Governing Emerging Solar Geoengineering: A Role for Risk-Risk Evaluation?

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Introduction

For most of human history, emerging technologies have faced little or no regulation, with the strongest guidance emerging from religious sources, shaping the development of technologies such as printing. Technology governance was shaped primarily by military and economic competition between imperial powers during and after the industrial revolution.[1] Only in the last century has there been a shared realization that new technologies might cause more harm than benefit. Even then, most efforts at governance and regulation have been reactive, with actions on climate risk being an obvious example.[2]

Recently, as the impacts of climate change have become more evident and harmful globally, and the scope for mitigation to reduce climate risk ebbs with depleting carbon budgets, there has been growing interest in 'solar geoengineering,' ways to reduce Earth temperatures by reflecting a small proportion of incoming sunlight.[3] However, such technologies may also introduce new, unanticipated risks to the climate system, international relations, and climate negotiations. As a result, most governments, publics,[4] and many scientists have so far resisted calls for research and development of solar geoengineering.[5] Both advocates and skeptics have suggested that the risks of solar geoengineering would be best assessed in the context of the threats from climate change, with some form of risk-risk analysis. This process consistently identifies and compares the risks of undertaking a particular intervention with those of not doing so.[6] Thus, I will discuss whether established approaches to risk management could provide a solid basis for risk-risk analysis regarding solar geoengineering.

Below, I consider two established but contrasting approaches to risk management. In each case, I describe the background of the approach, review its key features, and discuss briefly how it might be (or is being) extended to solar geoengineering. First, I outline the technocratic model of risk management, dominant in scientific and corporate spaces, which seeks to quantify impacts and probabilities and balance risks using technical and market tools, such as insurance. From this perspective, one would treat solar geoengineering as an emerging *climat*e technology and focus on the changing material climate risks involved. Then, I describe the securitized approach to risk management, which comes foremost in sovereign defense and international relations, oriented to defending against external threats. By contrast, in this mode of analysis, one would treat solar geoengineering as a *security* technology and examine possible political and material risks to determine whether to suppress or control the technology.

Ultimately, both approaches support using risk-risk analysis for different reasons, resulting in very different prescriptions. Here, I argue that neither has yet offered a sound foundation for a risk-risk analysis of solar geoengineering. Still, by studying the differences in these two approaches, we can better understand the challenges involved in meaningful risk-risk analysis for solar geoengineering. In particular, I conclude that undertaking such an analysis will require improved ways to address uncertainties through inclusive politics rather than leaving the issues to experts.

Domesticating Risk: The Technocratic Model

In the twentieth century, propelled by labor interests and growing public concern, most large economies adopted health, safety, and environmental regulations to mitigate risks, including those from new technologies; these rules were often accompanied by new regulatory institutions that implemented risk assessment techniques, which aimed to balance the risks and benefits of governance measures.[7] More recently, partially due to perceived regulatory overreach and industrial interests, risk displacement and other countervailing risks of regulation gained more attention, and techniques of risk trade-off analysis were promoted.[8]

Consequently, in this paradigm, risk management and trade-off analysis primarily focus on risks understood as quantifiable probabilities of particular impacts, measured using life expectancy or financial equivalents metrics, and draw on the well-established technique of cost-benefit analysis in economics.[9] Technocratic risk trade-off analysis thus relies on making risks quantifiable and fungible.[10] The technocratic paradigm also draws heavily on management methods from the financial industry, notably actuarial accounting, and insurance.[11]

In some polities, technocratic risk governance has extended to include the prospect of anticipatory governance of emerging technology, but regulators face a dilemma. In the early stages, when the technology is most malleable, its impacts and risks are uncertain. Once the risks are demonstrated, however, development and deployment pathways may already be locked in.[12] One possible response to this problem, adopted by the UN and EU, is the precautionary principle, which seeks to mitigate plausible but unproven environmental risks.[13] However, even in jurisdictions where precaution has been ratified, it is typically contested or only partially implemented.[14] Moreover, precaution involves a risk that beneficial technologies may be unnecessarily constrained for fears that might never materialize. On the other hand, regimes practicing precaution have tended to enable broader public engagement in the 'upstream' governance of technology, shaping research policies and directions on topics such as nanotechnology by reference to public values and visions.[15]

