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ORIGINAL PAPER

Evoking equity as a rationale for solar geoengineering research? Scrutinizing emerging expert visions of equity

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Abstract This paper examines how notions of equity are being evoked by expert advocates of more research into solar geoengineering. We trace how specific understandings of equity figure centrally—although not always explicitly—in these expert visions. We find that understandings of equity in such "vanguard visions" are narrowly conceived as epistemic challenges, answerable by (more) scientific analysis. Major concerns about equity are treated as empirical matters, requiring scientific assessment of feasibility, risks, or "win–win" distributive outcomes and optimizations, with concurrent calls to delimit risk or reduce scientific uncertainties. We argue that such epistemic framings sidestep, inter alia, the inequality in resources available to diverse non-experts—including the "vulnerable" evoked in expert visions—to project their own equity perspectives onto imagined technological pathways of the future. These may include concerns relating to moral or historical responsibility and/or lack of agency in shaping the directions of innovation. We conclude that the performative power and political implications of specific expert visions of equity, evoked as a rationale to undertake solar geoengineering research, require continued scrutiny.

Keywords Climate governance · Equity · Solar geoengineering · Climate models · Speculative ethics · Climate engineering · United Nations Framework Convention on Climate Change · Paris agreement

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1 Introduction

> Taking principles of global distributive justice seriously entails a moral obligation to conduct research on solar geoengineering (Horton and Keith 2016: 80)

In the above quote, Horton and Keith make an explicit justice and equity argument for undertaking research on solar geoengineering. In such a view, *not* contemplating such research is tantamount to the rich abrogating their responsibilities to the global poor in dealing with the inequities of climate change. This article undertakes an in-depth exploration of this kind of claim-making and its implications. Such an analysis is particularly timely in the wake of the Paris Agreement and its aspirational goal to limit global warming to 1.5 °C above preindustrial levels, to be implemented to reflect equity and the principle of common but differentiated responsibilities and respective capabilities (CBDR-RC). A growing number of observers argue that this goal potentially opens the door to solar geoengineering in mainstream climate policy, including on equity grounds (Horton et al. 2016; Shepherd 2016; Farber 2015; Irvine et al. 2017, Craik and Burns 2016; Parker and Geden 2016; Preston 2016: xi). If so, as part of a Special Issue on Equity and 1.5 °C, we interrogate how notions of equity are being evoked by some experts in advocating for further research on solar geoengineering. Our analysis thus addresses a key research gap: how particular understandings of equity are constructed by, and embedded within, emerging expert visions as a way to legitimize further research into solar geoengineering.

Geoengineering is broadly understood as a set of ideas to intentionally intervene in, and alter, the climate at a global scale (Royal Society 2009: ix). These approaches are generally divided into two broad categories: carbon dioxide removal and solar geoengineering (Royal Society 2009). Solar geoengineering options aim to alter the energy balance of the Earth by, inter alia, reflecting incoming solar radiation (Parson et al. 2017). These currently remain largely in the realm of speculative technologies, with very little scientific research funded to date beyond indoor modeling studies, although some scientists have expressed interest—and acquired funding—to conduct small-scale outdoor experiments. Explicit policy demand for this supply of science is minimal, evinced also by its general absence in mainstream climate policy discussions.

In such a context, some expert advocates of research into solar geoengineering are justifying a call for more research into these technologies partly—though not exclusively—on equity grounds. The implications of this, and the potential for such expert views to become more widespread (or not) are thus important to examine. According to the standard Oxford dictionary meaning of the term, equity is "the quality of being fair and impartial" with its multiple synonyms including fair-mindedness, justice, fair play, and rightfulness. Clearly, all of these notions are subject to diverse interpretations, not least in the contested context of imagining, anticipating and governing uncertain climate futures. As such, our aim here is not to advance our own understanding of equity but rather to distill and examine notions of equity advanced by those advocating for solar geoengineering research.

This also allows us to consider how emerging expert understandings of equity resonate with, upend, or further legitimize broader trends in conceptualizing and operationalizing equity within the contested politics of multilateral climate governance writ large. As one of us has argued elsewhere, there is arguably a shift underway in practice within multilateral climate governance, particularly in the post-Paris era, from a focus on the diverging historical *responsibilities* component of the CBDR-RC equity principle to the *capabilities* component (or, rather more narrowly, to the *capacities* to take action) (Gupta and van

Asselt 2017). One potential implication is that equity debates become less about ambitious mitigation by those with the greatest historical responsibilities, and more about enhancing the capacities to take action of those with lower responsibilities. While a focus on building the capacities, including of the most vulnerable, is a legitimate and desirable element of equity, it is important to consider whether such a shift in focus could also amount to a blunting of the politically contested edge of equity, and whether it is also evident in the expert visions we explore here.

Our analysis focuses on a specific sub-group of experts: those advocating for more research on solar geoengineering, particularly in the USA. We rely on qualitative methods for our analysis, including participant observation, interviews and analysis of primary and secondary literature. We draw, inter alia, on participant observation of multiple solar geoengineering expert meetings over the last five years,[1] where expert visions of the future (and the role of equity therein) are presented and discussed, as well as publicly articulated positions of scientist-advocates of solar geoengineering research as contained in websites, position papers, advocacy efforts and media debates. We supplement this with an extensive review of the published scientific literature as another key source of evidence.

We proceed as follows: the next section identifies the conceptual lens we deploy, drawing on notions of "sociotechnical imaginaries" and "vanguard visions" to analyze emerging expert notions of equity in the context of novel and largely speculative technologies. Section 3 then identifies and analyzes key equity claims advanced by solar geoengineering research advocates. We should note here that while this may not constitute a very large group of individuals at this stage, we do assume the *potential* for outsized influence by members of the group in shaping context-specific research trajectories (particularly in the US), either because of the eminence associated with the sites wherein their visions are articulated (e.g., elite universities and/or eminent scientific publishing outlets) or because of the visibility and high-profile, including in the media, of the scientists themselves. In concluding, we consider the political implications of these emerging expert evocations of equity in justifying solar geoengineering research, and identify what gets left out of such visions as well.

