communications earth & environment

Article

https://doi.org/10.1038/s43247-024-01518-0

Public perceptions on solar geoengineering from focus groups in 22 countries

Sean Low [1] ✉, Livia Fritz [1], Chad M. Baum [1] & Benjamin K. Sovacool [1,2,3]

Solar geoengineering maintains a vocal presence as a stop-gap measure in assessments of climate and sustainability action. In this paper, we map prospective benefits and risks, and corresponding governance approaches, regarding three major proposals for solar geoengineering (stratospheric aerosol injection, marine cloud brightening, and a space-based sunshield). We do so by engaging with 44 focus groups conducted in 22 countries split between the global North and South. We compare results against previous research on the public perceptions of solar geoengineering as well as wider activities in assessment, innovation, and decision-making. We find that global South groups exhibit greater hope but an arguably richer range of concerns for solar geoengineering, in the context of observable inequities in climate action and potential geopolitical conflict. Meanwhile, a strong, global preference for multilateral coordination and public engagement from the conduct of research onwards is offset by skepticism of effective multilateralism and public discourse.

Solar geoengineering—a set of hypothetical or unscaled proposals for offsetting global warming by reflecting incoming sunlight and lowering temperature at regional to planetary scales—maintains a vocal presence as a stop-gap measure in future climate and sustainability action[1]. Recent years have been marked by indications of solar geoengineering's rising profile and high stakes. Under such circumstances, a key dimension of assessment has been the conduct of public perceptions studies and wider forms of engagement. Public perception exercises have been largely funded by and conducted within the US, northern Europe, and Japan; yet, with prospectively planetary impacts, there is an arguable need to expand meaningful debate globally[2]. Still, many fear that geopolitical and commercial imperatives will further complicate how solar geoengineering is advocated for and developed, and how engagement and consent from public across the global North and South will be sought[3,4].

Public perceptions of solar geoengineering have been predominantly conducted through surveys, seeking aggregate preferences of national publics on several key themes: topical familiarity, support for solar geoengineering in comparison to other forms of climate action, the conduct and location of field experiments, prospective risks and benefits, and trust in kinds of governance actors[5–12]. A smaller body of works has explored these questions through deliberative focus group[13–17] or mixed methods[18,19], seeking additionally to trace rationales and reasonings behind preferences, and to counter acquiescence bias and other framing issues that emerge in survey work. To focus group efforts can be added engagements that focus not only on general members of the public but include experts and decision-makers[20,21] or participants with expertise or organized interests[22], to gauge situated or context-specific perspectives.

Our study seeks to reinforce two broad movements. Firstly, a first wave of engagements emphasizing technical questions of affordability, effectiveness, safety, and timeliness as the basis for public preferences was criticized, and partially replaced, by a second wave emphasizing open-ended deliberation of socio-political concerns, grounding in the larger context of climate action, and 'uncoupling' from the perceived necessity of integration into policy[23]. Secondly, responding to calls to correct the endemic shortfall of global South representation in assessment[2,24–27], studies are increasingly expanding in that direction[12,17,28–30]. Our assessment explicitly focuses on positions of the global South compared with the global North.

To ground our study, we engage with the public perceptions literature to see how a broadened set of publics nuances its most prevalent findings. Publics tend to cite lower familiarity and support for solar geoengineering in comparison to other climate action measures[18,19], citing a failure to reduce emissions or unsustainable behavior at source, geopolitical implications, and environmental impacts, as well as revealing a bias towards naturalistic framings of climate action[7,14,17,31,32]. On the other hand, public support is impacted by perceptions of the seriousness of climate impacts[7,32,33], exposure

[1]Department of Business Development and Technology, Aarhus University, Birk Centerpark 15, 7400 Herning, Denmark. [2]Science Policy Research Unit (SPRU), University of Sussex Business School, Jubilee Building, Arts Rd, Falmer, Brighton BN1 9SL, UK. [3]Department of Earth and Environment, , Boston University, 685 Commonwealth Ave, Boston, MA 02215, USA. ✉e-mail: sean.low@btech.au.dk

to media coverage and prominent frames that have emerged in different contexts[30,33–35], and whether solar geoengineering is viewed distracting from mitigation efforts. This lattermost dimension is known in expert assessment as mitigation deterrence[36,37] although some studies contest its veracity[38–40], and others argue that recognizing the possibility should spur stronger climate action[41].

Another key theme is on preferences for governance. There is a longstanding literature on proposed forms and functions of solar geoengineering assessment[42] and governance[43], ranging from frameworks for research[44] and experimentation[45] to templates based on international treaty regimes[46], to more polycentric arrangements[47]. Public perception studies show support for international coordination over upstream stages of research and field tests as well as deployment[14,31,47], or map trust for different political institutions and actors, including industry and academia[6,8,32]. Comparatively few (but contemporarily relevant) studies focus on perceptions of the implications of (hypothetical) field experiments in Japan[17] and the UK[16,48], which (elsewhere) have spurred social opposition and debate over appropriate governance[45]. Common themes include the degree of trust in the actors conducting the experiment, and how the near versus longer-term and physical versus societal implications of the experiment are defined and deliberated.

In this paper, we explore a range of public perceptions and deliberations across the global North and global South regarding prospective benefits, risks, and corresponding governance of three major types of solar geoengineering. The first, stratospheric aerosol injection (SAI), dominates discussion—assessed as having planetary scope, comparatively low direct implementation costs, and high leverage in lowering temperatures[49–54]. The second is marine cloud brightening (MCB), a regional approach that proposes to heighten cloud albedo[52,55–58]. The third is space-based geoengineering, a newer entrant to the field proposing a reflective shield constructed in outer space between the Earth and the sun—supported as part of longer-term efforts to economize or populate space but questioned for its infrastructural requirements[59,60]. The political implications of all three types remain deeply uncertain. Summarized in Table 1, we choose these three approaches for a balance between planetary versus regional scopes of deployment, high versus low attention in major reports, and characteristics and locales of infrastructure.

We engage with 44 focus groups (1 urban, 1 rural) in 22 countries, representing every inhabited continent (9 in Europe, 1 in North America, 3 in Latin and South America, 3 in Africa, 2 in the Middle East, and 4 in the Indo- and Asia-Pacific). To nuance our geographic and political representation, we divide these countries into three groupings: the global North (Australia, Austria, Germany, Switzerland, Poland, Spain, Italy, Norway, Sweden, the United Kingdom or UK, and the United States or US), the emerging South (South Africa, India, China, Indonesia, Chile, Brazil, Turkey, and Saudi Arabia), and the developing South (Kenya, Nigeria, and the Dominican Republic). We use the rough distinction between emerging and developing economies used by the International Monetary Fund's World Economic Outlook reports[61] to imperfectly acknowledge intra-South differences.

Our study follows a prior survey-based study[30] as part of a mixed-methods framework—with the survey sourcing nationally-representative preferences, and focus groups uncovering rationales and processes of reasoning that underpin preferences. Participants totaled 323, with 5–8 per group. Overt climate denialism was screened out from prospective participants, and groups were further screened for splits across gender, age cohorts, education level, income, occupation type, and region of residence (the latter four tailored by country). Informational materials (translated into national languages) were distributed to participants a week before meeting, with encouragement to discuss with one's local community. In-meeting questioning and deliberation was based on prospective benefits and risks, as well as corresponding governance; the guiding logic was to focus conversation on actors, actions, and agendas at the most tangible scale possible. The recorded transcripts were analyzed in two parts: using qualitative data analysis software MaxQDA to code cross-country themes organized according to the questions, followed by country-by-country analyses.

Highlighting similarities and differences between the global North, emerging South, and developing South, we map how technical and societal issues raised by focus groups translate to preferences and degrees of trust for actors from different sectors (scientific, civic, industry, policy) and scales (local, national, intergovernmental), mechanisms of assessment, funding, innovation, and policy, and governance rationales. Our discussion compares focus group perspectives on the prospective development or deployment of solar geoengineering approaches to expert debates and on-the-

Table 1 | Selection of solar geoengineering types

	Stratospheric aerosol injection (SAI)	Space-based geoengineering (space shield)	Marine cloud brightening (MCB)
What and how (characteristics of infrastructure)	Deploys modified aircraft to spray reflective aerosols into the stratosphere, creating a reflective layer.	Building a complex reflective architecture in outer space at Lagrange Point 1 between the Earth and the Sun.	Deploys modified ships to spray sea salt into the air over the oceans to brighten clouds, enhancing reflectivity.
Where (locales of infrastructure)	Stratosphere. (Uneven) effects of deployment depend heavily on locations where aerosols are injected. Bases and infrastructure must be accordingly distributed.	Space. Requires a functioning space economy that would be orders of magnitude larger than what currently exists.	Certain coastal areas—e.g., west-coastal subtropical zones. Viable locations may be limited; subject to fundamental technical/physical uncertainties, especially regarding cloud (micro) physics. Bases and infrastructure must be accordingly distributed.
Planetary versus regional physical implications	Planetary—atmospheric currents will carry particles around the planet regardless of entry point. Cooling effects (e.g., temperature and precipitation) will be heterogeneous, and the geographic point of deployment will further determine variations in effects.	Planetary. Cooling is modeled to be globally homogenous.	Regional, but still transboundary. Cooling and effects will be heterogeneous, and there are uncertain effects and feedback beyond the initial area of cooling.
Attention in major reports	Predominant solar geoengineering approach due to low implementation costs and swift, planetary leverage on temperatures. Central place in major reports.	A niche area of prospection in the aerospace industry. No attention in major reports on solar geoengineering.	Longstanding attention as a regional approach applicable to certain coastal areas. Supplementary place in major reports.
Recent events	Clandestine and commercial small-scale tests. Primary technical/modeling assessments taking place in US academic networks. Some global governance advisory bodies are drafting anticipatory principles or reports to ground future engagement.	Receiving a degree of contemporary discussion due to proposed escalation of (private) space economy.	Small scale tests as part of Australian Reef Restoration and Adaptation Program to protect the Great Barrier Reef.

ground developments regarding foundational assessments and experiments, research governance, and governmental or intergovernmental decision-making. In conclusion, we outline four rationales to guide further assessment, based on matching our results against our evaluation of the current governance landscape.

Results

Rather than creating separate sub-sections for SAI, space-based geoengineering, and MCB, we report on all three together. This is because (with certain exceptions), participants discussed complexes of hope, concern, and preferred governance that are robust across solar geoengineering approaches. In Table 2, we show that focus groups referred to solar geoengineering as a broad climate action strategy or category as much as or more than individual approaches, and saw overarching, shared characteristics of solar geoengineering as meaningful. Most often, these describe the process (shading sunlight) or envisioned implications (reducing or multiplying climatic or societal harms), as well as how solar geoengineering broadly affects efforts to reducing emissions or could be affected by corporate motives, geopolitics, or civic action. In Table 3, we show differences that emerged between approaches were variations on the same theme.

We structure our results as follows. Firstly, we highlight potential synergies or trade-offs with wider climate and sustainability action. Secondly, we highlight key hopes and concerns. Finally, we move to prospective or existing governance, and the roles, processes, and rationales of overlapping sectors in assessment, industry and innovation, (inter)governmental action, and public. Our reporting navigates two needs: summarization versus allowing participants to speak in their own words. In text, we deploy summary descriptions of themes, but make use of extensive quotations in Table 4 (climate and sustainability action), Table 5 (hopes and concerns), and Table 6 (governance) to give a sense of the diversity and depth of deliberations.

Synergies or trade-offs with wider climate and sustainability action

A clear juxtaposition emerged on the relative importance and relation between tackling the symptoms versus root causes of climate change and unsustainability. Emerging global South groups exhibited comparatively stronger representation for tackling the symptoms of global warming, primarily citing the need to dampen the severity of experienced or projected impacts, and secondarily implying that there was (or should be) no clear trade-off between reducing impacts and emissions. For a smaller but North–South crosscutting plurality, solar geoengineering might buy time for more comprehensive decarbonization efforts, implying a potential synergy between tackling symptoms and causes. This perspective had key nuances in the global South context, with participants arguing that the global North holds primary responsibility for historical emissions and future reductions (Brazil, Urban), or that solar geoengineering might buy space for developing countries to further industrialize (China, Urban). The largest

Table 2 | Perceived similarities between solar geoengineering approaches

Perceived similarities between approaches	Solar geoengineering, solar radiation management, or sunlight reflection methods as an umbrella category
Process	Shading sunlight—the exact mechanism is less relevant than the general concept.
Ideal outcomes versus skepticism	Ideally, reducing climate and societal harms; but accompanied by deep concerns about uneven and unforeseen climatic impacts, profit motives, and geopolitics.
Relation to climate action	Could buy time for decarbonization. Need to tackle impacts as well as causes of climate change. Could delay decarbonization (mitigation deterrence).
(Geo)politics	Profit-seeking incentives from innovators. Countries will likely design deployments to their own benefit. Feeding or creating geopolitical rivalries. Technology race. Conflicts over siting of infrastructure. More discussion of geopolitical risk for SAI and space-based sunshield than for MCB.
Public consultation	Likely that technology capable industries and governments will make decisions, but public who are affected (regardless of being from a tech-capable country) should be consulted. Desire for (innovating new forms of) global consultation offset by apathy and powerlessness, trust in government, and fear of technical complexity.

