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Linking solar geoengineering and emissions reductions: strategically resolving an international climate change policy dilemma

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ABSTRACT

Solar geoengineering appears able to reduce climate change risks but raises controversy, the leading cause of which is the concern that its research, development, and evaluation might inappropriately obstruct efforts to cut greenhouse gas emissions ('mitigation'). Describing how policies could effectively and feasibly manage such possible mitigation obstruction has proven elusive. One option would be to strategically link the international policies of mitigation and solar geoengineering. Here I explore this by disaggregating states based on their relevant characteristics. I propose linkages of mitigation policy with: (1) solar geoengineering research and development, (2) decision-making regarding whether to deploy solar geoengineering, and (3) how to deploy solar geoengineering. Based on the incentives that states would face under them, these linkages are assessed on whether they can be expected to effectively increase mitigation and are seem minimally feasible. Linkages in each of the three categories have potential and could occur sequentially. In the linkage which I believe has the greatest potential, one or more states would proclaim their right to deploy solar geoengineering if and only if they meet their own mitigation goals and the rest of the world insufficiently mitigates, and would promise to forego deployment if either condition is not met. I identify this proposed linkage's possible challenges, including legitimacy, credibility, optimal size, relations among targets of the linkage, stringency of mitigation goals, and potential counterproductivity. Limitations to this exploration and assessment include the speculative nature, the assumption that states' preferences regarding mitigation and solar geoengineering are properly related, and the use of noncooperative linkage.

Key policy insights

- Solar geoengineering could reduce the impacts of climate change but is controversial, in large part because of concerns that its research, development, or use might obstruct efforts to cut greenhouse gas emissions.
- I explore and assess whether linking international policies of greenhouse gas emissions reductions and solar geoengineering could feasibly and effectively increase emissions reductions.
- In the linkage that I believe has the greatest potential, one or more states would proclaim their right to deploy solar geoengineering if and only if they meet their emissions reductions goals and other countries do not.

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Introduction

The leading response to anthropogenic climate change has been reducing net greenhouse gas emissions, often called 'mitigation.' Mitigation efforts continue to be deeply inadequate after almost thirty years of internationally coordinated efforts. Plausible future mitigation is unlikely to keep global warming within the internationally agreed-upon 1.5–2 °C goal in the 2015 Paris Agreement (United Nations Environment Programme, 2020). Even if mitigation were aggressive, climate change and/or its impacts could be significantly greater than expected. Carbon dioxide removal (CDR; technically a component of mitigation; see Honegger et al., 2021) and adaptation are now clearly necessary complements to manage risks. Nevertheless, there are convincing reasons to expect that these actions may collectively fall short of preventing dangerous climate change and its impacts.

An additional set of potential responses is solar geoengineering (sometimes called solar radiation modification or management), a group of technologies that would cool the planet by blocking or reflecting a small portion of incoming sunlight (National Academies of Sciences, Engineering, and Medicine, 2021). The most studied method would mimic the natural cooling effect of large volcanic eruptions, whose ejected fine particles linger in the atmosphere and reflect some sunlight. Current evidence, mostly from models, indicates that a judicious use of stratospheric aerosol injection could effectively, rapidly, and reversibly reduce anthropogenic climate anomalies, would be global in effect, and would have low direct implementation costs (IPCC, 2021, Ch. 4 p. 83 to Ch. 4 p. 91; National Academies of Sciences, Engineering, and Medicine, 2021, p. 66; Smith, 2020). Also, its deployment seems technically feasible, in that no significant technical barriers have been identified, with particular attention given to custom high-altitude aircraft to deliver aerosols to the stratosphere (National Academies of Sciences, Engineering, and Medicine, 2021, pp. 66–67). Moreover, due to solar geoengineering's speed of action (Kravitz et al., 2013), it could manage climate change risks in the short term, which mitigation and adaptation could not. However, solar geoengineering would pose multiple serious physical risks and social challenges of its own, and its excessive or highly heterogenous use would cause severe negative environmental impacts.