2 Imagining solar geoengineering futures: vanguard visions and speculative ethics

Solar geoengineering is still confined largely to the realm of the imagination, yet climate futures that include it are ever more prominent in a burgeoning scientific literature. This proliferation notwithstanding, the imagined utopias (and dystopias) associated with solar geoengineering are not yet widely shared or institutionalized. As such, they do not yet constitute what Jasanoff and Kim term "sociotechnical imaginaries," i.e. "collectively

[1] Formal participant observation was conducted from 2014 to 2017 at the following meetings: Berkeley Workshop (Berkeley, CA, US, July 2014); Climate Engineering Conference (Berlin, Germany, August 2014); Workshop on the International Governance of Climate Engineering (Bellagio, Italy, October 2015); Meeting of the Academic Working Group of the Forum for Climate Engineering Assessment (Washington, DC, US, March 2016); Harvard University Solar Geoengineering Residency (Cambridge, MA, US, July 2016); Meeting of the Academic Working Group of the Forum for Climate Engineering Assessment (Tarrytown, NY, US, September 2016); Forum for Climate Engineering Assessment, Meeting on Emerging Technologies (Berkeley, CA, US, February 2017); Forum on US Solar Geoengineering Research (Washington, DC, US, March 2017); Geoengineering Research Governance Project: Workshop on Code of Conduct (Oxford, UK, June 2017); and Gordon Research Conference on Climate Engineering (Newry, ME, US, July 2017). Ten semi-structured interviews were conducted with climate experts over the same time period.

held, institutionally stabilized, and publicly performed visions of desirable futures" co-produced with advances in science and technology (Jasanoff and Kim 2009, Jasanoff 2015a, b: 6). Nevertheless, the emerging visions of smaller configurations of actors, such as expert advocates of solar geoengineering research, may have the potential to coalesce into more widely shared, collectively held imaginaries. Such visions may play a vital role in the development, assessment and governance of emerging technologies (see also Burri 2015: 233), making scrutiny of their content and prospects for institutionalization urgent and timely.

Our aim here is thus to scrutinize emerging expert visions through relying on the notion of "sociotechnical vanguards" advanced by Hilgartner (2015). Hilgartner understands this term to mean "relatively small collectives that formulate and act intentionally to realize particular sociotechnical visions of the future that have not yet come to be accepted by wider collectives" (Hilgartner 2015: 34). Following Hilgartner, we view emerging equity-related visions of a specific group of experts, viz. advocates of solar geoengineering research, as constituting such "vanguard visions." In deploying this notion, we do not aim to single out or identify specific individuals as belonging to this group, nor do we seek to draw rigid boundaries around it. Instead, we leave membership in this vanguard group to be ascertained *de facto* from those whose work and statements we include in our empirical analysis. In other words, we use the notion analytically rather than as a methodological tool, and deploy it here as a means to characterize as a "sociotechnical vanguard" any geoengineering researcher/expert who advocates, in his or her scientific or popular writings, media interventions or public talks, for further research into solar geoengineering, based upon identifiable contours of a vision of what an equitable future with (and without) solar geoengineering might mean.

In scrutinizing expert vanguard visions of equity, as they relate to largely speculative technologies and their role in imagined climate futures, our analysis also engages with an ongoing debate (among researchers of responsible research and innovation, and anticipatory governance) about the political implications of so-called "speculative ethics" (Nordmann 2007). According to Nordmann, the exercise of speculative ethics entails articulating ethical concerns about wholly speculative technologies manifesting in largely unknowable futures, with the danger that "an imagined future overwhelms the present" (2007, 32). Nordmann notes the inherent impossibility of anticipation as a way to know the future in anything more than a superficial sense, and hence the risk that (even) ethical *critique* of speculative technological futures may well serve to reify them (for further discussion and defense of this notion, see Stilgoe 2015: 39–41; for a critique, see Guston 2013; Selin 2014).

For our purposes, this debate draws attention to a well-established call within science and technology studies research, including on the sociology of expectations and sociotechnical imaginaries, to explore the political implications *in the present* of specific "fabrications of the future" (Jasanoff 2015a, b: 337) and the performative power in the present of expectations, ideas, promises and dreams about the future (Selin 2008; Borup et al. 2006; Beck and Mahony 2017; Wiertz 2016; Low 2017). Aligned with this, we interrogate here the specific content of one such set of speculative claims, those advanced by vanguards calling for more research into solar geoengineering on equity grounds. This allows us to discern the political implications of specific expert forms of engagement in "speculative ethics" in relation to potentially high stakes solar geoengineering research.

We turn next to our empirical analysis of the diverse equity-related rationales being advanced by advocates of solar geoengineering research.

3 Vanguards advocating for solar geoengineering research: evoking equity

In this section, we analyze how equity is being implicated in three sets of arguments advanced by sociotechnical vanguards advocating for more solar geoengineering research. The first is a call for more solar geoengineering research as *a means to shed light on the distributional outcomes* of envisioned futures with and without solar geoengineering. This includes a call to reduce uncertainties inherent in scientific models examining distributional outcomes of potential deployment of solar geoengineering. Accompanying such calls is a discernible shift in the content of science itself, from more extreme to more "realistic" modeled scenarios of deployment,[2] and from consideration of global to regional effects. The second equity-related rationale for more research is a call for *comparative risk–risk assessment*, underpinned by the claim that equity demands that potential risks and benefits of solar geoengineering be compared to the risks of climate change itself, especially to vulnerable populations. The third equity-related rationale for more solar geoengineering research is the evocation of the 1.5 °C aspirational goal of the Paris Agreement as *requiring* research on solar geoengineering, out of concern for the global poor and those most vulnerable to consequences of climate change. We address each in turn below.

3.1 Equity as distributional outcomes: winners and losers in solar geoengineered futures?

> You made a very strong claim that geoengineering is zero-sum. If true, I would oppose any further work on the technology. I responded that results from all climate models strongly suggest that this is not the case (David Keith, in Keith and Hulme 2013).

Climate modeling studies have become central to understanding posited future solar geoengineering effects and impacts (Kravitz et al. 2013), including distributional aspects and identification of "winners and losers" (Royal Society 2009: 51; Kravitz et al. 2014: 6). A major concern raised in debates about the advisability of moving forward with solar geoengineering research—and in technical studies—has been whether any potential deployment would "destabilize regional climates," exacerbating or (re-) producing climate-related inequities (Keith and Hulme 2013; Hulme 2014; Caldeira 2009; Hegerl and Solomon 2009; Irvine et al. 2010; Moreno-Cruz et al. 2012; Royal Society 2009; Scott 2012; Robock et al. 2008; Ricke et al. 2010; Klein 2014; Reynolds et al. 2016; Kravitz et al. 2014; Burns 2016). These debates have played out in the climate modeling community, with the focus of modeling efforts shifting and expanding over time from consideration of global to regional effects and from more extreme to more "realistic" modeled scenarios of deployment.

From the start, modeling and model results have been at the crux of taking proposed solar geoengineering techniques seriously. Current advocates of research claim to have been converted from skeptics to proponents after early modeling studies suggested that these techniques might be more effective and safer than initially assumed (Goodell 2010; Wiertz n.d; Stilgoe 2015; Biello 2010). While these early studies focused on the potential

[2] Here we refer to general circulation models, which constitute the vast majority of climate modeling studies on solar geoengineering to date (Irvine et al. 2017).

of solar geoengineering approaches to offset warming in an aggregate sense (i.e., compensating for changes in global mean temperature), more recent work has turned to questions of the *regional* impacts of potential deployment of solar geoengineering techniques (NAS 2015: 383).

