity to protect against the risk of termination shock. That is, if one actor or a set of actors begins deployment at climate-significant scales, then other actors need to ensure that they could begin or maintain a similar level if the original deployers abruptly abandoned or lost interest in continuing deployment. As the differing proposals from Elk and Mountain Goat suggest, however, ensuring redundant deployment capacity may or may not require developing, say, an extra fleet of planes that sit idle until needed.

A third implication of this scenario exercise is that it would probably be difficult to stop a decentralized deployment of solar geoengineering, especially without widespread cooperation among states. Fortunately, such efforts would likely be almost impossible to conceal, if indeed the scales contemplated by the scenario predictions prove to be possible. There is further cause to doubt that non-state actors could credibly deploy sufficient quantities of materials to create a substantial climatic effect and/or effectively conceal operations at this scale. [Crutzen \(2016\)](#) estimates that one metric ton of sulfur produces a net change in radiative forcing of -0.75 Wm^{-2} , so the -0.5 Wm^{-2} change estimated by scientists in the scenario would require roughly 667,000 tons. One estimate within the scenario places deployed materials at 500,000 tons. While this estimate may be off by as much as 50 %, it is likely on the correct order of magnitude. Assuming that a small homemade weather balloon can hold perhaps 5–10 kg of material, a decentralized deployment of half a million tons would therefore require one to two hundred million independent successful launches.⁵ On a planet of 8.5 billion people, this would require roughly one out of every thousand people to launch a balloon every month, or more than one out of every hundred people to launch a balloon every year. Taking into account the unknown rates of availability of information and materials, willingness to participate, and launch success, both groups found it unlikely—perhaps even absurd—that the global public could achieve such a level of radiative forcing without governmental backing. Therefore, when reflecting on the lessons in governance that can be learned from this scenario, we also need to consider a perhaps more plausible variation in which the movement fails to make any detectable impact on the climate but still makes a provocative political statement.

Regardless of the effectiveness of the grassroots movement, it can be presumed that public attempts at deployment will be more successful in states whose leaders approve of the movement's goals to some degree. Even if states cannot openly encourage participation for political reasons, a lack of government interference will undoubtedly straighten the path for members of the public who want to get involved. In contrast, group members disagreed about the extent to which disapproving governments could effectively stamp out the grassroots movement; considering failed previous attempts by states around the world to limit drugs, guns, ivory, and other contraband within their borders, some dedicated civilians may well be committed and resourceful enough to participate in the movement regardless of government prohibition. Banning the sale of solar geoengineering equipment could generate a lucrative illicit trade, in which the very illegality of the allegedly pro-social behavior motivates some people to buy and deploy the equipment. Prohibiting an existing community practice could thus potentially galvanize popular support in unpredictable ways. That said, a government acting to cut off supply chains and criminalize participation would certainly have at least some negative effect on deployment rates, especially since individuals' incentives to participate in geoengineering are very different than their incentives to participate in black markets for drugs, guns, and so on. The "Russian walkout" development suggests that, while some states might regard solar geoengineering as contrary to their interests, it is far from clear that they would resort to force to stop solar geoengineering, especially if it were being deployed by a broad coalition of actors. The probability of escalation would likely increase with the effects of the movement (i.e., the magnitude of changes to radiative forcing achieved) and decrease with the number and diversity of actors.

A final observation concerns the reluctance of either group to make targeted, normative recommendations to specific actors in the international community. Instead, based on internal concerns about the degree to which the ad hoc advisory groups' conveners could bestow legitimacy on the group, questions about the groups' demographic makeup, uncertainties over their short vs. long-term mandates to advise, the need for credible scientific advice that is not perceived as politically tainted, and the potential for their actions to create considerable political controversy, both Elk and Mountain Goat declined to specify specific governance objectives for given state and non-state actors to pursue. Some of the buck, as it were, was passed. This suggests the need for future exercises of this nature, real or imagined, to anticipate concerns about reputational risks, conflict avoidance, and representational equity in the

⁵ For comparison, [Reynolds and Wanger \(2019\)](#) assume that each balloon would hold approximately 5–10 kg of sulfur dioxide (SO_2), which amounts to roughly 2.5–5 kg of sulfur. But, as they note in considering the technical feasibility of decentralized deployment, other methods of delivery might emerge and aerosols with greater cooling power might be used instead.

recruitment and design of expert advisory groups. Relatively small changes in the scenario prompt might have altered the groups' willingness to recommend specific objectives. The groups might have regarded themselves as having more legitimacy if their mandate had come from the UN General Assembly or Secretary-General, for instance, rather than from the ad hoc collection of multilateral institutions and civil society organizations described in the prompt. They would presumably have worried less about the diversity of the group if the exercise had included more diverse participants or if the groups had received explicit instructions at the workshop to assume that the ad hoc advisory group would be appropriately representative, legitimate, and authoritative. Accordingly, present efforts at improving the research presence and capacity of diverse voices in these debates can be considered an investment in the quality and confidence of future advice, especially when it is urgently and prescriptively sought.

In sum, the exercise suggests that unregulated non-state solar geoengineering deployment could serve as a productive impetus to develop state-led governance regimes, if managed carefully with an eye towards the complex social legitimacy claims of stakeholders in the process and the geophysical risks associated with irregular deployment. This conclusion would also likely apply to deployment by a broad coalition of states. In particular, the lessons about the importance of independent monitoring, protecting against termination shock, and identifying possible interactions or imbalances from uncoordinated deployment could apply to decentralized state-backed deployments as well.

Even if the Geohackers of the future are unlikely to muster a climate-altering deployment, they may succeed in provoking new discussions between states and international bodies, which may proceed with new degrees of urgency and public concern. Independent of the politics surrounding climate change, the ability to monitor deployment and its effects through a range of channels is essential to good governance and international cooperation on solar geoengineering, and having redundant deployment mechanisms is important for minimizing the risk of termination shock. Ultimately, regardless of the circumstances in which deployment began, governance will require a mixture of tactful deliberation, data collection, and coordination between multiple stakeholders.

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