Table 3 | Perceived nuances between solar geoengineering approaches

Perceived nuances between approaches	Stratospheric aerosol injection (SAI)	Space-based geoengineering (space shield)	Marine cloud brightening (MCB)
Energy, resources, infrastructure	Infrastructure-extensive and energy-intensive.	Speculation over need of space economy. Especially, and for many prohibitively, infrastructure-extensive and energy-intensive.	Less infrastructure-extensive and energy-intensive.
Key actors	Global powers, aerospace industry.	Global (space) powers, aerospace industry, particularly emerging private space sector.	More feasible by smaller (groupings of) countries or (can be commercialized) by corporations.
Scale and leverage -impacts on side effects and geopolitics	Planetary reach implies greater climatic leverage, but more complex side-effects and politics.	Planetary reach implies greater climatic leverage, but more complex side-effects and politics.	Regional scale implies lesser leverage, but less complex side-effects and politics.
Field experiments	Small-scale tests needed—but (incongruously) to test widespread impacts.	Difficult to imagine how impacts testing would take place beyond simulation.	Small-scale tests needed – but (incongruously) to test widespread impacts.
Multi-lateral governance	Global cooperation viewed as necessary but unlikely—due to geopolitics first, and cost second. Twice as much support for multilateralism compared to MCB (as a regional approach).	Global cooperation viewed as necessary but unlikely—due to geopolitics and costs equally. Twice as much support for multilateralism compared to MCB (as a regional approach).	Regional cooperation viewed as more feasible.
Public consultation	Global public consultation viewed as less feasible (even if desirable), defaults to governmental decision-making. Sense of powerlessness especially strong.	Global public consultation viewed as less feasible (even if desirable), defaults to governmental or space-industry decision-making. Sense of powerlessness especially strong.	Stronger sense that affected publics can be heard due to regional scope.

Table 4 | Synergies or trade-offs with wider climate and sustainability action

Theme	Countries and focus groups (R for Rural, U for Urban)	Representative quotes
Tackle symptoms	North (5/11 countries): Australia R, Norway U, Poland U, Spain R + U, UK U Emerging South (7/8 countries): Brazil R + U, China R + U, India U, Indonesia R, Saudi Arabia U, Turkey R Developing South (1/3 countries): DR R + U	Yes. We shouldn't go for only one way, we can't just attack the cause (of global warming), both things (addressing both causes and symptoms of global warming) must happen at the same time… Maybe it (solar geoengineering) will not solve it (global warming), but at least soften it (Brazil, Urban)
Buy time	North (6/11 countries): Australia R + U, Germany U, Italy U, Norway R + U, Sweden U, UK R + U Emerging South (3/8 countries): Brazil U, China U, South Africa R + U	Onus on global North: We can see now in the COP that it's hard for the countries to agree on reducing the emission of carbon dioxide, the richest countries don't want to deal with it, so the interesting part of these ideas is working directly with the effects while there's no agreement regarding the emission. It's a solution for the short or mid-term. I think the benefit here is having a solution for the consequence while working to solve the real problem. (Brazil, Urban) Buying space for industrialization: If it is beneficial, I personally think it is more beneficial to developing countries, because does not need to reduce carbon emissions, and can let developing countries continue their own industrial model to develop. For developed countries, it has reached an advanced level of development…. (the) advantage that it (solar geoengineering) does not control carbon dioxide emissions, and thus less affects manufacturing industries in the world conducted by us. (China, Urban)
Need to address root causes/ Mitigation deterrence	North (7/11 countries): Austria R, Germany U, Italy U, Spain R + U, Sweden R + U, Switzerland R + U, UK R + U, Emerging South (7/8 countries): Brazil U, Chile R, China U, Indonesia U, Saudi Arabia U, South Africa R, Turkey R	Need to address root causes: By reducing the solar radiation hitting the earth, it would reduce the greenhouse effect. It would re-stabilize the temperature… But, it wouldn't be happening if we keep doing this system where we would waste energy, throwing garbage everywhere, using non-degradable trash. It helps. But, still. We have to help and do our part by not throwing trash everywhere, by using recycle-able goods, not using plastics, not using anything that would leave such an industrial waste. (Indonesia, Urban) Mitigation deterrence: All three approaches are the same… What happens is that pollution is already in the world, if the temperature goes down we are going to relax and there will continue to be pollution, we will continue to produce plastics, we will continue to do the same and global warming will return. The solution of the mirror, the clouds, the boat… are not feasible, they will generate a little change but not the change that is needed for us to live well. (Chile, Rural)

plurality—across North and South groups, and from most emerging South countries—posed a trade-off between symptoms and causes: that there is not only a need to address underlying systems of resource extraction and human industry and consumption, but that solar geoengineering might prolong such activities (the well-documented 'mitigation deterrence' concern).

Scale and leverage

Another key juxtaposition emerged on scale and leverage as criteria for preferences between planetary versus regional approaches. For some participants—represented strongly within urban groups in the South—global reach and swift climatic effects were cited as a benefit, with MCB being relatively deprioritized due to its more regional scale. For some (e.g., Kenya, Urban), this was connected to a sense of unequal deployment capacity, and that vulnerable regions might benefit from a global deployment led by technologically capable countries. Others—with comparatively stronger representation in global North groups—emphasized the double-edged nature of planetary approaches: that they would also implicate a greater range of geopolitical rationales and complications (see Geopolitics and inequity). In this sense, MCB was favored as an archetype of local-to-regional action, and envisioned as more targeted, contained, and if need be, more incrementally scalable.

Harms alleviated

Efforts to envision the key harms of climate change that would ideally be alleviated by solar geoengineering were surprisingly vague, given how precise background deliberations on experienced or projected climate impacts were. The most common response was a hope for widespread benefits: that human civilization and nature, broadly stated, could holistically benefit. This hints at some difficulty in imagining the reality of an engineered climate or the processes of sunlight reflection. At the same time, the most cited envisioned benefits were the alleviation of heat stress and improving food security. The latter was particularly well represented across the emerging and developing South as a direct concern, but with global North groups also citing food security as a systemic issue across global supply chains. Some, however, questioned the benefits and motives for large agribusinesses (Brazil, Urban), as well as whether an engineered climate would force growers to alter crops that they had adapted to a warming climate (Spain, Rural).

Side effects and infrastructure demands

An overwhelming majority of global North groups skeptically referred to solar geoengineering as science fiction—to space-based geoengineering first, SAI close behind, and MCB a distant third. By comparison, three global South groups did so. An obvious context is that science fiction is primarily a cultural medium in the global North, but it also hints at connecting deliberations in which global South groups—particularly urban groups in the emerging South—demonstrated a stronger optimism in technological innovation and capacity. Moreover, there were minority uses of this trope beyond expressing skepticism: positively, with some noting that socio-technical systems once described as science fiction are now everyday realities, as a tool for anticipating future politics, or for comparing climate action options.

Every group deliberated on the potential side effects, uncertainties, and knowns of deploying or even considering solar geoengineering. The greatest degree of questioning emerged on unequal cooling and deeply uncertain knock-on environmental and societal effects, with many groups extending this concern beyond unintended side effects to deliberately induced unequal effects tied to geopolitical agendas (see Geopolitics and inequity). A key concern (re)emerged on food security, with concerns about unequal impacts on regional agricultural conditions offsetting previously noted hopes. Some noted that uncertainty over impacts disadvantaged vulnerable countries or

Table 5 | Key hopes and concerns

Theme	Countries and focus groups (R for Rural, U for Urban)	Representative quotes
Scale and leverage	North (6/11 countries): Australia R, Austria R + U, Germany R + U, Italy R + U, Poland R + U, Sweden R Emerging South (4/8 countries): Brazil U, China U, India U, South Africa U Developing South (3/3 countries): DR R, Kenya U, Nigeria U	Preference for global scales: I'll go with stratospheric aerosol injection and space-based geoengineering… temperatures will drop globally, not only locally. I would totally disagree with the marine cloud brightening if I'm talking on behalf of Kenya (because) it really benefits a very small piece of region… So, I'll go for (SAI and space based geoengineering) because should the different governments and different stakeholders globally come together and they put this into effect, it would mean that we would also benefit from that. (Kenya, Urban) Preference for regional scales: MCB could be smaller scope, for example, regarding cooperation to organize actions on this issue. It is already concrete – specific clouds in a specific space. Although the rest of the world should also be addressed, maybe in such smaller areas. (Poland, Rural)
Widespread benefits	North (9/11 countries): Australia R, Germany R, Italy R + U, Norway R + U, Poland R + U, Spain R + U, Sweden R + U, US R, UK R + U Emerging South (8/8 countries): Brazil R + U, Chile R + U, China R + U, India R + U, Saudi R + U, South Africa R, Turkey R + U Developing South (3/3 countries): DR R + U, Kenya R + U, Nigeria R + U	We humans will get the benefits – plants, all aspects of the environment, and climate will also benefit! (China, Rural) These are meant to be global, so everyone on the planet would stand to gain from all of these actions, I think. (Norway, Rural) Everyone does, the environment benefits, human beings benefit, I think everyone benefits. (Saudi Arabia, Urban)
Alleviate key harm: Heat stress	North (5/11 countries): Germany U, Norway R + U, Spain U, Sweden U, US U Emerging South (3/8 countries): China R, India U, Saudi Arabia R + U Developing South (3/3 countries): DR R + U, Kenya R, Nigeria R + U	You know, we've also been breaking (temperature) records down here. So that will be very helpful especially to a lot of populations, like the elderly population. And you know, people don't have air conditioning in the summer. (US, Urban)
Alleviate key harm: Food security	North (6/11 countries): Australia U, Germany U, Norway R, Spain R + U, Sweden R, UK R + U Emerging South (6/8 countries): Brazil R + U, India U, Indonesia U, Saudi Arabia R + U, South Africa U, Turkey U Developing South (3/3 countries): DR R, Kenya R + U, Nigeria U	Subsistence effects: Especially when you talk about Kenya because 100%, we depend on the rainfall and if you check here one of the biggest effects is the rainfall. Would that have a negative effect on the farmers and people who rely on, on agriculture for that matter? (Kenya, Urban) Systemic effects: There are other places where it's perhaps not a life-threatening crisis directly, but that the changes in temperature and climate makes it so that you can no longer harvest or sow or breed the way they've always done. This again would affect the price of foods, so it's a broad-based influence. (Norway, Rural)
Science fiction	North (11/11 countries): Australia R + U, Austria R + U, Germany U, Italy R + U, Norway R + U, Poland R + U, Spain R + U, Sweden R + U, Switzerland R + U, UK U, US U Emerging South (3/8 countries): Brazil U, South Africa U, Turkey U	Reflecting skepticism: This is Star Trek style, putting a giant mirror in space to reflect sunlight. This is not something that will happen in our lifetime, let's not kid ourselves. Perhaps our children will live to see it, grandchildren maybe. Also, when you see the scale, at least how I see it, it seems so unreal, so cost-producing that other methods seem more reasonable than putting all our resources into something like this. (Poland, Urban) Reflecting innovation:… this is more science fiction, more impactful; but I wouldn't underestimate it at all. Speaking about the future and thinking about the future, we plan new and innovative things so I think it could be a valid alternative. (Italy, Rural)
Unequal cooling, environmental and societal effects	North (8/11 countries): Australia R + U, Austria R, Germany R + U, Norway U, Spain U, Sweden R, Switzerland U, UK U Emerging South (4/8 countries): China U, Indonesia R, South Africa R + U, Turkey R, Developing South (1/3 countries): Nigeria R + U	Unequal impacts: So, the same way that it could be beneficial, it could also be damaging for the environment because one doesn't know what the full consequences are, what the effects are going to be when there is too little solar radiation, or the solar radiation is just limited to certain regions. So, I think one basically creates the next climate problem or environmental problem with that. (Austria, Rural) Agricultural conditions: When you talk about SAI, given the fact that temperature would not be equal in all countries, it is going to have an adverse effect… Another thing is planting of crops. We are not planting crops at the same time, because the rainfall they are having there that is going to have positive effect on farm produce might have negative effects on our own – because we are not planting at the same time, and we are not experiencing the rainfall at the same time. (Nigeria, Urban) Uncertainty disadvantages countries with low adaptive capacity: I suppose, if it works flawlessly then it would be the worst-off countries that would benefit the most… But I suppose on the flip side… if there