The shift from a global to a regional focus has resulted, in part, from claims that even if solar geoengineering deployment could address climate change at the global scale, deployment could produce novel climate configurations at more localized scales, and potentially make things worse (especially regarding precipitation) for some regions of the world. This is because local discrepancies in radiative forcing as a result of deployment could lead to regional climate changes, and because the impact of solar geoengineering on precipitation and the hydrologic cycle is not well understood (NAS 2015).

Such concerns emanated, inter alia, from an inter-model comparison project established for geoengineering (the Geoengineering Model Intercomparison Project, or GeoMIP), which aimed to "understand the robust climate model responses to geoengineering" (Kravitz et al. 2015: 3380, referencing Kravitz et al. 2011). In addition to a predominantly global focus, early studies also tended to assume "extreme" scenarios, both of climate change itself and deployment (e.g., abrupt quadrupling of carbon dioxide emissions and aggressive solar "dimming") (for a critique of claims based on these studies, see Keith and Macmartin 2015). The "extreme scenarios" approach is seen by some scientists as vital to serving legitimate scientific ends, with those undertaking it noting that "simulations have repeatedly been shown to be a novel method of uncovering fundamental climate behavior" (Kravitz et al. 2015: 3380). However, some of these early studies also suggested quite negative regional implications of some scenarios of deployment and were interpreted as evidence for legitimate equity concerns. Findings included, for example, that solar geoengineering had "the potential to drive regional climates outside the envelope of greenhouse gas-induced warming, creating "novel" conditions" (Irvine et al. 2010: L18702); that solar geoengineering might weaken the Indian monsoon (Robock 2012); involve a large reduction in precipitation (Ferraro et al. 2014; Tilmes et al. 2013); or involve trade-offs in which there would inevitably be winners and losers (Ricke et al. 2010).

In response, some prominent advocates of solar geoengineering research now argue that these early studies are not acceptable evidence for making decisions about solar geoengineering research (particularly on the basis of equity concerns), because the scenarios they model are insufficiently realistic or policy-relevant (Keith and Macmartin 2015; Reynolds et al. 2016; Keith and Irvine 2016). This suggests some tension between intra-scientific standards of research (about the merits of modeling more extreme scenarios to explore fundamental climate dynamics versus more realistic scenarios to address imagined needs of decision-makers, especially regarding equity concerns).[3] Advocates of solar geoengineering research see the purpose of such research as supporting climate policy decisions and not to pursue "purely scientific goals" (Keith and Irvine 2016: 550).

In an implicit acknowledgement that scientific studies shape the windows of political opportunity in important ways, these vanguard research advocates thus critique the early "unrealistic" scientific studies as responsible for producing a trope of the likelihood of *inequitable* impacts in the solar geoengineering literature (Reynolds et al. 2016). As one scientist argued, "extreme scenarios," lead to "extrapolations about risks and about social impacts," which do not help us "study what the outcomes associated with a broader range of scenarios would be."[4] In any case, the legitimacy of pursuing (or not) solar

[3] Remote interview conducted with GeoMIP participant, 2017.

[4] Researcher quoted at Forum on US Solar Geoengineering Research, Washington, DC, US, March 2017.

geoengineering research on equity grounds has come to rest, partly, on the extent to which we can realistically know and predict the likely physical (distributive) outcomes of solar geoengineering deployment.

Going beyond physical *effects* on the climate system, advocates of solar geoengineering research also note the importance of assessing climate *impacts* from deployment of solar geoengineering.[5] Prominent researchers working on solar geoengineering have identified assessment of impacts, including (in-) equitable impacts, as central to understanding the consequences of proposed solar geoengineering techniques (Heyen et al. 2015; Irvine et al. 2017). In a detailed review of the state of impact modeling in solar geoengineering, Irvine and colleagues argue that “a thorough climate impacts assessment is needed to better evaluate *societally relevant consequences* of deploying solar geoengineering” (Irvine et al. 2017: 94, emphasis added). One scientist noted in an interview that a focus merely on climate effects such as “global average temperature and precipitation are fine, but they don’t help people in their daily lives.”[6] Even GeoMIP researchers note that future efforts will “encourage cooperation with […] impact assessment communities” (Kravitz et al. 2013: 13,103).

While scientists readily acknowledge that modeling results (whether relating to climate effects and/or impacts) are not the only way to decide whether solar geoengineering is advisable, and some note major issues with integrated assessment models for these purposes (see Heyen et al. 2015: 2, noting the “general limitations of simple assessment frameworks” for regional disparities), many advocates of research argue that the equity dimensions of solar geoengineering demand more policy-relevant research on likely effects and impacts. Thus, in sum, in these emerging epistemic visions of equity, the distributive outcomes of solar geoengineering deployment (in terms of both climate effects and impacts) come to the forefront.

What might be the implications of such a reading of equity? Anticipating “realistic” distributive outcomes from deployment of what still remain largely speculative technologies, and privileging epistemic authority in doing so, risks becoming, in our view, an exercise in speculative ethics. At the very least, such a consequentialist, outcome-oriented reading of equity must contend with the scientific uncertainties inherent in projecting anticipated future outcomes. As Szerszynski et al. (2013) point out, reliance on modeled projections of global or even regional outcomes linked to solar geoengineering deployment may overpromise on what science can deliver in complex domains, with attendant risks for the democratic governance of innovation.

The issue of the reliability of climate models as bolstering the case for more solar geoengineering research, including on grounds of equity, came to the fore in a published exchange between David Keith and Mike Hulme in 2013 in *The Guardian*, as follows:

> David Keith: I take solar geoengineering seriously because evidence from atmospheric physics, climate models, and observations strongly suggest that it could

[5] Climate *effects* (i.e. changes to the climate system, such precipitation patterns or sea level changes, etc.) are assessed via climate models, defined by the IPCC as “a numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties.” Climate *impacts* are examined using integrated assessment models, which are “a method of analysis that combines results and models from the physical, biological, *economic and social sciences,* and the interactions between these components in a consistent framework to evaluate the status and the consequences of environmental change and the policy responses to it” (IPCC 2007, emphasis added). Thus, climate impacts include integrated assessment of projected physical/biological changes to the climate systems *and* social and economic aspects as well.

[6] Remote interview conducted with GeoMIP scientist, 2017.

significantly reduce climate impacts to vulnerable people and ecosystems over the next half century.