Reliance on expert-led risk assessment is sometimes defended because—based on past experience with nuclear power, for example—publics appear to overestimate the material risks involved in novel technologies.[16] Although public perceptions may exaggerate technical harms, they do reflect real experiences and legitimate concerns surrounding the potential mismanagement of risks by corporate and political interests.[17] They also reflect a sense that the risks generated by technological society (e.g., nuclear war) are now much greater than those arising from natural hazards (e.g., earthquakes).[18] In addition, in the contemporary world, risks from novel technologies are also potentially exacerbated by planetary interconnectedness. For example, the potential for harm from artificial intelligence (AI) is much greater in a world connected by the internet. Therefore, public fears of catastrophic impacts may be entirely plausible, even if technically improbable, and merit serious attention.[19] Increasingly, many also see catastrophic impacts as a plausible, if improbable, result of climate change caused by the continued use of fossil fuels. A better understanding of such extreme ‘tail risks’[20] is one reason some researchers advocate for consideration of ‘exceptional measures’ on climate change, such as solar geoengineering, even though these techniques would only mask some of the impacts of climate change, not eliminate all the risks.[21]

Assessing emerging technology risks within a risk-benefit or risk-risk framework would seem essential in this context, even for technologies mooted to alleviate otherwise catastrophic risks, including solar geoengineering. However, those recently advocating for a risk-risk appraisal of solar geoengineering appear to be doing so out of concern that the risks involved with the technology are exaggerated compared to climate change.[22] Such a view would seem to be supported by the findings of cognitive science on risk perception, which suggests that people tend to overestimate the impacts of acute and novel risks and generally underestimate those from more familiar and chronic risks, such as dispersed climate impacts.[23] Thus, within the technocratic paradigm of risk assessment, expert assessments of geoengineering have tended to question the value of the precautionary principle and constrain any role for public engagement.[24]

In addition, few assessments have explicitly adopted a risk-risk approach. A 2022 report for the Carnegie Climate Governance Initiative offers the most developed example of an attempt at risk-risk analysis.[25] However, this study was still preliminary, focusing on the utilitarian assessment of modeled projections of physical impacts, with disproportionately little attention to ethical and political risks. All technocratic assessments of solar geoengineering have acknowledged significant uncertainties, but these are often sidelined as unquantifiable or even dismissed based on ideological presuppositions. For example, the prospect that some countries or major corporations might reduce their commitments to emissions reductions if solar geoengineering is promised tends to be treated as unlikely.[26] By contrast, physical climate risks—such as termination shock from an abrupt halt of solar geoengineering or negative effects on monsoon weather from uneven deployment shifting the inter-tropical convergence zone—are noted in these assessments.

Moreover, the scenarios of solar geoengineering explored are almost universally well governed, based on modeling with an implied single global decision maker, and often intentionally optimized to minimize distributional side effects. While assessments based on these scenarios often emphasize potential climate benefits, including unquantifiable reductions in the probability of exceeding critical climate tipping points,[27] these benefits may not be practically deliverable for technical and political reasons.[28] Moreover, whatever benefits solar geoengineering can offer, it is technically incapable of removing all climate risk. Even its most ardent advocates acknowledge that it should not substitute for emissions reduction.[29]

Securitizing Risk: The Model of Sovereign Defense

Contrasting with the rationalist, probabilistic, fungibility-based technocratic approach, the security sector—attuned to dealing with threats from actors able to learn and adapt—

approaches risks with worst-case thinking, recognizing unpredictability and incommensurability.[30] Securitized approaches to risk are understood to be applied in cases where a threat creates an existential risk to a valued referent object, typically the nation-state.[31] Securitizing a risk takes the threat out of the domain of politics as usual and justifies exceptional measures to defend against it. Such security analysis often uses scenarios and wargames with competing actors, includes cascading, interacting, compounding, and systemic risks, and examines plausible (not only probable) pathways, in contrast to the technocratic approach.[32]

Many would argue that the risks of climate change are existential, or at least catastrophic, which has led various actors, including states, international organizations, and activists, to call for securitization.[33] Specifically, there is a growing security sector consensus that climate change is a threat multiplier that intensifies geopolitical and conflict risks.[34] However, while climate securitization has enhanced military attention to adaptation and resilience and caused some 'greening' of military spaces, there have not yet been exceptional national or international responses. Moreover, exceptional measures to counter global warming, like cyber-interventions to close polluting facilities, enforced migration, carbon rationing, or solar geoengineering, may create additional political and security risks. Once again, there is a logical argument for a risk-risk evaluation of such interventions.