Table 5 (continued) | Key hopes and concerns

Theme	Countries and focus groups (R for Rural, U for Urban)	Representative quotes
		were effects on crops and rainfall then it would be those countries already struggling to grow enough food that would be impacted and it's the wealthier countries are more likely to be alright. (UK, Urban)
Energy and infrastructure costs	North (9/11 countries): Australia R + U, Austria R + U, Germany R + U, Italy U, Norway, U, Poland R + U, Spain U, Sweden R + U, Switzerland R + U Emerging South (6/8 countries): Brazil U, Chile R + U, China R, India U, South Africa U, Turkey R Developing South (2/3): Kenya U, Nigeria U	Energy, waste, siting: These three approaches… involve a large amount of time and money because all of them need to have aeroplanes or ships specifically for that. The space-based option would also generate space garbage, so we are trying to clean the earth by polluting other parts. And who will this benefit? We need to think about social issues because where would be the places where this will be implemented? (Brazil, Urban) Connection to mitigation deterrence: I also think it's a patch, it could reduce temperatures, we could cool down the planet, but we're not tackling the source of the issue. The issue is carbon dioxide emissions, and this won't change if we don't change the way we do things. Besides, with these we need planes, infrastructures and factories, which would emit pollution, and we don't know about the side effects either. (Spain, Rural)
Geopolitics	North (10/11 countries): Australia R + U, Austria R, Germany R + U, Italy R, Norway R + U, Spain R + U, Sweden R + U, Switzerland R + U, UK R + U, US U Emerging South (4/8 countries): Brazil R + U, Indonesia R + U, South Africa R + U, Turkey R + U Developing South (3/3 countries): DR U, Nigeria R + U, Kenya U	Countries will design deployment to their own benefit: I'm looking at these strategies – for example aerosol injection – it can easily be implemented by rich countries and the most impacts will be felt by the poor countries… and if there are any side effects, they will be felt by the poor because they don't have resources for intervention. (South Africa, Rural) Unilateral action, geopolitical rivalries: It is a paradox that an autocratically run country like China, or a country like America, which occasionally flouts standards when it suits them, would be most likely to be able to go through with something like this. If the technology were available and this country simply decides that something has to be done now, it is possible that they would simply do it…. That is why it is very illusory being able to implement something like this in a democratic way. (Switzerland, Urban) Technology race: I think the second idea, the one about putting a mirror in space, involves other interests than simply our individual interests because only a few countries have the means to contribute to this technology and it's a race in terms of knowledge, technology, the same way it was with Russia and the United States to land on the moon first. This can be a new race. (Brazil, Urban) Location of infrastructure: I don't see this MCB coming to life, you cannot share water, Russia, America, Ukraine, they have special (territorial) waters, American ship or submarines cannot pass through Chinese waters…This also has to do with airspace too…if Russian aircraft are passing through America, if they want to go and put particles there, they will not allow it… if they don't agree, they can start another war. (Nigeria, Rural)
Unequal capacities	North (9/11 countries): Australia U, Austria R + U, Germany U, Italy R, Norway R + U, Spain U, Sweden R + U, Switzerland R + U, UK R + U Emerging South (5/8 countries): Brazil R + U, Indonesia R, South Africa R + U, Turkey R Developing South (3/3 countries): DR U, Kenya U, Nigeria R	Optimism about tech-capable countries: And automatically, these countries should be wealthy countries. Even if it is, like, being organized, for example in a… uh, like, we want to save earth. Like, okay. Several spots are determined. And then, the ship/vessel/plane designed to do the spraying, like, whether it could be that… okay, countries such as UAE, maybe they could donate a certain amount of funds. Also, Japan or from superpower countries–maybe these countries could participate. Because automatically, developing countries would be, like, it's a bit difficult for these countries to contribute. (Indonesia, Rural) We need national or international partnerships… like what is being done in Nigeria now… construction is being done in partnership with the Chinese because (it) is capital intensive. (Nigeria, Urban) Skepticism about tech-capable countries: There is also a big risk of the South getting the damage that the North causes, like it is already the case. The North is generating the most CO_2 already, and this would be a problem globally. Africa would have the biggest problems, probably. They do not have the money to participate, and they are still a far cry from what the West is doing. They probably do not have the resources, financial and in general. I do not think the US or Russia or China would say that they would just pay for Africa as well. They always want to come first. (Germany, Urban)

Table 6 | Governance

Theme	Countries and focus groups (R for Rural, U for Urban)	Representative quotes
Systemic and multi-dimensional assessment	North (10/11 countries): Australia R + U, Germany R, Italy R, Norway R + U, Poland R, Spain R + U, Sweden R, Switzerland U, UK R, US R + U Emerging South (8/8 countries): Brazil R + U, Chile R, China R + U, India R, Indonesia R, Saudi Arabia R, South Africa U, Turkey R + U Developing South (3/3 countries): DR R + U, Kenya R + U, Nigeria R + U	Distribution and differentiation of impacts: The first thing I think is that it needs research to be done in different levels, maybe to research the people concerned, as well as scientific research, to see if it is appropriate for particular regions. (China, Urban) Whole systems risk assessment: A thorough plan on how it will happen. The whole project from beginning to the end; who will do it, where does material come from, what material it is. As mentioned, who will be the most affected, and the least affected, and who will win the most, and win the least. There has to be a real risk analysis over it. (Sweden, Rural) Avoid instrumental assessment: My expectation is that theories need also opposing scientists making sure nothing goes wrong. I want them to be able to think about the negative side of things. Rather than saying why it can be done, I would expect research on the part of why it should not be done or what kind of harm can occur (Turkey, Urban)
Calls for small-scale tests to gauge impacts	North (6/11 countries): Australia U, Poland R + U, Spain U, Sweden, R, Switzerland U, US U Emerging South (5/8 countries): China R + U, India U, Indonesia U, Saudi Arabia U, Turkey R + U Developing South (1/3 countries): Nigeria U	Scaling uncertainties: Certain things are so difficult to conduct research on in a small and harmless scale, and then, to think that it will be exactly the same when we do it in a thousand billion times bigger scale… I don't know. But it still feels really difficult to know exactly how it will be later on. You research a small sample, and you don't always know how it will be later on. (Sweden, Rural) Small(er) scale tests for impacts: Maybe a test in certain districts to ensure it works. It has to be practical that it improves the weather as well as not affecting productivity. That's my thoughts. (China, Urban) From my point of view, within the minimum scope to see a result, I would test it in different areas around the globe. I would sample farming areas, industrial areas, de-foresting areas, hot areas… The idea is to test the efficacy of this technology, and in order to do so we need to test it in different ways (Spain, Urban) I'm saying that a smaller-scale experiment should be done first. So one country has to be selected. An experiment should be conducted on that country. I think we should measure the harm and benefit for this country and then decide on bigger projects. (Turkey, Rural)
Remote testing	North (4/11 countries): Poland R + U, Spain R, Sweden U, Switzerland U Emerging South (2/8 countries): Saudi Arabia U, Turkey R Developing South (1/3 countries): Nigeria U	If possible, they should test it on another planet first. (Nigeria, Urban) I think this process should be executed first on a remote area that's suffering from global warming, an experiment at first on a small remote area so that if the technique has negative outcomes it doesn't result in much of it but a negligible effect, and to check whether these negative impacts could harm people of residential areas. (Saudi Arabia, Urban)
First mover innovation (National and private aerospace)	North (9/11 countries): Australia U, Austria U, Germany R + U, Italy U, Norway R + U, Poland U, Spain U, Switzerland U, US U Emerging South (4/8 countries): China U, India U, South Africa U, Turkey U + R Developing South (1/3 countries): Kenya U	It will definitely benefit the tech giants. They will add to their money. It will be of use to scientists. There is a high cost to implement such things. Requires a boost. Support is given on a country-by-country basis. It will be beneficial for those who make money with these transactions. What will it change in our lives? It won't change anything in the short term. Perhaps these costs will be reflected on us as a tax burden… Let's say it's a technology project that will come to life in twenty years, how much will I benefit from it? Maybe he just takes money out of my pocket for those twenty years. (Turkey, Rural)
Profiteering motives, greenwashing, benefiting from mitigation deterrence	North (9/11 countries): Australia R + U, Austria U, Germany U, Norway R, Spain R + U, Sweden R + U, Switzerland R, UK U, US U Emerging South (2/8 countries): South Africa U, Turkey U Developing South (1/3 countries): DR U	Patenting: I think the important issue will be around the patent of the technology because this is the technology that is supposed to save the world. So the hope is that whoever develops the technology will openly share so that everyone can create the technology can be used more widespread. Because if it's only one country that has the technology then they would monetize it and they can use it whatever way they feel is beneficial to them. (South Africa, Urban) Profit-driven deployment, MCB: I'm just thinking of these, like super big companies like the oil rig companies, not necessarily oil rig companies, but companies that have that amount of money. That would be doing that. The marine cloud brightening… they'd be like, privatizing it because that's on a smaller scale, offering it to like the small communities and countries and everything. (US, Urban) Mitigation deterrence: High-level companies like petrol companies could benefit from it, not only in terms of money but also indirectly, in the sense of less pressure and continuing with their work. (Spain, Urban)

Table 6 (continued) | Governance

Theme	Countries and focus groups (R for Rural, U for Urban)	Representative quotes
Global collaboration/ coordination to manage geopolitics	North (11/11 countries): Australia R + U, Australia R + U, Germany R + U, Italy U, Norway R + U, Poland R + U, Spain R + U, Sweden R, Switzerland R, UK U, US R + U Emerging South (4/8 countries): Brazil R + U, China R + U, Indonesia U, Turkey R + U Developing South (3/3 countries): DR R + U, Kenya U, Nigeria R	You can't go beyond the border (of countries) and do something in other places that belong to others…. It must (also) be done (managed) by the state, which has the power/capability of sending ships to do it, such as the Liaoning or Shandong (the Chinese navy's aircraft carriers). (China, Rural) And if we're going to bring in all these other countries, which we want to because it's not just the United States, it's South America, North America, Antarctica. It is a global issue. We have got to bring everybody to the table, and we have to have everybody on the same page. (US, Urban) I think that all administrations should agree on this, because it is a global issue, like with that COVID vaccination. Everyone had to agree to some extent, and most countries were in line. If all administrations leave their ideas aside and understand this is a global issue, there will come a point they will agree. (Spain, Urban)
Global commons		SAI: … no one pays taxes in the stratosphere, it's everyone….so I think there must be a unity of different countries. (Brazil, Urban) Space shield: No one actually owns space… For now, there needs to be an organization that has a wide reach, for instance the UN. (Norway, Rural) MCB: Because legally speaking, the open sea doesn't belong to any state… everyone needs to be involved in this decision. (Austria, Urban)
Affected should participate in governance	North (10/11 countries): Australia U, Austria R + U, Germany U, Norway U, Poland R + U, Spain R + U, Sweden R + U, Switzerland R + U, UK R, US U Emerging South (2/8 countries): China U, Turkey R + U Developing South (1/8 countries): Kenya U	Everyone is affected. It is a global problem and with the injections and everything, it cannot be that the big countries decide to simply inject something into the air, because it affects everyone and not just the countries deciding. (Switzerland, Urban)
Responsibility to help vulnerable	North (3/11 countries): Germany U, Norway U, Switzerland U Emerging South (1/8 countries): South Africa R Developing South (3/3 countries): DR U, Kenya U, Nigeria U	There needs to be a global project, something like a fire brigade for poor countries. If New York is in danger, there will be enough money for dams or other projects. This should be supranational because an African country at the coast would not have a chance. The UN should do it on behalf of the whole world. (Germany, Urban) I think the multinational bodies should come in and support NEMA (National Emergency Management Agency) because the government cannot do it alone, not this government that we have. (Nigeria, Urban)
Global multilateral framework is the ideal form to fit multiple functions	North (10/11 countries): Australia R + U, Austria R + U, Germany R + U, Norway R + U, Poland R + U, Spain R + U, Sweden R + U, Switzerland R, UK R + U, US R + U Emerging South (6/8 countries): Brazil R, China U, Indonesia R + U, Italy R, South Africa R, Turkey R + U Developing South (3/3 countries): DR R, Kenya U, Nigeria R + U	World Health Organization as template: There is the World Health Organization now… I mean it's unquestionable, it made great contributions to management. And can you imagine that such organizations exist, that there are people who are really trained in such organizations? … as the process progressed, I think people's perceptions really started to improve with the explanations. In the same way… governmental control and funding can be formed, commissions can be formed. (Turkey, Rural) Regional coordination for MCB: I think it could have co-operation among different countries. For example, it could have New Zealand, and Australia cooperating with Pacific Island nations, maybe nations like Indonesia, Papua New Guinea, taking one big whole region and cooperating or just within neighboring countries. (Australia, Urban)
Consensus difficult, global frameworks Implausible	North (5/11 countries): Australia R, Austria R + U, Germany U, Spain R, Sweden R Emerging South (2/8 countries): China R + U, Brazil R Developing South (1/3 countries): Nigeria R	Well, it is the conflict between natural science (meaning: technical assessment) and social science (meaning: corresponding laws and regulations)…because the development of social sciences and global governance have not reached such an advanced level. (There is a) lack of the same international laws and regulations across countries. If the United Nations General Assembly can pass an international law, of course, (but) the United Nations General Assembly has no right to pass a national law. (China, Urban)
Stronger consultation of publics in risk assessment	North (5/11 countries): Australia R, Germany U, Poland U, Sweden R, UK R Emerging South (8/8 countries): Brazil R + U, Chile R, China R, Indonesia R + U, Saudi Arabia R + U, South Africa U, Turkey U Developing South (3/3 countries): Nigeria R, Kenya U	Remember, any decision that you will take… it does not matter whether it will be taken by professional astronomers (meaning: technical experts), or whoever calls shots at the end of the day, it affects people on the ground, just educate the people on the ground, yes, and give people a chance to, participate and have an input, whether they go along with it, or the opposite side. I can give an example like COVID… when most of the people raised their voices, they were not listened to, and thought to be out of line. Those things

Table 6 (continued) | Governance

Theme	Countries and focus groups (R for Rural, U for Urban)	Representative quotes
		must not happen again. (South Africa, Urban) I was going to say that the internet is a way to communicate in almost every place, and could be the place to announce the necessity and the solution, but in a more detailed way, based on facts, scientific data, and the global population, considering the possibilities, could vote and give ideas. (Brazil, Rural)
Skepticism over the value of public consultation	North (7/11 countries): Australia R + U, Austria U, Germany R + U, Poland R, Spain R + U, UK U, US R + U Emerging South (7/8 countries): Brazil R, China R + U, India R + U, Indonesia U, Saudi Arabia R + U, South Africa R, Turkey R Developing South (0/3 countries)	Skepticism: I think getting the wider public involved is always dangerous in terms of the results because that is influenced by political sentiments, current events. (Germany, Rural) Trust in government and experts: As my country is concerned, I don't have much opinion about this. I need to condition myself to accept this mentally, and as far as my knowledge goes, I will try to promote this idea (approach) to others, to let others know more about this, for them to understand this. I might not be a technical person, but that's what I can do…. As an individual, right? In fact, we don't need much preparation, as long as the country passes this technology… For us personally, we absolutely support it. It belongs to the top-level of decision-making. (China, Urban) Lack of trust in government: I think a lot of times when we wanted to have a say in things, even you know, when we… protested about it or disagreed with it. You know, they didn't listen to us anyway. So I think that's really the reason why everyone's skipping over 'the locals should have a say', because I don't think it matters even if we do have a say. They're going to do what they want. (US, Urban)

populations with lower capacity to adapt to change, especially in the context of food security.