Mike Hulme: […] the point here is how much faith we can place in climate models to discern these types of regional changes. As the recent report from the UN's Intergovernmental Panel on Climate Change has shown, at sub-continental scales state-of-the-art climate models do not robustly simulate the effects of greenhouse gas accumulation on climate. What you are claiming is that we can rely upon these same models to be able to ascertain accurately the additional effects of sulphur loading of the stratosphere. Frankly, I would not bet a dollar on such results, let alone the fate of millions.

This discussion implicates, for one, the role that reducing scientific uncertainties plays in realizing (or not) equitable outcomes from solar geoengineering. Uncertainty and/or ignorance have become, as Steve Rayner (2014) notes, key rhetorical devices in debates about (the need for) solar geoengineering research. As two prominent scientists put it, "The stakes are simply too high for us to think that ignorance is a good policy" (Caldeira and Keith 2010: 62). From this perspective, whether solar geoengineering is a viable climate policy option or not (which depends, in part, on its ability to produce equitable outcomes), is a matter that demands further research to reduce our ignorance. In contrast, opponents of research have argued that ignorance is unavoidable ("there are limits to human knowledge" (Hulme 2014: 112), and that remaining ignorant constitutes good policy. Regardless of whether or not ignorance constitutes good policy, if fundamental uncertainties about distributional aspects of solar geoengineered futures cannot be reduced through provision of more science (on this point, see also Sarewitz 2004; Funtowicz & Ravetz 1990), then the case for more research as key to furthering equity becomes more tenuous.

3.2 Delimiting risk: Realizing equity through risk–risk comparison?

It is our hope that scientific and technical research over the next decade focuses more closely on well-articulated variants of the key policy-relevant question: could [solar geoengineering' be designed and deployed in such a way that it could substantially and equitably reduce climate risks? (Keith and Irvine 2016: 549)

Early justifications for research on solar geoengineering tended to center on the need to be prepared for its use in the event of a potential climate emergency. Several studies have analyzed the prominence of this framing (Markusson et al. 2014; Bellamy et al. 2012; Nerlich and Jaspal 2012; Gardiner 2013; Cairns and Stirling 2014). More recently, however, "climate risk management" has become a prominent frame for evaluating the pros and cons of solar geoengineering research among technical experts and advocates of research, as well as by prominent science advisory bodies (NAS 2015: 2; Keith 2017; Horton and Keith 2016; Long 2016). A recent report of an event launching a research program on solar geoengineering at Harvard University in the US argues that the interest in solar geoengineering research is a result of "the underlying realities [Paul Crutzen] described: increasingly severe risks from projected climate change, continued uncertainty about the character and timing of these risks, and increased recognition that mitigation and adaptation may be inadequate to manage the risks" (Parson et al. 2017: 5).

Rather than embedding ideas about solar geoengineering in notions of planetary-scale management in the face of a global climate emergency, the risk management frame draws attention to whether and how solar geoengineering can reduce climate risks (generally meaning various climate impacts) for particular people in particular places. A commonly used diagram in solar geoengineering meetings depicts future scenarios of climate risk reduction in which solar geoengineering is posited as a potential approach to shave peak temperatures and associated impacts, in a so-called portfolio response to climate risk reduction (MacMartin 2017, Fig. 1: 40).

Thus, some advocates of solar geoengineering research argue that assessing the risks—or merits—of solar geoengineering needs to be a relative endeavor. Evaluating solar geoengineering risks and benefits without considering the broader context of climate risks is nonsensical, the argument goes, since the harms of climate change could shift the terrain of assessment in important ways: if a world without solar geoengineering means catastrophic impacts on ecosystems and humans, societies might be more willing to accept some potential negative side-effects of solar geoengineering. As two prominent advocates of research put it, "[…] when managing risk is the framework for evaluation, *ethical* considerations demand that [solar geoengineering] be taken seriously (in addition to mitigation and adaptation)" (Horton and Keith 2016: 89, emphasis added).

Vanguard advocates of this comparative risk approach are now also framing the need for research explicitly in terms of equity, arguing that a "key policy-relevant question" for scientific research is whether solar geoengineering might "substantially and *equitably* reduce climate risks" (Keith and Irvine 2016: 549, emphasis added) especially for those most vulnerable to climate change (Keith 2017). One publication making the case that concern for the global poor entails a moral obligation to pursue research suggests that the key questions about solar geoengineering from an equity perspective are whether solar geoengineering can reduce surface temperature at a rate faster than mitigation, in a way that will be comparatively cheaper than adaptation, and without raising significant distributional concerns (Horton and Keith 2016).

More recently, David Keith has argued that because various climate effects (i.e. sea level rise, changes in weather patterns) could be limited by solar geoengineering, and "[b]ecause these changes would have the most powerful impact on the world's most vulnerable people, who *lack the resources to move or adapt*, one can make a strong ethical case for research to explore the technology" (Keith 2017: 71, emphasis added). In focusing particular attention on anticipating the distribution of future risks of climate change itself, especially for the global poor, this comparative risk–risk framework implies that an assessment of the equity dimensions of solar geoengineering *depends upon* further research on the topic. According to this vision, more empirical research on the distributional implications of solar geoengineering is not only justified for the conduct of comparative risk–risk assessment, but morally required. Furthermore, in such an approach to "equitable" risk reduction, those most historically responsible for climate change are recast as risk managers for the global poor, aiding and building capacities of the vulnerable to deal with inequitable impacts of climate change.

In our view, the claim that solar geoengineering deployment would address equity concerns by potentially reducing physical climate risks for those most vulnerable to climate change *more optimally* than other strategies (mitigation and adaptation) is another example of the exercise of speculative ethics, even as it sidesteps the value decisions implicit in such largely speculative (comparative) risk assessment (Winickoff et al. 2005).

As scholars of science and technology studies have long noted, decisions about the kinds of evidence seen as authoritative and choice of appropriate methodologies in processes of risk assessment are often as much political as technical (Jasanoff 2010; Gupta 2011; Dooley and Gupta 2017). If so, framing risk assessment as an epistemic matter can reify an assumed division of labor, where science is the institution most capable of steering technological emergence, and issues of broader governance are pushed downstream, with implications for who is empowered (or not) in shaping the terms of debate (Jasanoff 1999) and for the kinds of questions deemed relevant to ask (Sarewitz 2015). While many scientists are careful to acknowledge that political decisions about solar geoengineering are fundamentally a matter of value choices,[7] discussions of risk assessment and risk management often remain bifurcated.

In short, framing solar geoengineering and any attendant equity concerns as an epistemic issue of comparative risk analysis may (re)produce a perceived dichotomy between the production of scientific knowledge, on the one hand, and the resolution of broader political and normative debates, on the other. The viability of this separation has also been critiqued in public engagement exercises that suggest that the science and governance of solar geoengineering are often entangled (for a review, see Burns et al. 2016), and that—especially if justifications for responsible research rest on managing risks on behalf of the global poor—institutionalizing broader inclusion upstream is desirable.