Although the security implications of the *impacts* of climate change have received considerably more attention than those of *responses*, security scholars have begun looking at issues like the geopolitics of a shift to renewable energy, possible responses from fossil-producing and fossil-dependent countries, and potential conflicts over control of key mineral resources.[35] Concerning solar geoengineering, attention has begun shifting towards non-ideal deployments of the technology: undertaken in the interests of particular states or regions or even competitively between states seeking to maximize national interest, as opposed to cooperatively optimized geoengineering.[36]

Security experts are interested not only in the *climatic effects* of the aforementioned potential termination shock or the risk from hemispherically imbalanced solar geoengineering but also in the distribution of risks and relative advantages and disadvantages that might arise at a regional level.[37] Analysts also worry about threats of military conflict, including nuclear exchanges, triggered by the additional disruption to international relations generated by solar geoengineering. They recognize solar geoengineering as a hybrid security technology, a critical asset potentially destabilizing globally significant relations like those between the U.S. and China or India and Pakistan. They also see disinformation about the effects of geoengineering interventions spread by "enemy states" as inevitable, which will disrupt security.[38] Furthermore, extremist insurgent groups such as ISIS or Boko Haram are also foreseen as likely to use disinformation about climate impacts of geoengineering to recruit supporters or incite conflict, by, for instance, blaming droughts on 'climate weapons.'[39]

Based on such considerations, it is essential to understand the potential climatic benefits as well as the risks involved in both well-governed and non-ideal deployments of solar geoengineering, making an even stronger case for risk-risk analysis. Furthermore, the security perspective also suggests a need to approach such analysis armed with the understanding that policy has never rested purely on 'objective' scientific truth and that evidential and normative uncertainties should always be addressed.[40] However, this argument does not conclude that solar geoengineering itself should be securitized, as this would risk research and development being treated as a matter of national security, undertaken in secret with limited public involvement and scrutiny.

Lessons for Policy Making

The foregoing suggests that whether we treat it as a climate technology or a security technology, there are sound reasons to assess the risks of developing solar geoengineering and consider them in comparison with the dangers of not doing so. However, neither the technocratic nor securitized approaches to risk management address all the potential risks comprehensively and consistently; moreover, both approaches distance risk management from democratic politics: the technocratic by delegating to technical experts and markets, and the securitized by reserving authority to generals and presidents.

Furthermore, these distinctive risk analysis methods reveal distinct conceptions of risk: technocratic risks are probabilistic and predictable, while security risks are possibilistic and adaptive. As a result, we might expect a technocratic analysis to underestimate the countervailing risks of solar geoengineering in comparison to the residual risks of climate change that it might help abate. In contrast, a securitized analysis might well overestimate the countervailing risks and inappropriately preclude open scientific exploration of geoengineering.

These differences serve as a valuable reminder that risk is socially constructed both conceptually and materially: the technocratic and securitized models are distinctive social constructions. Individuals construct risks differently through cognitive and psychological processes, and groups and societies determine what constitutes risk and which measures can potentially mediate exposure and vulnerability to risks.[41] Thus, recognizing this feature is a precondition to policy, which requires being explicit about how 'risk' is constructed and which groups are involved. From a normative perspective, this suggests a need for an open political process rather than one dominated by any particular expert category. Recognizing the social construction of risk would also help policymakers stay alert to framing effects and risk distribution. Risk has different meanings to different groups, who will therefore have different appetites for risk: for elites and those with power and agency, risk is manageable or even valuable, but for precarious workers, risk is a threat and a problem to be avoided. Consequently, policymakers must be aware of their own positionality in this respect if policies are to be fair and just.

What else can be learned from this review of existing risk management approaches for how we might undertake a productive and fair risk-risk analysis of solar geoengineering? Here I suggest five critical lessons.