Groups across the global North and South widely questioned the energy and infrastructural costs of solar geoengineering options. Unsurprisingly, the greatest degree of skepticism was reserved for the space-based option, with participants struggling to comprehend the scale of its associated economy, and further questioning how much space debris might be created. However, participants applied comparable critique to SAI and MCB, questioning the costs and material demands for adapted aircraft or ships, the degree of innovation required, the locations for basing these vehicles (and the politics of siting), and the energy costs and emissions that would result from building and deploying such systems over extended periods. For some, this re-connected to concerns that all solar geoengineering options pose a trade-off with the fundamental logic of addressing the root causes of global warming.

Geopolitics and inequity

Most of the global North and developing South groups highlighted geopolitics: that wealthier, technology-capable states would inevitably shape deployment to their own benefits, or that incentives to do so would spur unilateral, club-based, and/or competing deployments and ensuing conflict. These concerns were shared by a strong plurality of emerging South groups – although (interestingly) no one in Indian or Chinese groups spoke to them. Other key themes emerged on the potential for a technology arms race, the underpinning context of resonant geopolitical rivalries (with combinations of China, the US, and Russia being the most cited, though not by Chinese and American participants), fears of weaponization or militarization, and potential conflicts over the location of infrastructure (e.g., bases and launch sites, or deployment zones).

Unequal capacities were acknowledged by groups from most countries, including all three developing South states, questioning if poorer countries would have the capacity to deploy any of the three approaches, or influence the planning of states that could. Groups from across North and South expressed hope that wealthier countries would seek a globally equitable set of climate outcomes in deployment. In global North groups, this was more often coupled with skepticism. Developing South groups could be more optimistic, sometimes citing economic development projects and aid.

Assessments and experiments

Groups from almost every country supported the conduct of systemic and multi-dimensional assessment, regardless of approach. Rationales covered technical and socio-political queries, as well as distributive and procedural demands: determining the distribution and impacts of shading across and within countries, calculating infrastructural costs and (extraction and location of) material resources, a whole systems perspective that emphasized impacts on different countries and societies through relief or worsening of vulnerabilities (e.g., health, agriculture, political corruption, introducing or exacerbating conflict), and constructing processes to integrate such assessments with international decision-making.

Two broad themes emerged. Input was stronger on function than form: perhaps unsurprisingly, participants deliberated with greater confidence and detail on what an ideal mode of assessment should do, rather than the processes or institutions by which it should be. Secondly, whether participants were hopeful or skeptical of solar geoengineering, envisioning the conduct and feasibility of coordinated global assessment tended to be more cautious than instrumental towards deployment. This reflected strong trust in scientists or expertise (broadly stated) – but less confidence in the capacity for intergovernmental cooperation or industry motives, to which scientific assessment was often contrasted.

Groups from a strong plurality of countries across North and South – with most countries from the emerging South – supported the conduct of small-scale field experiments, but most often with an incongruous provision: to test widespread impacts. This applied to all three approaches – but since participants understood MCB as a comparatively regional approach, they appeared to be more interested in testing the impacts of the planetary approaches. Participants tended to intuit the scaling difficulties of a space-based sunshield as infrastructure whose full impacts could not be tested at limited scales, which provided additional rationales for skepticism. However, participants tended to envision SAI field tests as contained demonstration pilots, resembling local infrastructural projects, or compared to weather modification (e.g., rain-making) schemes. Alternatively, a smaller number of groups called for testing in remote or uninhabited regions or on single countries, for an akin purpose of testing impacts while minimizing potential harms for people. This has especial implications for current controversies over small-scale field tests, which we address in discussion.

Industry

A large number of groups across the global North and South saw primary benefits for first-movers in innovation and manufacturing for all three approaches, subject to the understanding that deployment infrastructures would have to be designed and constructed. The greatest attention was paid to the space-based sunshield and to SAI, with primary benefits envisioned for the aerospace sector, and with nuances attached to a range of national aerospace industries and private companies. The US National Aeronautics and Space Administration and other national/regional agencies – the Indian Space Research Organization, or the European Space Agency – tended to be cited with greater trust. Elon Musk and SpaceX were highly cited but polarizing archetypes of a visibly emerging era of privately funded and commercialized space exploration, linking to background deliberation about the imperatives of innovation on science, technology, engineering and mathematics (STEM) in the modern global economy, and the material, intellectual and cultural resources that billionaires, major corporations, and advanced economies can marshal. Though not universally, the tone of discussion in certain emerging South groups (especially India) was characterized by greater optimism surrounding government-industry collaboration and innovative capacities – although these are complicated by concerns over unequal technological capacities in other emerging and developing South groups.

Skepticism was comparatively more prevalent (though again, not universal) in global North groups regarding excessive leeway given to advanced STEM industries, or inertial control of charismatic leaders (e.g., Elon Musk) in those industries over public discourse and policy-making. Grappling with the technical possibilities of planetary versus regional solar geoengineering, participants envisioned latent profiteering motives in patenting activities or garnering investment. An interesting dimension was noted for MCB, as an archetype of an approach with arguably more localized potential: that deployment services could be commercialized, and best benefit those able to pay. These discussions extended beyond first-mover innovators and the commercialization of deployment to benefits gained a wider range of carbon-dependant industries latching onto the prospect of solar geoengineering to continue business-as-usual – often discussed as an extension of greenwashing, and once again implicating mitigation deterrence.

Global multilateral framework

Three key rationales emerged for managing the research, development, and deployment of solar geoengineering approaches. The most widespread rationale was to ensure coordination or collaboration to forestall geopolitical contestation - groups from all global North and developing South countries spoke to this, but only half the countries from the emerging South. This rationale was underpinned by deliberations over multiple dimensions: that solar geoengineering deployment would to a large degree be a function of interstate planning; that national sovereignty and military capacity will be important factors in siting infrastructure, planning logistics, and designing deployments; that technology-capable countries (or hosting such sectors) would attempt to shape deployment to their own benefits; and that there would be complex dynamics surrounding forging alliances between states, and gaining (diplomatic, infrastructural, or military) support. A key component was the sense of deployment within a global commons, in which unilateral motivations and actions must be forestalled.

This transitions into a second – though lesser held – rationale that those affected should participate in governance, as opposed to support for technology-capable clubs – with the clearest implications emerging for the planetary-scope approaches of SAI and the space-based shield demanding global outreach and representation. Reflecting the preceding rationale over coordination, this perspective was widely held in the global North, but received much fewer mentions in the (emerging) South. The third rationale was held by a small but North–South crosscutting number of groups; aimed at technologically capable countries, it called for responsibility to help vulnerable countries. This ranged from developing solar geoengineering approaches as emergency mechanisms to alleviate or forestall climate harms, evoking disaster aid and response, to how deploying solar geoengineering could synergize with or distract from responsibility over historic emissions or forthcoming mitigation efforts.

Accordingly, there was an almost universal preference for a global multilateral organization or framework as ideal to fit these multiple functions. The envisioned functions of such a multilateral framework often extended beyond the management of geopolitics to multiple sectors and/or extended over all stages from research to deployment. Accordingly, such a body should house international expert assessments, and initiate processes for informing and consulting publics. Participants also cited the need to involve industry voices, both to encourage and coordinate technological innovation and transfer, as well as to curb profit-seeking motives.

The United Nations (UN), or the generic mention of an international body housed within the UN system, received broad citation. The most positively cited institution itself was the World Health Organization, which in the context of the Covid-19 pandemic was seen as an example of impartial science and information dissemination, and a fraught but ultimately successful navigation of political agendas in the face of global harms (e.g., vaccine politics, the origins of the virus, measures over mitigation and border control). The United Nations Framework Convention on Climate Change, by comparison, was treated more skeptically due to mixed successes and visible contestations at that institution.

A key nuance to multilateral governance was differentiation between scales. Key rationales – e.g., geopolitical management, or integrating those affected into decision-making – were commensurate to the scale of deployment between planetary (e.g., SAI and the space shield) and regional archetypes (e.g., MCB). MCB, for example, was often exempted from the need for a global level of multilateral governance, with more limited and regional arrangements – e.g., in the South Pacific or Mediterranean – deemed sufficient as long as they were representative and equitable within their zones of deployment. This reflected the juxtaposition between local-to-regional versus planetary scale and leverage, with MCB treated as being more contained in physical impacts and geopolitical implications—but it was not always assumed that agreement would be easier to reach within regional zones of deployment.

Indeed, a plurality cutting across all three country groupings highlighted the difficult of consensus or compromise within multilateral frameworks to determine an issue as complex as determining what should constitute ideal global climatic conditions. Participants most strongly cited the primacy of national sovereignty, the unclear capacities or previous failures of international law and the UN system to manage global governance issues, and harkened back to complex geopolitical and corporate agendas. On the whole, groups from the majority of global North and developing South saw multilateral governance as highly necessary – though with an unclear balance of hope in idealized global cooperation and examples of qualified success (e.g., pandemic governance), matched against resignation regarding realpolitik.

Publics

Calls for stronger consultation of publics in risk assessment were widespread, particularly across most global South countries – underpinned by rationales in favor of affected populations being included in systemic assessment and in decision-making. In turn, these contained nuances between national and global levels of consultation, and between constructive and disruptive action. Groups gravitated most towards national-to-local processes for information dissemination and public input, ranging from town halls to consultation processes or campaigns sponsored by combinations of universities, industry and government, to the election or support of political representatives. At a global level, many cited advances in the Internet and social media as platforms through which to elicit and compare preferences across national publics. Less commonly, groups cited more direct forms of (democratic) action such as (protest-based) social movements or referenda. This sense of disruptive urgency – underpinned by rationales of deep uncertainty regarding systemic risks, as well as by mistrust over government and corporate agendas – should not be lightly regarded.

These calls for public involvement and topical literacy were offset by strong skepticism over the value of public engagement – held likewise in groups across the global North and South. The most common rationale was the supposed incapacity of laypersons to grasp the technical complexity of solar geoengineering. Adjacent rationales included a lack of tolerance and/or nuance in public discourse: local or national parochialism, or a tendency towards manipulation by media trends towards polarization and sensationalism. These concerns reflected fears of the high geopolitical stakes of solar geoengineering, as well as – for groups in the global North – recent years of deep polarization regarding right-wing populism, dynamics of splintering within the European Union, social responses to pandemic management measures, and the Russo-Ukrainian War. The implications of skepticism further diverged into two camps: either offset by trust in expertise and one's government (particularly strong within the Chinese and Saudi groups), or heightened by a sense of powerlessness and a lack of trust that governments would take public concerns into account (more common, and spread across North and South groups).

Discussion

Does the Global South prefer solar geoengineering (particularly, SAI)? There is a longstanding debate among experts over the proposed benefits and risks of solar geoengineering – predominantly of SAI – for vulnerable populations, especially in the global South. Proponents emphasize that globally optimized schemes for SAI could reduce key climate risks for the most vulnerable[62]. Critics counter that SAI would likely be used by major emitters to delay decarbonization or induce geopolitical conflicts over ideal regional climatic conditions – which would disproportionately end up harming the most vulnerable[3]. Contentions of peremptorily speaking on behalf of Global South interests are made towards both critics[3] and advocates[2].