3.3 Equity as a moral imperative to realize 1.5 °C: Does the end justify the means?

> Historical obligations to the global South include mitigating harms not just in the long term, but in the near future as well; this duty cannot be fulfilled by emissions reductions alone (Horton and Keith 2016: 89).

The Paris Agreement, with its commitment to limit global average temperature increase to “well below” 2 °C above preindustrial levels, and to undertake efforts to limit it to 1.5 °C, avoids any explicit discussion of solar geoengineering. Some scholars argue that the agreement includes “the building blocks” for an international approach to climate engineering governance (Craik and Burns 2016) or that Paris “facilitates the eventual inclusion of [solar geoengineering] in the post-Paris system” (Horton et al. 2016: 5). Despite the fact that climate negotiators were silent on solar geoengineering, some advocates of solar geoengineering research are now arguing that the Paris Agreement’s aspirational temperature goal may *require* solar geoengineering (Horton et al. 2016), since “solar geoengineering is probably the only known, plausible way to stay below 1.5 degrees of warming—if it could be made to work, that is” (Parker and Geden 2016: 860).

This position bolsters ongoing arguments by some advocates of research that, since societies will inevitably face some degree of inequitable climate risk even if emissions stopped tomorrow, solar geoengineering might be the only way to mitigate inequitable impacts arising from these risks. In this perspective, given inertial climate change, effectively and equitably addressing climate risk—especially for the global poor—requires taking solar geoengineering seriously, even more so in a post-Paris context. In light of such arguments, it is worth considering whether Paris aspirational goals may

[7] At a recent event aimed at US policymakers, a prominent advocate of solar geoengineering acknowledged that the major issues around solar geoengineering research are about politics and values (Forum on US Solar Geoengineering Research, Washington, DC, US, March 2017).

promote a new "tyranny of urgency" (Stilgoe 2015: 199). In this instance, the urgency is less related to the need for solar geoengineering as a "Plan B" in the face of a potential future climate emergency, given failing multilateralism (a now criticized earlier framing used to justify calls for more geoengineering research), but rather linked to the *success* of multilateralism, and the (unexpectedly high) ambition signaled by the Paris Agreement's aspirational temperature goals.

What becomes of equity, in light of this particular rendition of the tyranny of urgency? One emerging new framing is that, in the post-Paris context, *historical responsibilities* require consideration of solar geoengineering as an option, as per the quotation above. Given that small island states and developing nations were central in pushing for the aspirational 1.5 °C goal, at least one publication sees this as an implicit demand from such actors for solar geoengineering research (Horton et al. 2016). However, as Suarez and van Aalst point out recently "it should be noted that many of the actors proposing the 1.5° target in the Paris agreement (especially those representing the most vulnerable), did not aim to endorse a package that included [solar geoengineering], but rather just aimed for very aggressive mitigation pathways. If in the context of the Paris agreement the most vulnerable can now be implicitly invoked in arguments for geoengineering, then we must call for a much more explicit engagement of those groups and their priorities, as well as a clearer framing of the range of implications of the 1.5° target" (Suarez and van Aalst 2017: 191–192).

The overarching question in the context of an equity discussion then becomes: who will bear the burden of striving for 1.5 °C, what means of doing so become tenable, and on what grounds? Vanguard advocates of solar geoengineering research zero in on the question of the *feasibility* of meeting the temperature targets agreed to in Paris, as a—if not *the*—central concern among experts advocating for the inclusion of solar geoengineering as an option in an international climate policy toolkit. Yet this focus on technical feasibility sidelines, to some extent, concerns over equitable burden-sharing, particularly in light of the fact that the 1.5 °C goal is aspirational. Legal scholar Dan Bodansky points out, for example, that the 1.5 °C target "serves not only a regulatory function, but also expressive and advocacy functions," and "provides a potent rallying cry for activists and a basis to push states and other actors to take stronger action (Bodansky 2016: 303; see also Hubert and Reichwein, 2015). Yet, the key question remains for whom, and how, the 1.5 °C will serve as rallying cry and what the political implications are of portraying solar geoengineering as potentially one of the only "realistic" pathways to moving toward such aspirational goals.

4 Conclusion: equity in vanguard visions advocating for solar geoengineering research

We have analyzed here how equity is being conceptualized by a group of experts advocating for more research into solar geoengineering. Our analysis reveals a number of interrelated ways in which equity acquires meaning within such vanguard visions. First, we show how equity is being equated with the need to assess the potential *distributional outcomes* of solar geoengineering deployment, including "winners and losers." Related to this is an argument that reducing scientific uncertainties around these distributive outcomes is a crucial imperative, in order to harness the equity-related potential of such research. Second, we have shown that vanguards advocate for more solar engineering research in a comparative risk–risk frame, as a moral imperative owed to the vulnerable suffering from the inequitable impacts of broader climate risks. Third and finally, we analyze how the 1.5 °C aspirational temperature goal of the Paris Agreement has given further impetus to vanguard calls for solar geoengineering research on equity grounds, as a moral obligation to those most vulnerable to climate impacts.

It is worth considering what overarching take on equity, if any, these elements of a vanguard vision represent. Most broadly, they view equity as an empirical question, answerable by (more) scientific analysis. Major concerns about equity are treated as empirical matters, requiring scientific assessment of feasibility, risks, or possible "win–win" distributive outcomes and optimizations. This also entails delimiting risk and uncertainties, as well as particular readings of aspirational temperature targets pushed for by "vulnerable states," as requiring research on solar geoengineering. Broadly speaking, such a consequentialist take on equity mirrors what Stilgoe has characterized as a focus on "the products of innovation… [i.e.] the positive and negative *impacts* of technologies and the changes they enact upon societies and economies" (Stilgoe 2015: 32, emphasis added) in the field of emerging technologies writ large.

Yet, given the uncertainties and unknowabilities inherent in this imaginative enterprise, predicting the consequences of solar geoengineering deployment is only one—arguably impoverished—view of the equity dimensions of technological innovation. Other perspectives, such as the capabilities approach developed by Sen (2011) and Nussbaum (2011), and applied to other emerging technologies (Oosterlaken and van den Hoven 2012), or Fortun's "ethics of promising" (2005) may usefully draw our attention to alternative ways of taking responsibility for realizing equity in the context of technological change. This includes enabling greater accountability for the political ramifications of anticipating desired futures (see also Guston 2014; Stilgoe 2015).