First, *definitions vary*, so we should carefully establish the task and parameters. The crux of the analysis should be to compare (a) the residual risks from climate change that might be abated by solar geoengineering—which is not all the risk that might arise from 'unmitigated climate change' nor even all that remains after anticipated emissions reduction—with (b) the additional risks arising from developing and deploying solar geoengineering, including the effects of any consequential reduction in mitigation action.[42] Including such rebound risks is critical in the case of failure or termination of geoengineering intervention.[43] Additionally, we should beware of framing the task in ways that imply that only solar geoengineering can further reduce climate risk: other valuable policy tools, each with their own potential co-benefits and countervailing risks, should also be incorporated into the analysis.

Second, there are *diverse pathways to risk*, so we should take a broad scope, including not only the direct material or physical risks associated with climatic factors but also the social or political risks. This focus should encompass both chronic risks, like sustained international tension and the rise of sea level, and acute risks, like the outbreak of war and extreme weather events. Moreover, the scope should encompass both the calculable risks, for which probabilities and impacts can be quantified and modeled, and the incalculable risks, such as international conflict or terrorist disinformation. Importantly, it is critical not to artificially subject risks to arbitrary quantification but rather to enable deliberative discussion and political judgment of their significance.

Third, *risks vary with the scenarios* envisaged, so we must use appropriate metrics and scenarios in a symmetric fashion: well-governed geoengineering scenarios should not be compared with failing mitigation.[44] Especially, extreme but unlikely tail risks of inadequate mitigation, such as tipping points, should be compared with the extreme tail risks of geoengineering, such as termination shock. Alternatively, suppose the scenario involves reflexive action to decrease the potential risks of geoengineering. In that case, it should be compared with scenarios in which the risks of elevated mitigation, ranging from failure to geopolitical conflict, are also reflexively addressed.[45] Also, this must include considering an appropriate diversity of scenarios, including non-ideal as well as optimized options.

Fourth, as *risks might be triggered or even locked in* at an early stage of development or research, our analysis should identify critical decision points and the associated risks and be iterated as often as necessary. In addition to deployment trials and actual deployments, key decision points should also include scaling up research into solar geoengineering and authorizing large-scale experimentation, as they could affect rebound risks as much as actual deployments.

Finally, *risks are unevenly distributed*, and their impacts are strongly conditioned by variegated vulnerability and exposure.[46] As a result, we should develop inclusive processes that expand the debate to encompass diverse cultural and epistemological viewpoints. Those whose health, security, or cultures are most threatened by climate change and geoengineering, such as indigenous peoples, impoverished communities, or even young people, should be particularly engaged in the discussion. Yet, we must also remember that participatory processes themselves can construct publics in misleading ways and take care to enable participants to help define the terms of participation.[47] More generally, in considering the distribution of risks and vulnerability, our assessment must be attentive to the fact that vulnerability is not simply a pre-existing natural state but something arising in environmental, social, and economic factors. Indeed, much vulnerability to climate impacts or conflict is sustained and reconstructed through the global extractive economy and how it distributes resources and dependencies. A complete risk-risk analysis would consider whether and how solar geoengineering might sustain or help dismantle those global power and economic relations.

Conclusions and Reflections

In the preceding section, I mapped out some ways in which a risk-risk assessment might be developed and refined. Finally, I want to note some outstanding challenges.

Both technocratic and securitized modes of risk management tend to *de*politicize, taking the issues away from democratic politics into the realms of experts. However, principles of justice seem to demand democratic and deliberative public involvement, especially where uncertainties pervade the decision space. New technologies might help address climate change, but we should recall that a lack of anticipatory governance was also a major contributor to the problem. The above suggestions imply a need to shift the issues arising from uncertainty and indeterminacy back into the political realm. Instead of generating a sweeping rejection of new technologies, precautionary measures might be employed to abate or avoid the identified risks. However, the institutions and mechanisms needed to conduct such risk management—for research as well as deployment—do not yet exist. Building them is an urgent task.

Re-politicizing the issues involved might also help with the second outstanding problem that a risk-risk analysis can too easily construe the problem as a false binary: “do solar geoengineering, or face these residual climate risks.” However, there might be “risk-superior” approaches that find alternative pathways in which the risk trade-off implicit in this binary does not arise, and climate, political, and conflict risks can be reduced simultaneously.[48] This essay is not the place to construct the possible risk-superior pathways which might be found in strategies of degrowth and resilience building or enhanced adaptation and localized cooling techniques, for example, that is the territory of inclusive political negotiation around climate change and global justice. Finding the optimal pathways for managing the fast-growing climate risks faced by societies worldwide will inevitably involve political trade-offs and the development of compromise policy packages, not just risk trade-offs.[49] Sound risk-risk analysis might inform such political decisions but cannot replace them.