Calls for public engagement in the global South[24] have resulted in a handful of exercises[7,12,21,28–30]. Most highlight that global South participants are more supportive about the prospect of solar geoengineering[12] in comparison to those in the global North[7,29,30]. Our results nuance these insights: global South focus groups exhibit greater hope but an arguably richer range of concerns for solar geoengineering, in the context of observable inequities in climate action and potential geopolitical conflict. We highlight three dimensions.

Firstly, in global South groups, there was a qualitatively stronger sense of vulnerability and immediacy that generated demand, hope, and desperation around solar geoengineering (reflecting previous work[28]); in all groups, demand was offset by a fear of entrenching unsustainable practices. Global South groups more commonly raised the need to dampen the effects of a warming climate. For comparison, some northern European groups noted that climate impacts are (for now) less locally relevant, and that their concerns were more systemic and global. However, just as much as in global North groups, global South groups highlighted the need to reduce carbon emissions and unsustainable behavior, and warned of what experts have termed mitigation deterrence.

Secondly, the support of global South groups – particularly from developing states – were conditioned by awareness of North–South inequities in funding, technology (transfer), commitments, and action towards decarbonization (reflecting previous work[21]). Nor was this limited to climate action, but expanded into other global governance issues —e.g., pandemic management – and geopolitical contestations. For (especially, developing) global South groups, there was a widespread demand for major powers and emitters to broadly lead on climate action, and to carry that ethic into the assessment, funding, development, technology transfer, and political coordination of solar geoengineering approaches –accompanied by considerable skepticism that they would. There was very limited discussion in developing South groups (e.g., Nigeria) on whether emerging South powers (e.g., China) could drive solar geoengineering governance in an arguably more equitable manner, acknowledging Chinese investment projects abroad as a possible reason in favor.

Finally, there was variation between the Indian, Chinese, and Saudi groups vis-à-vis Brazil, South Africa, and the rest. Discussions in the former grouping were marked by a stronger sense of national innovative capacity (e.g., aerospace) and state-industry coordination that was comparable to discussions from groups in northern Europe, Switzerland, and the US. There was also brief discussion in the Chinese and Indian groups of whether solar geoengineering might permit further space to industrialize – this discussion was not present in other groups (previous work bears the same result regarding Chinese respondents[7]). A final factor setting groups from China, India, and Saudi Arabia apart was the absence of discussion over geopolitical agendas – of their own government(s) or any other. Global North and other (more developing) South groups tended to agree on the centrality of geopolitics, with discussions reflecting the perspectives of haves and have-nots.

How do publics view early-stage field experiments? A recent companion study in our project finds that that global South publics favor further field tests in comparison to global North publics, and that no publics favor banning solar geoengineering in comparison to further assessment and testing[30]. We engage with this finding, but first lay out the context.

Debate over the necessity and governance of early-stage, small-scale tests of solar geoengineering in the open environment – as distinct from lab-based assessments – is extremely polarized. Such tests are the first stage and scale of a longer typology of outdoor activity, ranging from initially reduced scales of testing components, deployment mechanics, and environmental processes, then moving further to time-limited impacts testing, and finally to a sustained period of deployment[52].

There is longstanding contestation over the permissibility of small-scale tests. A lack of clear governmental guidance has contributed to an ad-hoc system of self-regulation by scientific and commercial actors, and a lack of widely accepted governance for field tests. This particularly regards the conduct of public engagement. For example, researchers disagree about whether engagement design should focus public input on localized, near-term technical and physical issues of the field trial itself, or the wide-ranging, long-term sociopolitical implications of where experiments might eventually lead[45]. This has clear implications for bounding what risks are presented to publics as relevant. Critics are concerned about a 'slippery slope' from early-stage testing to inevitable deployment, the potential for mitigation deterrence, and deep disruptions to global governance. Proponents contend that these concerns overplay long-term anticipation ahead of what they see as 'mundane' basic research, and some do not see the need for public engagement at all[17,45].

In the meanwhile, considerable civic and expert opposition has followed early-stage SAI and MCB field tests. SAI tests have either been canceled in the face of civic opposition and expert dispute[45,48], or been criticized for introducing commercial motives through the sale of unilaterally defined 'cooling credits' or for being conducted in a clandestine manner[63]. The most successful test was on MCB, which found a facilitative framing as (preliminarily testing) a regional form of ecosystems protection, as part of a long-term effort – an Australia-wide consortium of governmental, academic, and innovation actors – to improve the resilience of the Great Barrier Reef against climate change and other threats (the Reef Restoration and Adaptation Programme[64,65]). Due in part to the infrastructural requirements, no strident calls exist for feasibility testing of (components of a) space-based sunshield that resemble debates over open-air testing for SAI and MCB[59].

Studies about public preferences regarding field tests – as opposed to deployment – are few (in Japan[17], the UK[16,48], and Germany[6]), but illuminating. Participants strongly prefer that the (technical) risks should be contained and reversible, but are divided on whether the political risks could be contained – for example, the prospect of a 'slippery slope' from testing to deployment[16,17]. Indeed, the long-term consequences of tests are treated as seriously as the immediate impacts, for both good and ill: relieving impacts on the vulnerable or future generations, or delaying mitigation and entrenching Anthropocentric hubris[6,17,48]. Finally, participants are in favor of transparent governance of early-state research over moratoria or bans[16,63].

Our results confirm that global South groups favor small-scale field tests in comparison to global North groups, and add that similar rationales in favor of tests are found across global North and global South groups. However, we emphasize that public rationales delivered in the focus groups have two key contextualizing dimensions that should temper interpretations of broad support. Firstly, latter-stage climatic and geopolitical consequences are primarily of interest, rather than early-stage technical testing. Secondly, tests should be contained or remote, initially limited to smaller locales, or to particular countries – how such countries are to be identified remains an open question.

This is a mismatch between public expectation and the capacity of preferred tests, and it is particularly relevant to SAI as a more technically feasible approach with a necessarily planetary scope. In SAI assessment, small-scale, time-limited tests can examine aspects of atmospheric physics or (scaled-down) deployment mechanisms. However, gauging the differentiated physical (and political) impacts of SAI over time requires a scale and length of 'testing' that is equivalent to planetary deployment[52,66]. Public hopes for local-to-national scales, remote locations, and contained implications[6,16,17] are impossible to meet, given the planetary scope necessitated for impacts-testing. This is similarly true of the space-based sunshield – although publics discussed the testing of this option far less, as they found imagining its infrastructure to be daunting. It is unclear if large-scale testing for MCB as a more regional approach might still meet the criteria for limited scope and containability – not least in light of the relationship with tipping points[58]. The recent efforts in the Great Barrier Reef offer the insight that framing efforts around targeted regional protection could help to alleviate concern.

A caveat is necessary: participants largely did not appear aware of or discuss the distinct capacities of different stages and scales of field tests. Our study did not provide informational materials on such a typology. In the absence of such direct steering, the misconception about the capacity of contained tests to gauge transboundary risks unintentionally persisted. Nevertheless, the misconception is revealing, and prompts future work to ask: what range and scales of field tests would be deemed permissible, if publics understood that no such tests below global deployment would answer their most salient concerns? How would public expectations over the knowability of future outcomes be adjusted? Would public support in the global South or North be altered for SAI or solar geoengineering more broadly?

Our results do not imply that publics would oppose early-stage, small scale field tests with limited technical objectives. It is worth noting that many participants – more in the global North than South – stated that they would oppose any indication of solar geoengineering development, implying the inclusion of field tests. However, our results show that participants across the global North and South would conditionally support tests – though far more in the South than North – as part of systemic risk assessment that combines technical and socio-political inquiry, demonstrates international collaboration, and eschews commercial motives (reflecting previous work[16]). Engagements over field tests in particular locales also offer opportunities to extrapolate and explore how 'whole systems' of development and deployment[67] might be distributed: each solar geoengineering approach, and variations of deployment schemes within each approach, would have resource demands and locations for infrastructure that would directly affect certain actors over others[68].

Moreover, the misconception over the capacity of contained field tests was not universal, with a smaller number of inputs acknowledging the impossibility of field-testing for long-term differentiated impacts, and in its place, noting the need for extensive simulations (reflecting previous work[16,17]). Certainly, this validates an expanding range of earth systems modeling studies[54] that is beginning to inquire after impacts relevant to global South countries and regions[69–71]. At the same time, a prominent strand of modeling works on constructing idealized deployment schemes to construct globally optimal climatic outcomes[51]. While providing a basis for international

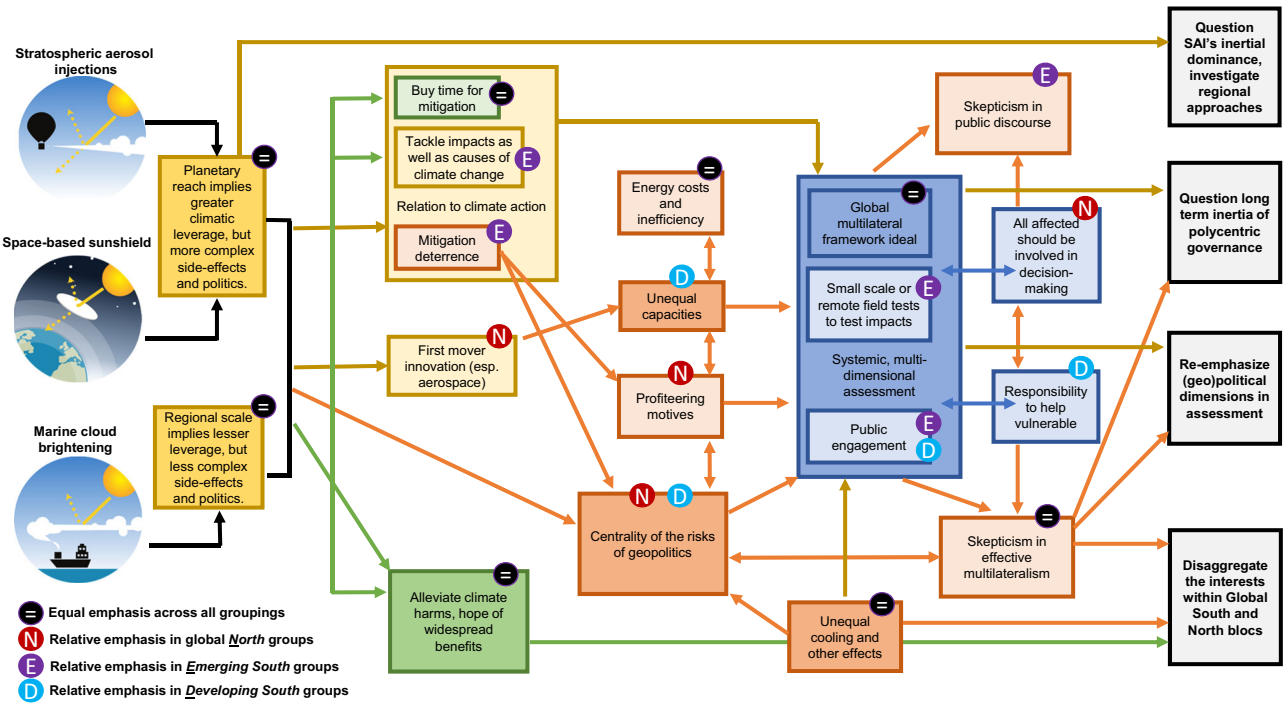

Fig. 1 | Complexes of hopes, concerns, and corresponding governance issues associated with solar geoengineering. To the left are the three types of solar geoengineering. The pictures are those provided in information materials sent to participants. The solar geoengineering types are connected to hopes (in green), concerns (in orange), and themes with elements of both (in yellow). Governance rationales and activities are in blue. The arrows signify linkages between hopes, concerns, and corresponding governance; the colors of the arrows correspond to the aforementioned scheme – positively, as a hope (green); negatively, as a concern (orange), both (yellow), and connections between governance (blue). The darker the color of the boxes, the more focus groups spoke to the theme contained therein. These complexes connect to one or more of the four governance rationales in the conclusion, outlined in the black blocks to the right. The smaller colored circles refer to relative emphases placed on themes by focus groups from the global North, emerging South, and/or the developing South.

coordination, optimized scenarios are at odds with conflicting, geopolitically-motivated agendas and non-ideal deployments – which are not only a strong focus of our focus group deliberations, but remain greatly underassessed in both modeling and broader assessments[44,72,73]. It will be necessary to bridge climate modeling with expert, policy, and public engagement to construct a range of geopolitically cooperative and conflicting scenarios[74–76].

Multilateral, multi-purpose, and multi-stage governance is seen as ideal. Our results show support for the pursuit of multilateral agreements between states – most often citing a UN-based framework as template – from groups in the global North and developing South, as well as in groups from half the emerging South countries (including China and Brazil). Moreover, publics were concerned not only with managing the geopolitics of deployment, but discussed the need to coordinate assessment, development, and – especially for global North groups – screening out commercial motives. These results broadly confirm previous studies that show support for international coordination over upstream stages of research and field tests as well as deployment[14,31,77], and show that support is conditioned by trust in political institutions and actors, including industry and academia[6,8,32].