Solar geoengineering is controversial for multiple reasons, among which are questions regarding sufficiently precise control of its deployment, potential international conflict, and doubts about social acceptability. The strongest, most widespread, and most influential concern is that its evaluation, research, and development would lessen mitigation, a possibility that is here called 'mitigation obstruction.' Despite a decade of serious discussion about solar geoengineering, there have been no proposals to limit mitigation obstruction that would, in my assessment, be effective and feasible. However, an approach that may have potential would be to link mitigation and solar geoengineering in international policy-making, as suggested by Albert Lin (2013) and Edward Parson (2014).

This paper expands on, explores, and assesses proposed strategic linkages of international mitigation and solar geoengineering policies. The next two sections provide background on mitigation obstruction and international issue linkage, respectively. The subsequent section justifies the approach, clarifies my assumptions, and systematically considers states' relevant characteristics. The next three sections describe others' and my proposals: linking mitigation policies with the *research and development* of solar geoengineering, with decision-making regarding *whether to deploy* solar geoengineering; and with that regarding *how to deploy*. These are assessed regarding whether they can be expected to decrease mitigation obstruction (that is, to increase mitigation relative to no linkage) and appear minimally feasible (that is, to be consistent with states' apparent interests to join, comply, and enforce as appropriate). The conclusion offers an overall assessment, some limitations of my approach, and lines of further inquiry.

Mitigation obstruction

The prospect that solar geoengineering's evaluation, research, and development would lessen mitigation is the strongest, most widespread, and most influential associated concern. Yet without mitigation, atmospheric greenhouse gas concentrations would rise, more solar geoengineering would be necessary, and its limitations, negative environmental impacts, and governance challenges would become increasingly severe. It is for this reason that most calls for expanded solar geoengineering research—including all major institutional assessments—recommend also more aggressive mitigation, often as the first plank (e.g. Crutzen, 2006; National Academies of Sciences, Engineering, and Medicine, 2021, p. 8).

An important early work by climate change researcher David Keith names the possible phenomenon 'moral hazard,' a persistent but inaccurate appropriation of a term from insurance economics (Keith, 2000, pp. 276–277). The mitigation obstruction concern had a demonstrable impact as early as the drafting of a 1992 US National Academies climate change report (Institute of Medicine et al., 1992, pp. 433–464; Schneider, 1996, p. 295). It was the primary basis for a taboo on discussing and researching solar geoengineering, resulting in the death of a 2001 proposal inside the US White House to support research (MacCracken, 2006, p. 239). Today, the mitigation obstruction concern remains a—if not *the*—leading reason that solar geoengineering is subordinate within climate change policy discussions (Lawrence & Crutzen, 2017).

As the taboo has weakened (Crutzen, 2006; Shepherd et al., 2009), mitigation obstruction has received increasingly detailed scholarly attention. However, there is no consensus on whether mitigation obstruction is likely, what processes could cause it, whether solar geoengineering plus possible mitigation obstruction would be a net negative, or which governance mechanisms, if any, could prevent or reduce it (Hale, 2012, p. 114).