In sum, the expert-driven, outcome-oriented, and risk-based understanding of equity examined here has a number of implications, not the least of which is whether and how such a vision is persuasive to the "vulnerable" on whose behalf vanguard experts claim to speak. This is especially the case if equity is understood as more than just a "fair" distribution of outcomes, but also more procedurally, as being about representative and inclusive knowledge production and decision-making. As others have also noted, "technoscientifically mediated activities" shape lives in ways that extend well beyond concerns of a distributive nature (Woodhouse and Sarewitz 2007: 140). Yet even in the distributive context, environmental decision-making is characterized by mediation between multiple and sometimes contradictory conceptions of fairness. This demands that the views of affected ("vulnerable") parties regarding the principles and criteria for fair processes and outcomes be explored upstream in the innovation process, and not to be a matter for a narrow set of privileged experts to delineate. As Sheila Jasanoff highlights, while a focus on vulnerability in the context of sociotechnical change is certainly legitimate and desired, it is problematic if the vulnerable, particularly in expert renditions, get cast as "passive agent(s) in the path of potentially disastrous events." Thus, if equity is to be equated with prioritizing delivery of benefits to the vulnerable, those characterized as such need to "regain their status as active subjects, rather than remain undifferentiated objects in yet another expert discourse" (Jasanoff 2003: 241).

Aligned with this, early evidence from a public engagement exercise relating to solar geoengineering with environmental practitioners in the Global South highlighted a broader set of concerns relating to equitable participation in debates around research and deployment of novel technologies (Winickoff et al. 2015). The analysis revealed that participants were persistently concerned that models were insufficiently credible to produce meaningful knowledge about the equity implications of solar geoengineering research and deployment, both because of a lack of trust in scientific endeavors in which they had little say, and a distrust in the credibility of models to say anything useful at temporal and spatial scales that were seen to be most pertinent to managing and reducing vulnerabilities. Participants also emphasized broader concerns around moral responsibility, historical global injustices, the ability to be included in, and benefit from, technological development, and concerns around lack of agency and self-determination in determining innovation pathways (Winickoff et al. 2015, see also Carr and Preston, forthcoming).

In short, as boundaries are drawn between what is and is not an equity concern, so, too, are boundaries drawn around who is authorized to speak with regard to the advisability and contours of solar geoengineering research (for a meta-analysis of whether and how voices from the global South are being heard in these debates, see also Biermann and Möller 2016). Our analysis in this paper thus highlights the need to pay attention to who, and what, gets excluded from expert discourses of equity in the context of solar geoengineering research.

Finally, we see as a point for further empirical analysis whether the vanguard visions of equity explored here reflect a broader shift in operationalizing equity now potentially discernible within multilateral climate politics, particularly in the post-Paris era of "self-differentiation." This is a deflection of attention away from debates around equity centered on "fair" burdens for ambitious mitigation based on differential historical responsibilities, to equity as akin to *building the capacities* of those most vulnerable to climate change. Implicit in the vanguard call for comparative risk–risk assessment, for example, is that ambitious mitigation, aligned with historical and current responsibilities, is imperative but *may not be forthcoming*, thus necessitating other fast-acting alternatives. If so, notions of historical responsibility take on a new avatar in these visions, with those bearing the greatest responsibility for climate change now recast as "risk managers" on behalf of the global poor and the vulnerable (see also McLaren 2016: 152 on the "framing out" of responsibility in climate engineering debates).

In concluding, we return to the notion we began our analysis with: that vanguard visions of equity analyzed here are still emerging and tentative, and are thus by no means guaranteed to crystallize into collectively held sociotechnical imaginaries, with the potential to shape future technological and policy trajectories. If so, the immediate question becomes whether and whose (speculative) visions will be taken up, ignored or reinterpreted, including within established institutional contexts such as the Intergovernmental Panel on Climate Change (IPCC) and its forthcoming reports and assessments, as well as the UNFCCC. The performative power and political implications of emerging (and alternative) visions thus merit continued attention.

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References

Beck, S., & Mahony, M. (2017). The IPCC and the politics of anticipation. *Nature Climate Change, 7*(5), 311–313.

Bellamy, R., Chilvers, J., Vaughan, N. E., & Lenton, T. M. (2012). A review of climate geoengineering appraisals. *Wiley Interdisciplinary Reviews: Climate Change, 3*(6), 597–615.

Biello, D. (2010). What is geoengineering and why is it considered a climate change solution? *Scientific American*. https://www.scientificamerican.com/article/geoengineering-and-climate-change/.

Biermann, F., & Möller, I. (2016). Rich man's solution? Climate engineering discourses and the marginalization of the global poor. Paper presented at the 2016 *Nairobi conference on earth system governance,* Nairobi, Kenya, 7–9 December (On file with authors).

Bodansky, D. (2016). The paris climate change agreement: A new hope? *The American Journal of International Law*, *110*(2), 288. doi:10.5305/amerjintelaw.110.2.0288.

Borup, M., Brown, N., Konrad, K., & Van Lente, H. (2006). The sociology of expectations in science and technology. *Technology Analysis & Strategic Management, 18*(3–4), 285–298.

Burns, W. C. G. (2016). Commentary: A response to "Five Solar Geoengineering Tropes That Have Outstayed Their Welcome." http://ceassessment.org/commentary-a-response-to-five-solar-geoengineering-tropes-that-have-outstayed-their-welcome-wil-burns/.

Burns, E. T., Flegal, J. A., Keith, D. W., Mahajan, A., Tingley, D., & Wagner, G. (2016). What do people think when they think about solar geoengineering? A review of empirical social science literature, and prospects for future research. *Earth's Future, 4*(11), 536–542.

Burri, R. V. (2015). Imaginaries of science and society: Framing nanotechnology governance in Germany and the United States. *Dreamscapes of modernity: Sociotechnical imaginaries and the fabrication of power*. Chicago: University of Chicago Press.

Cairns, R., & Stirling, A. (2014). "Maintaining planetary systems" or "concentrating global power?" High stakes in contending framings of climate geoengineering. *Global Environmental Change, 28,* 25–38.

Caldeira, K. (2009). Geoengineering to shade the Earth. In Worldwatch Institute (Ed.), *State of the World 2009: Into a warming world: A WorldWatch Institute report on progress toward a sustainable society* (Vol. 1). New York: W.W. Norton & Co.

Caldeira, K., & Keith, D. W. (2010). The need for climate engineering research. *Issues in Science and Technology, 27,* 57–62.

Carr, W. & Preston, C. J. (forthcoming). Skewed vulnerabilities and moral corruption in global perspectives on climate engineering. *Environmental Values.*

Craik, A. N., & Burns, W. C. G. (2016). *Special report: Climate engineering under the Paris Agreement: A legal and policy primer*. Center for International Governance Innovation. https://www.cigionline.org/sites/default/files/documents/GeoEngineering%20Primer%20-%20Special%20Report.pdf. Accessed 25 May 2017.