Three adjoining insights are notable. Firstly, the scope of inclusion in decision-making was almost always fitted to the geographic/geopolitical scope of the approach's impacts, but with differentiated rationales. For global North groups, the key guiding principle was explicitly based on all affected populations and countries being represented in decision-making, rather than just technology-capable countries. In contrast, groups from all three African countries and the Dominican Republic voiced a hope that decision-making would include countries lacking technological capacity and with greater climate vulnerabilities. Emerging South deliberations almost completely lacked either rationale – this fits with the comparatively lower support for formal multilateralism expressed therein, and speaks to the logics of an emerging multi-polar international system.

Secondly, unilateralism, coalitions of the willing, and competing deployments[78–80] were spoken to as plausible across global North and South groups, but we warn against extrapolating interpretations of support for them. Concerns about multilateral frameworks were most often based on skepticism that they could work. However, this never translated into open consensus in any group for unilateralism or coalitions of tech-capable major powers – even in countries where multilateral governance was not clearly supported. Some developing South groups questioned if they might benefit from being sponsored by more powerful actors in ad hoc or mini-lateral arrangements, but were more often concerned about a lack of geopolitical leverage. Meanwhile, groups in the North or the emerging South treated such arrangements with a combination of caution and ambivalence: if deployments might not be collectively optimal, would they be singularly (dis)advantageous? Much depended on how participants trusted the capacities of their national governments.

Thirdly, no groups discussed moratoria or bans for any kind of solar geoengineering as a governance option – either in support, or against. We again note results that moratoria and bans have seen less public support in comparison to further assessment and even development – although support for moratoria and bans constitute strong minorities globally, and tend to be higher in the global North[16,30,63]. Unfortunately, our results could not provide clarity on such preferences. A key reason was likely the design of the focus groups: participants were explicitly asked to consider what actions needed to be taken "before there is consideration to implement this approach" (see Methods), which created less discursive room for prohibitive frameworks. We might also consider how high levels of skepticism toward SAI and the space-based sunshield, especially in the global North, might have translated in deliberations that compared permissive and prohibitive frameworks. Nevertheless, there is a clear gap between public and expert understandings of the value of (temporary) bans, which have received a degree of support from both proponents of further research and testing (applying only to deployment[81]) as well as critics (applying to government funding, testing, and deployment[3]).

In sum: for the majority of groups, a prevailing need for nose-to-tail collaboration across stages and scales of activity was strongly offset by geopolitical issues and skepticism over the capacity for such collaboration. Some of this is mirrored by how expert conversations have evolved in the last two decades from legal, international regulation of deployment[78], towards combinations of international institutions as templates for a range of permissive or prohibitive functions[46], and finally towards more pragmatic, polycentric arrangements of research governance[43,47]. This has been due to two factors: a lack of clear fit with the mandate of any single existing multilateral governance institution (a situation that persists), and because there was until recently little appetite at various global bodies to consider solar geoengineering governance. For example, efforts to introduce such discussions in 2018 at the UN Environment Programme (UNEP) failed[47]. In the near term, the most relevant governance mechanisms remain those of the Convention on Biological Diversity[82,83] and London Convention and Protocol on marine pollution (specifically, on geoengineering approaches in marine environments[84,85]), which maintain rules on the scope of legitimate research.

The situation may be shifting. The European Commission, the UN Educational, Scientific and Cultural Organization (UNESCO), UNEP, and the UN Human Rights Council have drafted anticipatory principles or reports to ground future engagement – which remain preliminary and precautionary in nature[86–89]. Nevertheless, it reopens a discussion about whether a piecemeal, sum-of-parts coordination between institutions could plausibly be found[43], or whether the challenges of planetary forms of solar geoengineering would distort existing regime mandates and agendas[3]. Moreover, distinctions between approaches imply different architectures. Regimes such as the Outer Space Treaty of 1967, which establishes outer space as the "province of all mankind", and the UN Commission on Peaceful Uses of Outer Space, which promotes that benefits of space technologies be extended to all, might be applicable to space-based geoengineering[59]. MCB may eventually qualify as a form of marine geoengineering (currently, only ocean fertilization does); the London Convention and Protocol has the clearest regulations of any institution on the scope of field testing. SAI – arguably the most visible of all options – has no clear landing spot, and key advocates underplay the need for one[43]. It remains unclear from our results whether global publics would see a polycentric variant of international governance as desirable or pragmatic, compared to arrangements with clearer mandates and oversight.

Finally, publics often expressed powerlessness regarding any meaningful role in consultation or decision-making. The degree of scepticism over the value of public consultation across global North and global South groups regarding the two planetary approaches – SAI and the space-based sunshield – was surprising. Our results show a widespread recognition that individuals and communities would likely play no direct role in decision-making – complexes of powerful governments and (private) industries would inevitably shape innovation and deployment. This echoes an old debate in SAI governance: whether a planetary technology necessitates a more aspirational, direct, and deliberative shape of democratic control[14], or whether democratic input can assume a less ideal, more conventional shape, filtered through political representatives and an evolving range of norms and institutions[90].

Our results show that under conditions of deep uncertainty, global North groups (with implicit trust in their nations' geopolitical and innovative capacity rather than the sitting government) and some emerging South groups (with explicit trust in their political system) seem either resigned to or comfortable with the latter shape of democratic input. In addition, confidence in technocracy – for example, positive references to Elon Musk – played a minor but strident role. However, we should also note countervailing mistrust regarding both government and industry.

Indeed, there are further reasons for concern that should provide impetus for designing new, more ambitious forms of public input. Groups cited a variety of additional rationales reflecting doubt in the value of public consultation: technical complexity, national or local parochialism, media sensationalism, and the high geopolitical stakes involved. Each rationale is a concerning dimension of public discourse. Taken together, they betray a lack of confidence in public discourse itself. Falling trust in public discourse

– or at least, greater ambiguity – is particularly discernible in global North groups, who cite recent political events in which public (mis)information played crucial roles.

Given this troubling implication, future research might consider innovating processes for public consultation[2,24] that avoids leaning into the functional entrenchment of solar geoengineering into policy[91] through framings of climate emergency[92]. There may be benefits to generating a global public discourse at this foundational stage: recall the rationales that all affected should be consulted (more prevalent in global North groups) and that the powerful should incorporate the needs of the powerless (more prevalent in developing South groups), as well as concerns about powerlessness cutting across all groups. At the same time, the logistics are daunting – particularly for the planetary approaches. Our study offers a template for a global scope of study, although it is limited by the time and funding available to academic grants (as well as the limited topical familiarity of publics). Again, there are few calls for such engagements to take place regarding a space-based sunshield. But for SAI, non-government organizations are conducting and planning engagements in the global South[93,94]. Conversations amongst research advocates in the US have turned to national programs of assessment[4,52,95], which must include sustained public engagement initiatives[4,96]. There will be a future need to aggregate polycentric engagements, should these escalate. Our study may prove useful as an early global baseline, identifying key hopes and concerns as well as crucial areas of dissonance within and between countries.

Conclusion

In closing, we highlight four rationales to guide further assessment, based on the results of our global focus group deliberations, and on our judgment of shortcomings in the research and governance landscape (Fig. 1).

Firstly: assessment should question SAI's inertial dominance over other solar geoengineering approaches in expert assessment and nascent policy conversations. Comparatively low implementation costs and swift, global leverage on reducing temperatures have become received wisdoms, and are argued to justify the focus on SAI[52]. Fundamental technical uncertainties continue to confront MCB[57], and assessment of a space-based shield remains nascent[59]. However, our results show that much public hope and concern center around a planetary versus regional dichotomy. A planetary reach implies greater climatic leverage, but more complex side effects and politics, and demands more comprehensive, inclusive input into decision-making – and vice versa. Public support exists for more regionally bounded approaches, and this is worth noting in light of non-SAI proposals for protecting keystone systems – such as the Great Barrier Reef[65] or Arctic and Antarctic sea ice[97].

Secondly: polycentric governance may not be sufficient. Our results show that participants (though somewhat less in certain emerging South powers) prefer international collaboration from upstream stages of research onward. This preference is offset by scepticism regarding the feasibility of effective multilateralism, and by degrees of confidence regarding national capacities to pursue geopolitical interests – but these, by themselves, are never preferred to multilateralism. Polycentric research governance – diverse and distributed scientific networks, national programs, and bodies of norms and rules for field tests – may be a pragmatic avenue today[47]. But path-dependence is a concern. In time, polycentricity at upstream stages might become formalized in field-testing and even deployment, entrenching conflicting and multipolar logics. A US-based assessment program should be aware of the optics and incentives generated in unilateral action[91]. The danger of jurisdiction shopping between international institutions and regimes remains underassessed[98].

Thirdly: assessment must become re-geared towards political questions. In recent years, solar geoengineering assessment – again, dominated by SAI – has primarily consisted of earth systems modeling studies, and contestations over the permissibility of small-scale field-tests. Our results show that publics are hopeful about the prospect of solar geoengineering to alleviate a range of climatic harms, but this is heavily offset by the reality of geopolitical inequities, and the plausibility of contestation and conflict. Modeling globally optimal deployment schemes and climatic benefits treats geopolitical conflicts as if they do not exist, and form an incomplete basis for informing decision-making[44,72,74]. All areas of assessment can be better geared towards political questioning. There is a need for more direct engagement with national strategic and security planning communities, instead of taking a benevolent global planner perspective[21,73]. Climate modeling can be combined with expert, policy and public engagement to construct a range of scenarios that reflect not only optimal schemes, but conflicting schemes that serve the priorities of different (groupings of) states[74]. Assessment – with field tests providing an additional opportunity – can examine commercial interests (e.g., patenting, cooling credits), or anticipate whole systems of infrastructure, resources, and zones of deployment[67]. We have seen indications of falling trust in public discourse that should be combatted; global public discourse on solar geoengineering might be enhanced through innovative, transnational forms of input.

Finally, assessment should refine and disaggregate the interests of the global South. Our results show intra-South differences in perspective between participants in emerging powers (especially China, Saudi Arabia, and India) and other global South countries, particularly less developed states. Differences center around technological capacity and geopolitical clout, where global North and emerging global South powers have more comparable capabilities. Developing South participants conceived of their interests being – at best – protected or sponsored within bilateral, minilateral, or multilateral arrangements driven by more powerful states. Given the prospects of an emerging multi-polar world with a shifting, a la carte approach to international alliances, assessment will need to take a more fluid approach assessing solar geoengineering politics than exclusive reliance on global planner or North versus South lenses would permit.

Methods

Inclusion and ethics statement

All components of the research were granted ethical approval by the Research Ethics Committee of Aarhus University (#2021-13). Full and informed consent was given by all participants before the beginning of the study, along with all participants being notified about the fact that their data would be handled in a fully anonymous manner and in complete accordance with the General Data Protection Regulation and any other pertinent data-security regulations, that any data would be analyzed in an aggregate fashion and would not be personally identifiable in any way, and that they had the right to withdraw their participation at any time. The research has been broadly undertaken with the aim of better understanding public perceptions of solar geoengineering approaches, including in the Global South and by means of more qualitative methods that can better elucidate the variability and importance of the local context. At this stage, no local researchers have been included. The specific roles and responsibilities of those in the author team was discussed prior to the research. Insofar as possible, we have striven to have taken into account local and regional research in the citations.

Mixed methods framework

We utilize a multi-methods framework combining (a) a survey instrument with (b) focus groups. The two methods are complementary. The large-N survey[30], given statistically significant sample sizes and screening, sources aggregate and nationally representative preferences – but gives less sense of rationales and processes of reasoning that underpin preferences. Focus groups aim to map such rationales, with the in-depth treatment and detail that comes with deliberation, and with references to local or national contexts that can inform further situated (or locale and context-specific) assessment. The survey's design and results[30] examines both carbon removal and solar geoengineering approaches. The focus groups form the basis of two papers: this paper, and another on carbon removal[99].

Carbon removal

The run-time of each focus group was evenly split between discussion of solar geoengineering and carbon removal approaches. These two suites of

approaches have historically been grouped together under the umbrella concept of (climate) geoengineering, or increasingly, climate interventions. Debate on whether solar geoengineering and carbon removal should be separately (representing different socio-technical characteristics and governance demands) or comparatively assessed (for synergies and trade-offs in the context of wider climate action) remains inconclusive. This paper focuses on solar geoengineering, while a twinned paper on carbon removal has been recently published[99].

Urban versus rural

Due to a need to refine the focus of this paper, we chose not to undertake a deep investigation of the differences between perspectives of urban versus rural groups cutting across approaches and countries. A separate paper that examines these dimensions is in preparation.

Country selection

We conducted 44 focus groups (1 urban, 1 rural) in 22 countries: the United States of America, the United Kingdom, Australia, Germany, Austria, Switzerland, Italy, Poland, Norway, Sweden, Spain, South Africa, India, Chile, Brazil, China, Turkey, Saudi Arabia, Indonesia, Kenya, Nigeria, and the Dominican Republic. We aimed at a split between countries in the global North and global South, geographic spread across UN/continental regions, and inclusion of regional powers. A prior stage deployed a survey instrument in 30 countries was deployed in a prior stage. These included all 22 countries assessed in this study, as well as Canada, France, the Netherlands, Norway, Estonia, Greece, Denmark, Singapore, and Japan[30]. Constrained resources led the reduction of countries from the survey to the focus groups; the countries removed are all in the global North, in keeping with our desire to expand the geographic scope of assessment to the global South.