Some scholars who have considered mitigation obstruction are worried but diverge on how it would arise and why it would be harmful. Lin states that mitigation obstruction is likely through a widespread inaccurate belief, compounded by common psychological biases, heuristics, and culturally mediated risk perception, among the public and policy-makers that solar geoengineering would provide sufficient protection against climate change. This would consequently undermine support for emissions-reducing policies and efforts which would, in Lin's eyes, be harmful because mitigation is inherently preferable to solar geoengineering (Lin, 2013, p. 678, 711). Christian Baatz's proposed mechanism is similar to Lin's, but with greater emphasis on specific influential political actors who—rightly or wrongly—would believe that they may mitigate less due to solar geoengineering's prospective or actual availability. This would increase the severity of solar geoengineering's sudden and sustained termination, which would have negative impacts (Baatz, 2016, p. 31, 33). Duncan McLaren asserts that decisions based on narrow objectives (such as minimizing global warming)—which integrated economic and climate models often use—would favour solar geoengineering at the expense of mitigation. Driven by problematic individual, societal, and political processes, he believes that this would prevent the achievement of broader objectives (such as 'climate justice') that mitigation could, at least in principle, fulfil (D. McLaren, 2016, p. 600). Finally, while Jeremy Baskin seems concerned that solar geoengineering's rise on the climate agenda could dilute mitigation efforts, to him, the discourse's emphasis on potential obstruction unduly elevates 'the methods, epistemologies and implicit values of mainstream neo-classical economics' at the expense of wider ethical and political issues (Baskin, 2019, pp. 177–178, 198–200).

Other scholars are relatively sanguine. An early contribution by Benjamin Hale asserts that the concern is too ambiguous to be effectively supported or rebutted (Hale, 2012, p. 114). Others variously note that, consistent with the evidence and theory of risk compensation, the negative impacts of modest mitigation obstruction could be outweighed by solar geoengineering's greater reduction of climate risks (Fabre & Wagner, 2020; Halstead, 2018; Lockley & Coffman, 2016; Morrow, 2014; J. Reynolds, 2015; Wagner & Merk, 2018; Weil, forthcoming). They sometimes also point to empirical evidence from public surveys and psychological experiments in which respondents, in response to solar geoengineering, consistently increase their resolve or willingness to pay to mitigate (summarized in J. L. Reynolds, 2019, pp. 37–40).

Describing how policies could manage obstruction effectively and feasibly has proven elusive. Bidisha Banerjee argues for 'a deliberative sequence with a protocol for recognizing when to stop turning to technological refinement to resolve a problem that ethical reasoning suggests should be resolved socially' (Banerjee, 2011, p. 35). Lin suggests that solar geoengineering research and development should be limited to the lower-risk techniques that have been endorsed by the international community; that scientists and others should emphasize solar geoengineering's risks and uncertainties; and that populations that are most vulnerable to solar geoengineering's negative impacts should have substantial decision-making roles (Lin, 2013, pp. 707–711). David Morrow more moderately recommends ensuring diverse research, careful communication, and proactive engagement with the public and decision-makers (Morrow, 2014, pp. 10–11). Echoing this as well as Banerjee, McLaren endorses others' proposals that solar geoengineering should be communicated and framed as no substitute for mitigation (D. McLaren, 2016, p. 600). John Halstead argues that a research programme that focuses, at least initially, on solar geoengineering's governance and security issues instead of its environmental effects would have a lesser risk of mitigation obstruction than one that focuses on its environmental effect (Halstead, 2018, pp. 73–75). I consider a moratorium on research beyond a certain scale and magnitude of intervention, but mostly reject it due to 'interrelated challenges of intertemporal credibility, legitimacy, and effectiveness' (J. L. Reynolds, 2019, p. 206).

However, though the above suggestions for managing mitigation obstruction may be able to help, they would likely have only limited impacts. Diverse research, careful communication that emphasizes mitigation's primacy and solar geoengineering's risks, and engagement with the public and decision-makers are all already being done, and with unclear effects on mitigation. There is a consensus that vulnerable populations should have central roles in making decisions that would have widespread impacts (Rahman et al., 2018), but such decision-making is not yet occurring except to modest degrees in intergovernmental forums, such as the Intergovernmental Panel on Climate Change, the UN Environment Assembly, and the Convention on Biological Diversity Conference of Parties, that have global participation. Research and development of only low-risk solar geoengineering techniques could still obstruct mitigation, if not more so than high-risk methods, because the low-risk ones might have more appeal. Banerjee's proposal for 'a deliberative sequence' remains unspecified beyond citizens' workshops and requirements that solar geoengineering research funders include deliberative stakeholder engagement, the latter of which is currently common, again with unclear effects. Research that is limited to governance and security issues could not be informed by knowledge of solar geoengineering's expected environmental effects, which is a prerequisite for effectively discussing governance and security issues. Independent of whether these suggestions would be effective, another possible means to manage mitigation obstruction would be to strategically link international policies of solar geoengineering and mitigation (Lin, 2013; Parson, 2014)—the subject of this paper.