Dooley, K., & Gupta, A. (2017). Governing by expertise: The contested politics of (accounting for) land based mitigation in a new climate agreement. *International Environmental Agreements: Politics, Law and Economics, 17*(4), 483–500.

Farber, D. (2015). Does the Paris agreement open the door to geoengineering? *The Berkeley Blog*. http://blogs.berkeley.edu/2015/12/14/does-the-paris-agreement-open-the-door-to-geoengineering/. Accessed 25 May 2017.

Ferraro, A. J., Highwood, E. J., & Charlton-Perez, A. J. (2014). Weakened tropical circulation and reduced precipitation in response to geoengineering. *Environmental Research Letters, 9*(1), 014001.

Fortun, M. (2005). For an ethics of promising, or: A few kind words about James Watson. *New Genetics and Society, 24*(2), 157–174.

Funtowicz, S. O., & Ravetz, J. (1990). *Uncertainty and quality in science for policy*. Berlin: Springer.

Gardiner, S. M. (2013). Geoengineering and moral schizophrenia. In W. C. G. Burns & A. L. Strauss (Eds.), *Climate change geoengineering* (pp. 11–38). Cambridge: Cambridge University Press. http://ebooks.cambridge.org/ref/id/CBO9781139161824A009. Accessed 30 May 2017.

Goodell, J. (2010). *How to cool the planet: geoengineering and the audacious quest to fix earth's climate*. Boston: Houghton Mifflin Harcourt.

Gupta, A. (2011). An evolving science-society contract in India: The search for legitimacy in anticipatory risk governance. *Food Policy, 36*(6), 736–741.

Gupta, A. & Van Asselt, H. (2017). Transparency in multilateral climate politics: Furthering (or distracting from) accountability? *Regulation and Governance*. online first (http://onlinelibrary.wiley.com/doi/10.1111/rego.12159/abstract).

Guston, D. H. (2013). "Daddy, Can i have a puddle gator?": Creativity, anticipation, and responsible innovation. In R. Owen, J. Bessant, & M. Heintz (Eds.), *Responsible innovation* (pp. 109–118). Chichester, UK: John Wiley & Sons Ltd.

Guston, D. H. (2014). Understanding "anticipatory governance". *Social Studies of Science, 44*(2), 218–242.

Hegerl, G. C., & Solomon, S. (2009). Risks of climate engineering. *Science, 325*(5943), 955–956.

Heyen, D., Wiertz, T., & Irvine, P. J. (2015). Regional disparities in SRM impacts: The challenge of diverging preferences. *Climatic Change, 133*(4), 557–563.

Hilgartner, S. (2015). Capturing the imaginary: Vanguards, visions and the synthetic biology revolution. In *Science and democracy: Making knowledge and making power in the biosciences and beyond* (pp. 33–55). New York: Routledge, Taylor & Francis Group.

Horton, J., & Keith, D. W. (2016). Solar geoengineering and obligations to the global poor. In C. J. Preston (Ed.), *Climate justice and geoengineering: Ethics and policy in the atmospheric anthropocene* (pp. 79–92). London: Rowman & Littlefield International.

Horton, J. B., Keith, D. W., & Honegger, M. (2016). *Implications of the Paris Agreement for carbon dioxide removal and solar geoengineering* (Policy Brief). Harvard Project on Climate Agreements, Belfer Center.

Hubert, A.-M., & Reichwein, D. (2015). *IASS working paper, InSIS occasional paper: An exploration of a code of conduct for responsible scientific research involving geoengineering*. Potsdam, Oxford.

Hulme, M. (2014). *Can science fix climate change?: A case against climate engineering*. Cambridge: Polity Press.

IPCC. (2007). *AR4 Annex II: Glossary*. https://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_appendix.pdf.

Irvine, P. J., Kravitz, B., Lawrence, M. G., Gerten, D., Caminade, C., Gosling, S. N., et al. (2017). Towards a comprehensive climate impacts assessment of solar geoengineering. *Earth's Future, 5*(1), 93–106.

Irvine, P. J., Ridgwell, A., & Lunt, D. J. (2010). Assessing the regional disparities in geoengineering impacts. *Geophysical Research Letters*, *37*(18).

Jasanoff, S. (1999). The songlines of risk. *Environmental Values, 8*(2, Special Issue: Risk), 135–152.

Jasanoff, S. (2003). Technologies of humility: citizen participation in governing science. *Minerva*, *41*(3), 223–244.

Jasanoff, S. (2010). A new climate for society. *Theory, Culture & Society, 27*(2–3), 233–253.

Jasanoff, S. (2015a). Future imperfect: Science, technology, and the imaginations of modernity. *Dreamscapes of modernity: Sociotechnical imaginaries and the fabrication of power*. Chicago: University of Chicago Press.

Jasanoff, S. (2015b). Imagined and invented worlds. *Dreamscapes of modernity: Sociotechnical imaginaries and the fabrication of power* (pp. 321–339). Chicago: University of Chicago Press.

Jasanoff, S., & Kim, S.-H. (2009). Containing the atom: Sociotechnical imaginaries and nuclear power in the United States and South Korea. *Minerva, 47*(2), 119–146.

Keith, D. W. (2017). Toward a responsible solar geoengineering research program. *Issues in Science and Technology, XXXIII*(3), 71–77.

Keith, D., & Hulme, M. (2013). Climate science: can geoengineering save the world? *The Guardian*. https://www.theguardian.com/sustainable-business/blog/climate-science-geoengineering-save-world. Accessed 25 May 2017.

Keith, D. W., & Irvine, P. J. (2016). Solar geoengineering could substantially reduce climate risks—A research hypothesis for the next decade. *Earth's Future, 4*(11), 549–559.

Keith, D. W., & MacMartin, D. G. (2015). A temporary, moderate and responsive scenario for solar geoengineering. *Nature Climate Change, 5*(3), 201–206.

Klein, N. (2014). *This changes everything: capitalism vs. the climate* (First Simon & Schuster hardcover edition.). New York: Simon & Schuster.

Kravitz, B., MacMartin, D. G., Robock, A., Rasch, P. J., Ricke, K. L., Cole, J. N. S., et al. (2014). A multi-model assessment of regional climate disparities caused by solar geoengineering. *Environmental Research Letters, 9*(7), 074013.

Kravitz, B., Robock, A., Boucher, O., Schmidt, H., Taylor, K. E., Stenchikov, G., et al. (2011). The geoengineering model intercomparison project (GeoMIP). *Atmospheric Science Letters, 12*(2), 162–167.

Kravitz, B., Robock, A., Forster, P. M., Haywood, J. M., Lawrence, M. G., & Schmidt, H. (2013). An overview of the geoengineering model intercomparison project (GeoMIP): Geomip introduction. *Journal of Geophysical Research: Atmospheres, 118*(23), 13103–13107.