[1]**Notes and References**

Malm, A. *Fossil Capital: the rise of steam power and the roots of global warming* (London: Verso, 2016).

[2] Beck, U. *Risk Society: towards a new modernity* (London: Sage, 1992).

[3] Solar geoengineering, also called solar radiation management or solar radiation modification (SRM) comprises a group of largely speculative interventions including stratospheric aerosol injection (SAI), marine cloud brightening (MCB) – both of which would reflect some incoming sunlight, and – working through a different mechanism that would allow more longwave radiation to escape to space - Cirrus Cloud Thinning (CCT). For more details see National Academy of Sciences *Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance* (Washington DC: National Academy of Sciences, 2021).

[4] The term publics is preferred to 'the public' as acknowledgement that there is not one universal and homogenous public, even within a given country.

[5] See https://www.solargeoeng.org/non-use-agreement/; Such as those made in National Research Council of the NAS, *Climate Intervention: Reflecting Sunlight to Cool Earth* (Washington DC: National Academy of Sciences 2015) and NAS, *Reflecting Sunlight.*

[6] E.g., Wagner, G., *Geoengineering the gamble* (Polity Press, 2021); Parson, E.A. "Geoengineering: Symmetric precaution," *Science* 374, no. 6569 (2021): 795-795; Sovacool, B.K., C.M. Baum and S. Low, "Risk–risk governance in a low-carbon future: Exploring institutional, technological, and behavioral tradeoffs in climate geoengineering pathways," *Risk Analysis* (2022): https://doi.org/10.1111/risa.13932; Risk is defined and understood differently in different settings. Here I am generally using it in the way it is understood by the IPCC: as a potential for harm to people or ecosystems: see Reisinger, A., M. Howden, C. Vera, et al., *The Concept of Risk in the IPCC Sixth Assessment Report*. (Geneva: Intergovernmental Panel on Climate Change, 2020). I am not presuming that a risk can always be quantified with respect to both impact and probability.

[7] Fisher, E., R.L. Mahajan, and C. Mitcham. Midstream modulation of technology: governance from within, *Bulletin of Science, Technology & Society* 26, no. 6 (2006): 485-496.

[8] Graham, J.D. & J.B. Wiener (eds), *Risk vs. Risk: Tradeoffs in Protecting Health and the Environment* (Cambridge MA: Harvard University Press, 1996).

[9] Fischhoff, B. "The realities of risk-cost-benefit analysis," *Science* 350, no. 6260 (2015).

[10] Groves describes the process as 'domesticating' risk, in an administrative social imaginary (Groves, C. *Care, Uncertainty and Intergenerational Ethics.* London: Palgrave Macmillan, 2014).

[11] This could be problematic given the incentives in the financial sector to displace and transfer risk in the interests of optimising the risk-return ratio, rather than controlling for some absolute level of acceptable risk, such as staying within the 1.5C temperature guardrail.

[12] Genus, A. and A. Stirling "Collingridge and the dilemma of control: Towards responsible and accountable innovation," *Research Policy* 47, no. 1 (2018): 61-69.

[13] The precautionary principle states that cost-effective action is justified to mitigate plausible but unproven serious risks to the environment and human health, even in the face of scientific uncertainty. It was codified in the Rio Principles agreed at the 1992 Earth Summit as guidance for states: "*Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." (see https://www.iau-hesd.net/sites/default/files/documents/rio_e.pdf)*; European Environment Agency (EEA), "Late lessons from early warnings: the precautionary principle 1896-2000," *Environmental issue report, No 22 (*Luxembourg: Office for Official Publications of the European Communities, 2001).

[14] See for example Victor, M. "Precaution or Protectionism?--The Precautionary Principle, Genetically Modified Organisms, and Allowing Unfounded Fear to Undermine Free Trade," *The Transnational Lawyer* 14, no 1. (2001): 295-321.