There have been concerns that the evaluation, research, and development of adaptation and of CDR also might lessen mitigation. Like solar geoengineering, these are sets of proposed techniques that could limit climate change impacts without reducing gross greenhouse gas emissions. Regarding adaptation, such concerns were one reason that it was relegated to a second tier in early climate change scholarship, consultations, and policy (Kane & Shogren, 2000, p. 94). However, these concerns dissipated as climate-vulnerable countries pushed adaptation up agenda. Regarding CDR, concerns arose after modellers assumed the techniques at very large-scale in high-level scenarios of greenhouse gas concentrations that would be expected to keep global warming within the 2 °C goal (Fuss et al., 2014). One suggested means to reduce possible mitigation obstruction from CDR[1] would be to require separate accounting for gross and net emissions, and separate targets for emissions reduction and CDR (D. P. McLaren et al., 2019). Unlike the proposals related to solar geoengineering, this is potentially effective, in part because there are existing relevant institutional mechanisms for implementing it: countries' emissions reporting under the UN Framework Convention on Climate Change (UNFCCC) and their nationally determined contributions to 'achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases' under the Paris Agreement (Art. 4.1). In principle, separation could be applied to solar geoengineering as well. For example, only greater mitigation could contribute toward countries' requisite progressively higher ambition in their successive nationally determined contribution. One challenge is that, unlike CDR, solar geoengineering may not be within the scope of the UNFCCC and the Paris Agreement (J. L. Reynolds, 2019, pp. 92–96). Regardless, this warrants further exploration.

Issue linkage

Issue linkage is 'attempts to gain additional bargaining leverage by making one's own behaviour on a given issue contingent on others' actions toward other issues' (Axelrod & Keohane, 1985, p. 239). It is a cornerstone of negotiation, including in international domains (Aggarwal, 1998; Axelrod & Keohane, 1985; Haas, 1980; Maggi, 2016; Oye, 1993; Poast, 2012; Sebenius, 1983). It can increase the probability of a stable agreement, provide an enforcement mechanism, signal commitment, and/or expand or stabilize a coalition. Issue linkage can increase states' welfares, such as through mutually beneficial exchange; decrease welfares, perhaps through threats and coercion; or merely redistribute gains. Thus, it can be a welcome offer or an unwelcome threat. Importantly, in order to yield net gains, asymmetries or interdependencies among the issues are necessary (Maggi, 2016). Issue linkage can be informal or formal, private or public, and implicit or explicit. It is similar to—but not synonymous with—side payments: while a mutually beneficial linkage is a side payment, a coercive one (discussed below) is not, and a cash side payment is not issue linkage. There is modest empirical evidence that issue linkage can be effective (Hafner-Burton, 2005; Leeds & Savun, 2007; Poast, 2012), although this research faces methodological difficulties.

It is not self-evident which issues can and should be linked. They can be related substantively or only tactically by the linking party.[2] The distinction is not clear, as parties can disagree on whether the issues are related substantively—a situation called fragmented or failed substantive linkage (Aggarwal, 1998, pp. 16–17; Haas, 1980)—or even already constitute a single issue. Furthermore, parties' perceptions can change as new information is revealed and their interests change. Care must be exercised, as even seemingly successful issue linkage can unduly complicate discussions and agreements, and attempts at unwanted linkage can poison negotiations. Issue linkage in which some parties—the 'linkers'—unilaterally attempt to force linkage on others—the 'targets'—is of particular interest in this paper. Variously called blackmailing, extortion, or coercion, (Axelrod & Keohane, 1985, pp. 240–241; Maggi, 2016, pp. 557–560; Oye, 1993, pp. 40–43), such noncooperative issue linkage is often (although not always) threats of punishment.[3] This is evident in, for example, trade sanctions for human rights violations.