Participation and recruitment

In total, 323 participants were part of the focus groups. Recruitment aimed at 8 participants per focus group, and achieved at least 5 per group despite technical difficulties and dropouts. Norstat, a European-based data collection company (https://norstatgroup.com/), conducted the recruitment of participants in collaboration with the authors.

Prospective participants were screened via an online survey for several mandatory criteria. These criteria were defined in collaboration between the authors and Norstat. Prospective participants displaying an overt degree of climate denialism were screened out – defined by answering "No" to "Do you believe climate change is happening?". Focus groups were further screened for an even split between female and male genders, and between 18 and 44 year-old and above 45 year-old cohorts. For division into urban (including suburban) and rural focus groups, participants were screened through self-definition, by responding "Urban", "Suburban", or "Rural" to the question: "How would you describe the area in which you live?".

Two further soft screens (guiding but not mandatory) were held. The first was for distribution across education level, income, and occupation type, each tailored by country. The second was for distribution across within-country regions within, in most cases defined by formal (e.g., federal) administrative regions. A smaller number of countries (USA, India, Brazil, Indonesia) with a high number of administrative regions were defined by broad geographic regions.

Materials and languages

Two sets of materials were developed by the authors in collaboration with Norstat. The first was a discussion guide of questions and instructions for moderators. The second was a set of information materials on solar geoengineering (and carbon removal) approaches that were distributed to participants beforehand. Materials were written originally in English and communicated in that language with focus groups in US, UK, Kenya, Nigeria, South Africa, Australia, and India. Materials were also translated by Norstat personnel into: German (Germany, Austria, Switzerland); Italian (Italy); Polish (Poland); Norwegian (Norway); Swedish (Sweden); Spanish (Spain, Chile, Dominican Republic); Portuguese (Brazil); Mandarin Chinese (China); Turkish (Turkey); Arabic (Saudi Arabia), and Bahasa Indonesia (Indonesia). To ensure quality, academic colleagues in climate and energy governance known to the authors translated key technical terms from English into their native languages, for use by Norstat translators.

Discussion guide

The discussion guide consisted of the following groupings of questions. The guiding logic was to focus conversation on actors, actions, and agendas at the most tangible scale possible.

The first grouping of questions was based on prospective benefits: What are the benefits from any of these approaches? Who might gain the most from these benefits, and why? If these were implemented in your community or country, who would be affected positively – and how and why?

The second grouping of questions was based on prospective risks: What are the risks from any of these approaches? Who might be most negatively impacted from these risks, and why? If these were implemented in your community or country, who would be affected negatively – and how and why?

The third grouping of questions was based on governance responding to prospective benefits and risks: In an ideal world who are the most important people that should help make decisions on this approach – in your community, or your country, or even the world? What actions should be taken before there is consideration to implement this approach – what would you like to see done? How would you want yourself, and the wider public, to be involved in making decisions on these approaches?

A concluding 'headlines exercise' as a creative mini-scenario exercise was held: Participants were asked to create a (newspaper) headline in 2030, with four elements: an approach, an actor, and an event, in sum representing a good or bad outcome related to the approach (a headline that makes the participant feel hopeful or worried).

Informational materials on approaches

Information materials were sent to participants a week prior to the conduct of the focus group. Participants were encouraged to do further research, and to discuss with members of their community[100]. This step was taken to account for the limited discussion time, the lack of feedback and deliberation with technical experts, and a lack of directly lived experience with regard to these approaches.

The information materials consisted of the following elements. There was one introductory page each for carbon removal and solar geoengineering separately, with short points on overarching technical characteristics. Each approach was then accompanied by a column of approach-specific text, taking up one-third to half a page each. Each column contained: a brief technical description; a picture deliberately stylized to avoid reification; a short list of infrastructural needs; and one to two technical pros and cons that were abbreviated to forestall as much framing as possible.

Meeting logistics

The majority of meetings were conducted online, via Zoom (version 5.17.7 (31859)), which we selected for ease of logistics, costs, recording, and transcription. Meetings in Dominican Republic, Nigeria, Kenya, South Africa, and the rural group for India were held in person or in hybrid format. Meetings were moderated by Norstat personnel, in the same language as the translated materials. All focus groups ran from 2 to 2.5 h. The carbon removal and solar geoengineering suites each received half the allotted time. Half of the focus groups began by discussing carbon removal, and the other half with solar geoengineering – the division was made at random by Norstat. We recognize that the time allotted was limited in comparison to other deliberative exercises, which we defend as necessary given our financial resources and the inclination of our research design towards greater geographic coverage, particularly in the global South.

Transcription
Online groups were recorded via Zoom. Various other recording mediums were used for hybrid and in-person groups. Norstat transcribed all deliberations. Transcribers and the authors undertook multiple rounds of clarification to ensure accuracy and quality.

Coding and analysis
The authors conducted a two-part analysis. The first part used qualitative data analysis software MaxQDA (Standard 2022, Release 22.8.0, (c) 1995–2022 VERBI GmbH Berlin) to code themes across focus groups and countries. The coders were Sean Low (SL) and Livia Fritz (LF). SL coded all urban groups and LF coded all rural groups, alongside frequent inter-coder reliability checks. Coding followed the questions of the discussion guide, cross-referencing solar geoengineering approaches with perspectives on: (a) Climate change causes and impacts; (b) Benefits and 'Winners'; (c) Risks and 'Losers'; (d) Governance; and Publics, with further coding emerging on (f) Contexts and analogies and (g) Technical uncertainties. The second part consisted of writing qualitative summaries on each focus group; then combining the urban and rural portions into country-by-country analyses. LF analyzed all rural groups; SL analyzed all urban groups. The key technical and societal issues presented in the results section are derived primarily from the thematic coding, supplemented by the country-by-country analyses when differences between countries or groupings of countries required further clarification.

Reporting summary
Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability
The dataset[101] generated for this study is available at https://doi.org/10.5281/zenodo.11184155.

Received: 17 January 2024; Accepted: 18 June 2024;
Published online: 27 June 2024

References
1. Buck, H. J. et al. Evaluating the efficacy and equity of environmental stopgap measures. *Nat. Sustain.* **3**, 499–504 (2020).
2. Táíwò, O. O. & Talati, S. Who are the engineers? Solar geoengineering research and justice. *Glob. Environ. Polit.* **22**, 12–18 (2020).
3. Biermann, F. et al. Solar geoengineering: the case for an international non-use agreement. *WIREs Clim. Change* **13**, e754 (2022).
4. Stephens, J. C., Kashwan, P., McLaren, D. & Surprise, K. Toward dangerous US unilateralism on solar geoengineering. *Environ. Polit.* **32**, 171–173 (2022).
5. Corner, A. & Pidgeon, N. Like artificial trees? The effect of framing by natural analogy on public perceptions of geoengineering. *Clim. Change* **130**, 425–438 (2015).
6. Merk, C., Pönitzsch, G., Kniebes, C., Rehdanz, K. & Schmidt, U. Exploring public perceptions of stratospheric sulfate injection. *Clim. Change* **130**, 299–312 (2015).
7. Visschers, V. H. M., Shi, J., Siegrist, M. & Arvai, J. Beliefs and values explain international differences in perception of solar radiation management: insights from a cross-country survey. *Clim. Change* **142**, 531–544 (2017).
8. Braun, C., Merk, C., Pönitzsch, G., Rehdanz, K. & Schmidt, U. Public perception of climate engineering and carbon capture and storage in Germany: survey evidence. *Clim. Policy* **18**, 471–484 (2018).
9. Mahajan, A., Tingley, D. & Wagner, G. Fast, cheap, and imperfect? US public opinion about solar geoengineering. *Environ. Polit.* **28**, 523–543 (2019).
10. Raimi, K. T., Maki, A., Dana, D. & Vandenbergh, M. P. Framing of geoengineering affects support for climate change mitigation. *Environ. Commun.* **13**, 300–319 (2019).
11. Jobin, M. & Siegrist, M. Support for the deployment of climate engineering: a comparison of ten different technologies. *Risk Anal.* **40**, 1058–1078 (2020).
12. Hussain, A., Sipra, H. F. K., Waheed, A. & Ukhurebor, E. Exploring the academic perceptions of climate engineering in developing countries. *Atmósfera* **38**, 311–325 (2024).
13. Corner, A., Parkhill, K., Pidgeon, N. & Vaughan, N. E. Messing with nature? Exploring public perceptions of geoengineering in the UK. *Glob. Environ. Change* **23**, 938–947 (2013).
14. Macnaghten, P. & Szerszynski, B. Living the global social experiment: an analysis of public discourse on solar radiation management and its implications for governance. *Glob. Environ. Change* **23**, 465–474 (2013).
15. Pidgeon, N., Parkhill, K., Corner, A. & Vaughan, N. Deliberating stratospheric aerosols for climate geoengineering and the SPICE project. *Nat. Clim. Change* **3**, 451–457 (2013).
16. Bellamy, R., Lezaun, J. & Palmer, J. Public perceptions of geoengineering research governance: an experimental deliberative approach. *Glob. Environ. Change* **45**, 194–202 (2017).
17. Asayama, S., Sugiyama, M. & Ishii, A. Ambivalent climate of opinions: tensions and dilemmas in understanding geoengineering experimentation. *Geoforum* **80**, 82–92 (2017).
18. Merk, C. et al. Public perceptions of climate engineering: Laypersons' acceptance at different levels of knowledge and intensities of deliberation. *GAIA - Ecol. Perspect. Sci. Soc.* **28**, 348–355 (2019).
19. Carlisle, D. P., Feetham, P. M., Wright, M. J. & Teagle, D. A. H. The public remain uninformed and wary of climate engineering. *Clim. Change* **160**, 303–322 (2020).
20. Bellamy, R. & Healey, P. 'Slippery slope' or 'uphill struggle'? Broadening out expert scenarios of climate engineering research and development. *Environ. Sci. Policy* **83**, 1–10 (2018).
21. McLaren, D. P. & Corry, O. Clash of geofutures and the remaking of planetary order: faultlines underlying conflicts over geoengineering governance. *Glob. Policy* 12, 20–33 (2021)
22. Carvalho, A. & Riquito, M. 'It's just a Band-Aid!': public engagement with geoengineering and the politics of the climate crisis. *Public Underst. Sci.* **31**, 903–920 (2022).
23. Bellamy, R. & Lezaun, J. Crafting a public for geoengineering. *Public Underst. Sci.* **26**, 402–417 (2017).
24. Winickoff, D., Flegal, J. & Asrat, A. Engaging the Global South on climate engineering research. *Nat. Clim. Change* **5**, 627–634 (2015).
25. Rahman, A. A., Artaxo, P., Asrat, A. & Parker, A. Developing countries must lead on solar geoengineering research. *Nature* **556**, 22–24 (2018).
26. Biermann, F. & Möller, I. Rich man's solution? Climate engineering discourses and the marginalization of the global south. *Int. Environ. Agreem.* **19**, 151–167 (2019).
27. Delina, L. L. Potentials and critiques of building a Southeast Asian interdisciplinary knowledge community on critical geoengineering studies. *Clim. Change* **163**, 973–987 (2020).
28. Carr, W. A. & Yung, L. Perceptions of climate engineering in the South Pacific, Sub-Saharan Africa, and North American Arctic. *Clim. Change* **147**, 119–132 (2018).
29. Sugiyama, M., Asayama, S. & Kosugi, T. The North–South divide on public perceptions of stratospheric aerosol geoengineering? A survey in six Asia-Pacific Countries. *Environ. Commun.* **14**, 641–656 (2020).
30. Baum, C. M., Fritz, L., Low, S. & Sovacool, B. K. Public perceptions of climate intervention technologies across the Global North and South. *Nat. Commun.* **15**, 2060 (2024).