[15] Fisher et al., *Midstream modulation*; Pidgeon, N. and T. Rogers-Hayden, "Opening up nanotechnology dialogue with the publics: Risk communication or 'upstream engagement'?," *Health Risk & Society* 9, no. 2 (2007): 191-210.

[16] Slovic, P. *The Perception of Risk* (London: Earthscan, 2000).

[17] EEA, *Late lessons.*

[18] Beck, *Risk Society.*

[19] Leonard, M. *The Age of Unpeace: How Connectivity Causes Conflict* (London: Penguin, 2022).; Rockström, J., W. Steffen, K. Noone, Å. Persson, F. S. Chapin III, E. Lambin, et al. "Planetary boundaries: exploring the safe operating space for humanity," *Ecology and Society* 14, no. 2 (2009); Armstrong McKay, D.I., A. Staal, J. F. Abrams, R. Winkelmann, B. Sakschewski, S. Loriani, et al. "Exceeding 1.5C global warming could trigger multiple climate tipping points," *Science* 377, mo. 6611 (2022): 7950.

[20] The term 'tail risks' refers to those possible but unlikely risks at the extreme upper tail of a risk distribution. In the context of climate change this includes the possibility that rising temperatures or other incremental effects will push climate or earth systems past 'tipping points' into a new and effectively irreversible configuration (see Armstrong McKay et al *Exceeding 1.5C).*

[21] NAS, *Reflecting sunlight*; Wagner, *Geoengineering the gamble*. Advocates of solar geoengineering also highlight the procrastination in undertaking mitigation that has characterised the last 30 years of climate politics.

[22] See for example, Parson, *Symmetric precaution*; Felgenhauer, T., G. Bala, M. Borsuk, M. Brune, I. Camilloni, J. B. Wiener, et al. *Solar Radiation Modification: A Risk-Risk Analysis* (New York, NY: Carnegie Climate Governance Initiative, 2022).

[23] Slovic, *The Perception of Risk*; Such calls also implicitly indicate that past efforts to evaluate geoengineering such as those by the NAS, *Climate intervention,* or the Royal Society, *Geoengineering the climate: science, governance and uncertainty* (London: Royal Society, 2009) which generated cautious recommendations for further research, were either flawed, unheeded or now outdated.

[24] Royal Society, *Geoengineering the Climate*; NAS, *Climate Intervention*; Schafer, S., M. Lawrence, H. Stelzer, W. Born and S. Low (eds) *European Transdisciplinary Assessment of Climate Engineering (EuTRACE)* (Potsdam: IASS, 2015)

[25] Felgenhauer et al., *Solar Radiation Modification;* A detailed critique of Felgenhauer et al., *Solar Radiation Modification* would require more space than available here. As a preliminary effort it is helpful. As a guide for policy it has multiple shortcomings, not least its focus on rational, ideal scenarios of solar geoengineering deployment, counterposed with more politically realistic, non-ideal efforts at emissions mitigation.

[26] Such evaluations are typically based on work which suggests *individuals* would not reduce their commitment to emissions reduction, rather than considering incentives for corporations or countries.

[27] Tipping point refers to the possibility of a hard to reverse, or abrupt state-change in the climate system (see Armstrong McKay et al *Exceeding 1.5C).*

[28] McLaren, D. "Whose climate and whose ethics? Conceptions of justice in solar geoengineering modelling," *Energy Research & Social Science* 44, (2018): 209-221.

[29] The physical climate forcings from solar geoengineering do not match those from greenhouse gases (GHGs). A world in which solar geoengineering offsets the global temperature rise from elevated GHGs would be drier, warmer at the poles/cooler in the tropics and with different patterns and distributions of climate than one without either forcing.

[30] While the climate system may not adapt and react in such ways, both mitigation and solar geoengineering responses to climate change would be implemented by such actors.

[31] Buzan, B., O. Wæver and J. De Wilde, *Security: A new framework for analysis* (Boulder, CO: Lynne Rienner Publishers, 1998).

[32] Pescaroli, G. and D. Alexander, "Understanding Compound, Interconnected, Interacting, and Cascading Risks: A Holistic Framework," *Risk Analysis* 38, no. 11 (2018): 2245-57.; Renn, O., M. Laubichler, K. Lucas, W. Kröger, J. Schanze, R. W. Scholz, et al. "Systemic Risks from Different Perspectives," *Risk Analysis* 42, o. 9 (2022): 1902-1920.