Issues have been linked in the environmental issue area (a recognized cluster of interdependent issues, per Haas, 1980). For example, the states that were vulnerable to stratospheric ozone depletion offered financial assistance and the transfer of alternative technologies to the less vulnerable ones and threatened modest trade restrictions, all enshrined in the Montreal Protocol (Benedick, 1998; Parson, 2003).

There has been only a small degree of international issue linkage in order to increase mitigation (see Jinnah, 2011). In the UNFCCC, developing countries' obligations are explicitly contingent on industrialized ones transferring technology and providing financial resources so that those obligations can be met (Article 4.7). Yet this can have only marginal impact, as developing countries have low per capita emissions and have not yet been expected to substantially mitigate. Industrialized countries tactically offered World Trade Organization membership to Russia in exchange for its ratification of the UNFCCC's Kyoto Protocol, pushing the agreement into effect. This issue linkage was neither formalized nor officially acknowledged (Arvedlund, 2004). Although linking mitigation and trade policies—such as through border tax adjustments—has been discussed for many years (e.g. Pitschas, 1995), there has been almost no actual linkage here due, in part, to potential conflict with international trade law (Weber, 2015). Some international policies for the conservation of biological diversity and mitigation have been linked, particularly via land use, land-use change, and forestry, although this linkage's marginal effect on mitigation is uncertain. This low level of meaningful linkage could be due to mitigation's local costs, global benefits, and resulting collective action problem. Just as it is not in a single state's interest to aggressively mitigate, it is not in its interest to offer substantial concessions or side payments to induce aggressive mitigation elsewhere.

In principle, an exception could arise when states' mitigation costs significantly differ, in which case those with high costs could offer concessions or side payments to those with low costs to mitigation. But because these groups are, generally and respectively, industrialized countries with high historical greenhouse gas emissions and developing countries with low emissions, such potential linkages are often frowned upon as major emitters avoiding their obligations and even neo-colonially exploiting developing countries (e.g. Bachram, 2004).

Foundation for linking mitigation and solar geoengineering policies

Internationally linking mitigation and solar geoengineering policies may be able to reduce mitigation obstruction and/or increase mitigation. I explore and assess options for this because, as noted above, (1) solar geoengineering appears able to reduce climate change risks and impacts, (2) mitigation obstruction is a major concern, and (3) existing suggestions to manage mitigation obstruction seem of limited effectiveness and feasibility. Even if some or all of these suggestions were effective and implemented, and even if solar geoengineering was ineffective, risky, and/or never used, then linkage may be able to complementarily further help reduce mitigation obstruction and/or increase mitigation.

It is more useful for linkage to aim to increase mitigation instead of to reduce mitigation obstruction. Both sceptics and proponents of solar geoengineering research, as well as those who are and are not concerned about mitigation obstruction, desire greater mitigation. (Indeed, Lin and Parson satisfy both opposing pairs, respectively.) Regardless, mitigation obstruction is indemonstrable because there are no counterfactual alternate realities with greater or lesser evaluation, research, and development of solar geoengineering. The diverse suggested causal processes are likewise challenging to observe and reduce as they are ideational, cognitive, and subtle. What's more, because there is disagreement among the concerned as to mitigation obstruction's causal process, no proposal to reduce it can alleviate all of their concerns. Thus, independent of whether mitigation has been obstructed and how it may have been caused, greater mitigation is desired widely.