31. Wibeck, V. et al. Making sense of climate engineering: a focus group study of lay publics in four countries. *Clim. Change* **145**, 1–14 (2017).
32. Fenn, J. et al. Identifying key-psychological factors influencing the acceptance of yet emerging technologies–A multi-method-approach to inform climate policy. *PLOS Clim.* **2**, e0000207 (2023).
33. Rosenthal, S., Irvine, P. J., Cummings, C. L. & Ho, S. S. Exposure to climate change information predicts public support for solar geoengineering in Singapore and the United States. *Sci. Rep.* **13**, 19874 (2023).
34. Bolsen, T., Palm, R. & Luke, R. E. Public response to solar geoengineering: how media frames about stratospheric aerosol injection affect opinions. *Clim. Change* **176**, 112 (2023).
35. Bolsen, T., Palm, R. & Kingsland, J. T. How negative frames can undermine public support for studying solar geoengineering in the US. *Front. Environ. Sci.***10**, 850514 (2022).
36. McLaren, D. P. Mitigation deterrence and the 'moral hazard' of solar radiation management. *Earth's Future* **4**, 596–602 (2016).
37. Lin, A. C. Does geoengineering present a moral hazard. *Ecol. Law Q.* **40**, 673–712, https://escholarship.org/uc/item/7th0d0pd (2013).
38. Merk, C., Pönitzsch, G. & Rehdanz, K. Knowledge about aerosol injection does not reduce individual mitigation efforts. *Environ. Res. Lett.* **11**, 054009 (2016).
39. Merk, C. & Wagner, G. Presenting balanced geoengineering information has little effect on mitigation engagement. *Clim. Change* **177**, 11 (2024).
40. Cherry, T. L., Kroll, S., McEvoy, D. M., Campoverde, D. & Moreno-Cruz, J. Climate cooperation in the shadow of solar geoengineering: an experimental investigation of the moral hazard conjecture. *Environ. Polit.* **32**, 362–370 (2023).
41. Wagner, G. & Zizzamia, D. Green moral hazards. *Ethics Policy Environ.* **25**, 264–280 (2022).
42. Gupta, A. et al. Anticipatory governance of solar geoengineering: conflicting visions of the future and their links to governance proposals. *Curr. Opin. Environ. Sustain.* **45**, 1–10 (2020).
43. Reynolds, J. L. *The governance of solar geoengineering: Managing climate change in the Anthropocene* https://doi.org/10.1017/9781316676790 (Cambridge University Press, 2019).
44. McLaren, D. P. & Corry, O. The politics and governance of research into solar geoengineering. *WIREs Clim. Change* **12**, e707 (2020).
45. Low, S., Baum, C. M. & Sovacool, B. K. Taking it outside: exploring social opposition to 21 early-stage experiments in radical climate interventions. *Energy Res. Soc. Sci.* **90**, 102594 (2022).
46. Lin, A. C. The missing pieces of geoengineering governance. *Minnesota Law Rev.* **100**, 2509–2576, https://scholarship.law.umn.edu/mlr/230 (2015).
47. Nicholson, S., Jinnah, S. & Gillespie, A. Solar radiation management: a proposal for immediate polycentric governance. *Clim. Policy* **18**, 322–334 (2018).
48. Stilgoe, J., Owen, R. & Macnaghten, P. Developing a framework for responsible innovation. *Res. Policy* **49**, 1568–1580 (2013).
49. Keith, D. *A Case for Climate Engineering*. (MIT Press, 2013).
50. Shepherd, J. et al. *Geoengineering the climate: science, governance and uncertainty*. (The Royal Society, 2009).
51. MacMartin, D. G. & Kravitz, B. Mission-driven research for stratospheric aerosol geoengineering. *Proc. Natl Acad. Sci.* **116**, 1089–1094 (2019).
52. National Academies of Sciences. *Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance*. https://doi.org/10.17226/25762 (National Academies of Sciences, 2021).
53. Wanser, K., Doherty, S. J., Hurrell, J. W. & Wong, A. Near-term climate risks and sunlight reflection modification: a roadmap approach for physical sciences research. *Clim. Change* **174**, 23 (2022).
54. Zhang, Y., MacMartin, D. G., Visioni, D. & Kravitz, B. How large is the design space for stratospheric aerosol geoengineering? *Earth Syst. Dyn.* **13**, 201–217 (2022).
55. Latham, J. et al. Marine cloud brightening. *Philos. Trans. R. Soc. A* **370**, 4217–4262 (2012).
56. Stjern, C. W. et al. Response to marine cloud brightening in a multi-model ensemble. *Atmos. Chem. Phys.* **18**, 621–634 (2018).
57. Diamond, M. S. et al. To assess marine cloud brightening's technical feasibility, we need to know what to study—and when to stop. *Proc. Natl Acad. Sci.* **119**, e2118379119 (2022).
58. Hirasawa, H., Hingmire, D., Singh, H., Rasch, P. J. & Mitra, P. Effect of regional marine cloud brightening interventions on climate tipping elements. *Geophys. Res. Lett.* **50**, e2023GL104314 (2023).
59. Baum, C. M., Low, S. & Sovacool, B. K. Between the sun and us: expert perceptions on the innovation, policy, and deep uncertainties of space-based solar geoengineering. *Renew. Sustain. Energy Rev.* **158**, 112179 (2022).
60. Matloff, G., Bangs, C., & Johnson, L. Mitigating global warming using space-based approaches. in *Harvesting space for a greener Earth*. (eds. Matloff, G., Bangs, & Johnson, L.) 173–184 (Springer New York, 2014).
61. International Monetary Fund. *World economic outlook* (International Monetary Fund, 2023).
62. Horton, J. B. & Keith, D. W. Solar geoengineering and obligations to the global poor. In *Climate justice and geoengineering: Ethics and policy in the atmospheric Anthropocene*. (ed. Preston, C. J.) 79–92 (Rowman & Littlefield, 2016).
63. Baum, C. M., Fritz, L., Low, S. & Sovacool, B. K. Like diamonds in the sky? Public perceptions, governance, and information framing of solar geoengineering activities in Mexico, the United Kingdom, and the United States. *Environ. Polit*. **33**, 868–895 (2024).
64. McDonald, J., McGee, J., Brent, K. & Burns, W. Governing geoengineering research for the Great Barrier Reef. *Clim. Policy* **19**, 801–811 (2019).
65. Sovacool, B. K., Baum, C. M., Low, S. & Fritz, L. Coral reefs, cloud forests and climate protection: Radical interventions for geoengineering and ecosystem restoration in Australia's Wet Tropics and Great Barrier Reef. *PLOS Clim.* **2**, e0000221 (2023).
66. Keith, D. W., Duren, R. & MacMartin, D. G. Field experiments on solar geoengineering: report of a workshop exploring a representative research portfolio. *Philos. Trans. R. Soc. A* **372**, 0175 (2014).
67. Sovacool, B. K., Baum, C. M. & Low, S. Climate protection or privilege? A whole systems justice milieu of twenty negative emissions and solar geoengineering technologies. *Polit. Geogr.* **97**, 102702 (2022).
68. Oksanen, A. A. Dimming the midnight sun? Implications of the Sámi Council's intervention against the SCoPEx project. *Front. Clim.* **5**, 994193 (2023).
69. Pinto, I., Jack, C., Lennard, C., Tilmes, S. & Odoulami, R. C. Africa's climate response to solar radiation management with stratospheric aerosol. *Geophys. Res. Lett.* **47**, e2019GL086047 (2020).
70. Abiodun, B. J. et al. Potential impacts of stratospheric aerosol injection on drought risk managements over major river basins in Africa. *Clim. Change* **169**, 31 (2021).
71. Carlson, C. J. et al. Solar geoengineering could redistribute malaria risk in developing countries. *Nat. Commun.* **13**, 2150 (2022).
72. Low, S. & Honegger, M. A precautionary assessment of systemic projections and promises from sunlight reflection and carbon removal modeling. *Risk Anal.* **42**, 1965–1979 (2022).
73. Sovacool, B. K., Baum, C. M. & Low, S. The next climate war? Statecraft, security, and weaponization in the geopolitics of a low-carbon future. *Energy Strat. Rev.* **45**, 101031 (2022).
74. McLaren, D. P. Governing emerging solar geoengineering: a role for risk-risk evaluation. *Georgetown J. Int. Affairs* **24**, 234–243 (2023).

75. Low, S., Baum, C. M. & Sovacool, B. K. Undone science in climate interventions: contrasting and contesting anticipatory assessments by expert networks. *Environ. Sci. Policy* **137**, 249–270 (2022).
76. Aldy, J. E. et al. Social science research to inform solar geoengineering. *Science* **374**, 815–818 (2021).
77. Cummings, C. L., Lin, S. H. & Trump, B. D. Public perceptions of climate geoengineering. *Clim. Res.* **73**, 247–246 (2017).
78. Victor, D. G. On the regulation of geoengineering. *Oxford Rev. Econ.Policy* **24**, 322–336 (2008).
79. Rabitz, F. Going rogue? Scenario for unilateral geoengineering. *Futures* **84**, 98–107 (2016).
80. Reynolds, J. L. & Wagner, G. Highly decentralized solar geoengineering. *Environ. Polit*. https://doi.org/10.1080/09644016.2019.1648169 (2019).
81. Parson, E. A. & Keith, D. W. End the deadlock on governance of geoengineering research. *Science* **339**, 1278–1279 (2013).
82. CBD, UNEP. Decision adopted by the Conference of the Parties to the Convention on Biological Diversity at its Eleventh Meeting: XI/20 climate-related geoengineering UNEP/CBD/COP/DEC/XI/20. https://go.nature.com/2w2M4Pe (2012).
83. CBD, UNEP. Decision adopted by the Conference of the Parties to the Convention on Biological Diversity: XIII/14 climate-related geoengineering CBD/COP/DEC/XIII/14. https://go.nature.com/2rdL6K0 (2016).
84. International Maritime Organization. *Resolution LP.4(8) on the Amendment to the London Protocol to Regulate the Placement of Matter for Ocean Fertilization and Other Marine Geoengineering Activities* LC 35/15 Annex 4 (International Maritime Organization, 2013).
85. International Maritime Organization. *Assessment Framework for Scientific Research Involving Ocean Fertilization*. LC 32/15 Annex 6, 2.2.2 (International Maritime Organization, 2010).
86. European Commission. *Joint Communication to the European Parliament and the Council. A New Outlook on the Climate and Security Nexus: Addressing the Impact of Climate Change and Environmental Degradation on Peace, Security and Defence*. JOIN (2023) 19 final (European Commission, 2023).
87. United Nations Educational, Scientific and Cultural Organization. *Report of the World Commission on the Ethics of Scientific Knowledge and Technology (COMEST) on the Ethics of Climate Engineering*. SHS/COMEST-13/2023/1 REV (United Nations Educational, Scientific and Cultural Organization, 2023).
88. United Nations Environment Programme. One atmosphere: an independent expert review on solar radiation modification research and deployment. https://wedocs.unep.org/handle/20.500.11822/41903 (2023).
89. Human Rights Council. *Impact of New Technologies for Climate Protection on the Enjoyment of Human Rights*. A/HRC/54/47 (Human Rights Council, 2023).
90. Horton, J. B. et al. Solar geoengineering and democracy. *Glob. Environ. Polit.* **18**, 5–24 (2018).
91. Stephens, J. C., Kashwan, P., McLaren, D. & Surprise, K. The dangers of mainstreaming solar geoengineering: a critique of the National Academies report. *Environ. Polit.* **32**, 157–166 (2023).
92. Asayama, S., Bellamy, R., Geden, O., Pearce, W. & Hulme, M. Why setting a climate deadline is dangerous. *Nat. Clim. Change* **9**, 570–572 (2019).
93. The Degrees Initiative. *Our workshops*. https://www.degrees.ngo/events/ (2024).
94. The Alliance for Just Deliberation on Solar geoengineering. *Glob. Engage. Program*. https://sgdeliberation.org/activities/projects/ (2024)
95. Lin, A. C. & Hourdequin, M. Further reflections on the National Academies report on solar geoengineering: a response to Stephens et al. *Environ. Polit.* **32**, 167–170 (2022).
96. Conca, K. Prospects for a multi-stakeholder dialogue on climate engineering. *Environ. Polit.* **28**, 417–440 (2019).
97. Moore, J. C. et al. Targeted geoengineering: local interventions with global implications. *Glob. Policy* **12**, 108–118 (2020).
98. Möller, I. Political perspectives on geoengineering: navigating problem definition and institutional fit. *Glob. Environ. Polit.* **20**, 57–82 (2020).
99. Low, S., Fritz, L., Baum, C. M. & Sovacool, B. K. Public perceptions on carbon removal from focus groups in 22 countries. *Nat. Commun.* **15**, 3453 (2024).
100. Cox, E., Spence, E. & Pidgeon, N. Public perceptions of carbon dioxide removal in the United States and the United Kingdom. *Nat. Clim. Change* **10**, 744–749 (2020).
101. Low, S., Sovacool, B., Fritz, L. & Baum, C. 951542-GENIE-ERC-2020-SyG SRM focus groups dataset. zenodo https://doi.org/10.5281/zenodo.11184155 (2024).

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the European Research Council (ERC) Grant Agreement No. 951542-GENIE-ERC-2020-SyG, "GeoEngineering and Negatlve Emissions pathways in Europe" (GENIE). The content of this deliverable does not reflect the official opinion of the European Union. Responsibility for the information and views expressed herein lies entirely with the author(s). The authors acknowledge the numerous colleagues who helped translate key terms into different languages for the information materials; Norstat personnel for organizing and moderating the focus groups; and D.P. McLaren and E. Cox for technical clarifications and comments on the interview questions and discussion guide.

Author contributions

S.L. designed the study, undertook data analysis and synthesis, wrote the first draft of the manuscript, and edited the manuscript to completion. L.F. designed the study, undertook data analysis and synthesis, and edited the manuscript to completion. C.M.B. designed the study, provided input for data analysis and synthesis, and edited the manuscript to completion. B.K.S. designed the study, and edited the manuscript to completion.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s43247-024-01518-0.

Correspondence and requests for materials should be addressed to Sean Low.

Peer review information *Communications Earth & Environment* thanks the anonymous reviewers for their contribution to the peer review of this work. Primary Handling Editors: Niheer Dasandi and Martina Grecequet. A peer review file is available.