[33] Various definitions of existential and catastrophic risk exist, but in general they include large-scale, high impact risks to human societies and civilization, not just risks of human extinction. See for example Avin, S., Wintle, B., Weitzdörfer, J., Ó'hÉigeartaigh, S., Sutherland, W., & Rees, M. "Classifying global catastrophic risks," *Futures* 102 (2018): 20-26.; and Huggel, C., L. M. Bouwer, S. Juhola, R. Mechler, V. Muccione, B. Orlove, et al. "The existential risk space of climate change," *Climatic Change* 174, no. 1 (2022): 1-8; McDonald, M. *Ecological Security: Climate Change and the Construction of Security.* (Cambridge: Cambridge University Press, 2021).

[34] Goodman, S. and P. Baudu, "Climate change as a 'threat multiplier': history, uses and future of the concept," *Centre for Climate and Security Briefer* 38, (Washington DC: January 2023)

[35] Mirumachi, N., A. Sawas and M. Workman, "Unveiling the security concerns of low carbon development: climate security analysis of the undesirable and unintended effects of mitigation and adaptation," *Climate and Development* 12, no. 2 (2020): 97-109.

[36] Tang, A. and L. Kemp, "A Fate Worse Than Warming? Stratospheric Aerosol Injection and Global Catastrophic Risk," *Frontiers in Climate* 3, (2021).

[37] Robock, A. "20 Reasons Why Geoengineering May Be a Bad Idea" *Bulletin of the Atomic Scientists*, 64, no. 2 (2008) 14–18. Even if solar geoengineering were on average globally beneficial, the regional distribution of risks such as drought and disease would alter, potentially leaving some regions more exposed or disadvantaged.

[38] Russian reports describing a US research program as directed at creating climate weapons were recently spread by media in India (see https://www.easternherald.com/2023/03/12/us-prepares-to-use-climate-weapons-against-russia/ and https://ria.ru/20230312/klimat-1856861090.html).

[39] Based on interviews analysed by the author.

[40] Groves, C. "Post-truth and anthropogenic climate change: Asking the right questions" *Wiley Interdisciplinary Reviews: Climate Change* (2019) e620.

[41] Krimsky, S. and D. Golding (eds), *Social Theories of Risk* (London: Praeger, 1992).

[42] This might seem obvious, but many calls for risk-risk risk assessment (such as Wagner, *Geoengineering the gamble*) talk of the alternative to geoengineering as 'unmitigated climate change'. In fact, it is likely that substantial action to mitigate climate change will occur, but it might well be inadequate to eliminate all climate risk: solar geoengineering interventions might then be deployed to abate some (but for technical reasons, not all) of that residual risk.

[43] Any failure to reduce emissions cannot be ignored even if its climatic effects might be counterbalanced by additional geoengineering, as – for example – there would still be sustained impacts on health from fossil fuel combustion; as well as increased climate impact in the event of premature termination of geoengineering.

[44] Clark, B. "How to Argue about Solar Geoengineering," *Journal of Applied Philosophy*, Online advance, https://doi.org/10.1111/japp.12643

[45] For example, Felgenhauer et al, *Solar Radiation Modification* treats the possibility of mitigating risks asymmetrically – identifying ways to make SRM less risky, but - within the selected scenarios - treating climate risks as fixed.

[46] McLaren, D. Whose climate and whose ethics?

[47] Chilvers, J. and M. Kearnes, "Remaking Participation in Science and Democracy" *Science, Technology, & Human Values* 45, no. 3 (2019): 347–380.

[48] Risk-superior pathways are highlighted as desirable by Graham and Wiener, *Risk vs Risk*; and found to be present in many asserted risk trade-off situations (see Hansen, S.F. M.K. von Krauss & J.A. Tickner (2008) The precautionary principle and risk-risk tradeoffs, *Journal of Risk Research*, 11:4 (2008) 423-464).

[49] Jebari, J., O.m.O. Táíwò, T.M. Andrews, V. Aquila, B. Beckage, M. Belaia, et al. “From moral hazard to risk-response feedback,” *Climate Risk Management* 33, (2021)