Unlike linkage with trade or side payments, that with solar geoengineering policies may be able to increase mitigation, for several reasons. At the very least, as a new issue, solar geoengineering may have unrecognized linkage potential. Because solar geoengineering and mitigation are two means to the same objective, attempts to link them—even noncooperative ones—may be perceived as more legitimate. Moreover, given solar geoengineering's apparent low costs and technical achievability, instigating linkage could be an option for a wide range of states, not just those that are powerful enough to regularly control negotiating agendas. Finally, its consequences—environmental impacts, alterations of international relations, and heightened uncertainties —would occur in the near-term, in contrast with mitigation's temporally distant benefits.

Before proceeding, some simplifications and assumptions are necessary. In the case of climate change, the relevant actors are states. They are the primary locus of international mitigation efforts and would insist on control of any solar geoengineering deployment. For purposes of considering potential linkage, I treat states here as unitary decision-makers who act rationally in pursuit of their diverse interests, bounded by their capacities and resources, while recognizing the limitations associated with this rational actor model. I assume that all states share some general preferences, such as retaining freedom to act, maintaining a positive international reputation, influencing international decision-making, and avoiding harmful climate impacts.

I assume that each state is already at an equilibrium of mitigation. For example, their leaders have presumably undertaken policies that balance mitigation's marginal domestic benefits (reduction of climate change impacts, second-order environmental benefits, satisfaction of residents' desires, support by domestic industries, and international reputational gains) and its marginal domestic costs (higher costs of goods and services, restricted economic activity, and resistance from domestic industries). Internationally, any possible linkages with issues such as trade and technology transfer, cash side payments, and noncooperative threats are also at equilibrium. Importantly, states' mitigation levels are likely suboptimal. Domestically this might be due to rent seeking by politically influential, entrenched industries and internationally because of mitigation's collective action problem.

Effective linkage must capitalize on states' heterogeneity. First, states differ in the amount of additional mitigation that they would undertake in response to a given external change in their circumstances, such as a concession in another issue. Some states would find additional mitigation relatively more difficult, expensive, or politically unpopular, at the margin, whereas others could do so easily and cheaply. Second, states differ in how much they would be willing to sacrifice in order to increase mitigation elsewhere by a given amount. Putting these two characteristics together, those states that relatively strongly desire greater total mitigation are willing to offer concessions in other issues to induce mitigation, and those that could relatively easily and cheaply mitigate more are willing to accept such concessions.

In most of the proposals below, linkers that desire more mitigation noncooperatively offer a promise and/or make a threat in order to increase mitigation among targets, at least some of which are willing to mitigate more. Their more ambitious targets could take diverse forms: lower than expected absolute emissions, lower than expected relative emissions, reduced emissions intensity of economic activity, reaching an existing emissions milestone at an earlier date, achieving a particular mix of energy sources more rapidly, implementation of particular policies, and more.

States' preferences regarding solar geoengineering also vary. In this regard, questions of *whether* and *how* to use it are largely distinct. Regarding the former, there is an implicit international rejection of using solar geoengineering at this time, and any uni- or minilateral implementation contrary to international consensus would presumably be met with opprobrium. Therefore, for the foreseeable future, a state that wished to deploy solar geoengineering would need not only sufficient financial resources and technical capacity, but also the political clout and/or willingness to act in ways that could be contrary to the wider international community. Some states that might wish to use solar geoengineering would restrain themselves to maintain a positive reputation and avoid a chance of retaliation, whereas others—such as superpowers, those on the fringes of the international order, and those at risk of serious impacts of climate change—may be quicker to take actions contrary to the apparent consensus. For simplicity, the terms 'conformers' and 'dissenters,' respectively, are used henceforth. Although only a handful of states could act as lone dissenters, there may also be some 'moderate' dissenters that could act as part of a larger dissenting coalition.