Kravitz, B., Robock, A., Tilmes, S., Boucher, O., English, J. M., Irvine, P. J., et al. (2015). The geoengineering model intercomparison project phase 6 (GeoMIP6): Simulation design and preliminary results. *Geoscientific Model Development, 8*(10), 3379–3392.

Long, J. C. S. (2016). Bringing Geoengineering in the mix of climate change tools. *Climate justice and geoengineering Ethics and policy in the atmospheric anthropocene*. London: Rowman & Littlefield International.

Low, S. (2017). The futures of climate engineering. *Earth's Future, 5*(1), 67–71.

MacMartin, D. G. (2017). Comments on Solar Geoengineering. In *Report: Forum on U.S. Solar Geoengineering Research* (pp. 39–40).

Markusson, N., Ginn, F., Singh Ghaleigh, N., & Scott, V. (2014). "In case of emergency press here": framing geoengineering as a response to dangerous climate change: Framing geoengineering as a response to dangerous climate change. *Wiley Interdisciplinary Reviews: Climate Change, 5*(2), 281–290.

McLaren, D. (2016). Framing out justice: The post-politics of climate engineering discourses. In C. J. Preston (Ed.), *Climate justice and geoengineering: Ethics and policy in the atmospheric anthropocene* (pp. 139–160). London: Rowman & Littlefield International.

Moreno-Cruz, J. B., Ricke, K. L., & Keith, D. W. (2012). A simple model to account for regional inequalities in the effectiveness of solar radiation management. *Climatic Change, 110*(3–4), 649–668.

National Academy of Sciences. (2015). *Climate intervention: Reflecting sunlight to cool earth*. Washington, D.C.: National Academies Press.

Nerlich, B., & Jaspal, R. (2012). Metaphors we die by? Geoengineering, metaphors, and the argument from catastrophe. *Metaphor and Symbol, 27*(2), 131–147.

Nordmann, A. (2007). If and then: A critique of speculative nanoethics. *NanoEthics, 1*(1), 31–46.

Nussbaum, M. C. (2011). *Creating capabilities: the human development approach*. Cambridge, MA: Belknap Press of Harvard University Press.

Oosterlaken, I., & van den Hoven, M. J. (2012). *The capability approach, technology and design*. Dordrecht: Springer.

Parker, A., & Geden, O. (2016). No fudging on geoengineering. *Nature Geoscience, 9*(12), 859–860.

Parson, E. A., Burns, L., Dykema, J., Irvine, P., Keith, D., & Wagner, G. (2017). Background paper: Forum on U.S. solar geoengineering research. In *Report: Forum on U.S. Solar Geoengineering Research* (pp. 3–14).

Preston, C. J. (Ed.). (2016). *Climate justice and geoengineering: Ethics and policy in the atmospheric anthropocene*. London: Rowman & Littlefield International.

Rayner, S. (2014). To know or not to know? A note on ignorance as a rhetorical resource in geoengineering debates. In *Climate Geoengineering Governance Working Paper Series, 010*.

Reynolds, J. L., Parker, A., & Irvine, P. (2016). Five solar geoengineering tropes that have outstayed their welcome: Five solar geoengineering tropes. *Earth's Future, 4*(12), 562–568.

Ricke, K. L., Morgan, M. G., & Allen, M. R. (2010). Regional climate response to solar-radiation management. *Nature Geoscience, 3*(8), 537–541. doi:10.1038/ngeo915.

Robock, A. (2012). Will geoengineering with solar radiation management ever be used? *Ethics, Policy and Environment*, *15*(2), 202–205. doi:10.1080/21550085.2012.685573.

Robock, A., Oman, L., & Stenchikov, G. L. (2008). Regional climate responses to geoengineering with tropical and Arctic SO_2 injections. *Journal of Geophysical Research, 113,* D16101.

Royal Society (Great Britain). (2009). *Geoengineering the climate: science, governance and uncertainty*. London: Royal Society.

Sarewitz, D. (2004). How science makes environmental controversies worse. *Environmental Science & Policy, 7*(5), 385–403.

Sarewitz, D. (2015). CRISPR: Science can't solve it. *Nature, 522*(7557), 413–414.

Scott, D. (2012). Geoengineering and environmental ethics | Learn science at scitable. *Nature Education Knowledge, 3*(10), 10.

Selin, C. (2008). The sociology of the future: Tracing stories of technology and time. *Sociology Compass, 2*(6), 1878–1895.

Selin, C. (2014). On not forgetting futures. *Journal of Responsible Innovation, 1*(1), 103–108.

Sen, A. K. (2011). *The idea of justice* (1. Harvard Univ. Press pbk. ed.). Cambridge, MA: Belknap Press of Harvard Univ. Press.

Shepherd, J. (2016). What does the Paris Agreement mean for geoengineering? | In Verba | Royal Society. *The Royal Society In Verba*. http://blogs.royalsociety.org/in-verba/2016/02/17/what-does-the-paris-agreement-mean-for-geoengineering/. Accessed 25 May 2017.

Stilgoe, J. (2015). *Experiment Earth: Responsible innovation in geoengineering*. Oxford: Routledge.

Suarez, P., & van Aalst, M. K. (2017). Geoengineering: A humanitarian concern. *Earth's Future, 5*(2), 183–195.

Szerszynski, B., Kearnes, M., Macnaghten, P., Owen, R., & Stilgoe, J. (2013). Why solar radiation management geoengineering and democracy won't mix. *Environment and Planning A, 45*(12), 2809–2816.

Tilmes, S., Fasullo, J., Lamarque, J.-F., Marsh, D. R., Mills, M., Alterskjaer, K., et al. (2013). The hydrological impact of geoengineering in the geoengineering model intercomparison project (GeoMIP): The hydrologic impact of geoengineering. *Journal of Geophysical Research: Atmospheres, 118*(19), 11036–11058.

Wiertz, T. (n.d.). *Virtual climates: solar radiation management between science and fiction*. http://ecpr.eu/Filestore/PaperProposal/b4507f53-f778-426e-8c33-e1d7b452981f.pdf. Accessed 15 Oct 2014.

Wiertz, T. (2016). Visions of climate control: Solar radiation management in climate simulations. *Science, Technology and Human Values, 41*(3), 438–460.

Winickoff, D. E., Flegal, J. A., & Asrat, A. (2015). Engaging the global south on climate engineering research. *Nature Climate Change, 5*(7), 627–634.

Winickoff, D., Jasanoff, S., Busch, L., & Grove-White, R. (2005). Adjudicating the GM food wars: science, risk, and democracy in world trade law. *Yale J. Int'l L., 30,* 81.

Woodhouse, E., & Sarewitz, D. (2007). Science policies for reducing societal inequities. *Science and Public Policy, 34*(2), 139–150.