Regarding *how* solar geoengineering would be used, the climate intervention's effects would be shaped by several parameters such as which technique and materials are utilized as well as the interventions' timing and location. For simplicity, I focus on only the most important one: the amount of incoming shortwave radiation that is reflected, blocked, or released from the earth. States would vary in their desired magnitude of solar geoengineering. I can describe them as 'high-magnitude' and 'low-magnitude' preferring states. In the absence of hypothetical counter-solar geoengineering (Parker et al., 2018), its magnitude is cumulative: states could increase but not decrease it. Some low-magnitude states might be willing to offer concessions for others to refrain from or to reduce their solar geoengineering.

Linkage with research and development

I now consider possible strategic linkages of international policies of mitigation and solar geoengineering. Because effective issue linkage requires heterogeneity among states, my proposals disaggregate them. In each, linkers make a promise and/or threat concerning solar geoengineering in order to increase targets' mitigation, and I ask whether the linkage can be expected to increase mitigation relative to no linkage and whether it appears consistent with states' interests to join, comply, and enforce as appropriate. In some cases, acceptance of the linkers' offer allows the compliant targets to join the former's coalition. I begin with potential linkage with solar geoengineering *research and development*, subsequently considering *whether to deploy* and *how to deploy*.

Previously, Lin has suggested that states make investments in solar geoengineering research and development dependent on analogous steps in mitigation and adaptation (Lin, 2013, p. 710). However, he does not explain why states would collectively do this in the absence of their preferences or the incentives that they face changing.

I propose that linkers offer targets the opportunity to participate in solar geoengineering research and development. Such participation could include (preferential) access to financial resources, expertise, intellectual property, discussions, plans, and results, as well as input into design, management, and decision-making regarding priorities and programmes. The advantage of this *R&D Linkage* is that it could occur immediately, including in the absence of deployment, and thus poses no intertemporal commitment problem (which some other proposed linkages below do). Moreover, potential targets might believe that the R&D Linkage coalition would grow in influence, perhaps even evolving into one where operational decisions are made (such as those discussed below). This would increase their motivation to join even more.

This linkage has three limitations. First, states' R&D capacities, emissions, and wealth correlate. High-emitters may see limited marginal value in complying with R&D Linkage. In terms of direct financial benefits, joining an international research programme might be worth tens of millions of US dollars for a single state. What's more, solar geoengineering, and consequently its research and development, is still uncertain. This modest, uncertain benefit suggests that these wealthy targets' willingness to additionally mitigate would also be limited. Likewise, while complying with R&D Linkage could offer significant benefits for developing countries, they have relatively low emissions and consequently could contribute little additional mitigation.

Second, a conditional offer to participate in a research and development programme implies a threat to exclude noncompliant targets, which would be contrary to scientific norms of cooperation and transparency. Although national and closed research and development are not uncommon in contested domains, cooperation and transparency are particularly important in solar geoengineering (Craik & Moore, 2014; Rayner et al., 2013, pp. 506–507). In fact, the proposal could backfire on the linkers: if no or few states join them, then they could end up isolated and losing prestige. Furthermore, balkanizing research and development could poison the international atmosphere surrounding solar geoengineering, weakening future discourse and negotiations.

Third, solar geoengineering research and development might be undertaken only by states that would expect its deployment to proceed and to benefit them. That is, some conformers might find this linkage unappealing, which could reduce the pool of states that are willing to offer and accept such linkage. On the other hand, those states that are sceptical or even opposed to solar geoengineering may value having input into programmatic decision-making regarding research and development.

A variant of R&D Linkage would take a harder line. In *Non-proliferation Linkage*, the linkers limit access to the requisite technical knowledge and materials to *only* those targets that mitigate more. Yet in addition to facing the above challenges of R&D Linkage, the spread of knowledge and materials would be difficult to control. Moreover, targets may be able to acquire the knowledge and materials on their own. It also remains uncertain whether solar geoengineering would require unsubstitutable and unreplicable expertise and materials that the developers could control and use as leverage.

Linkage with whether to deploy

Policies regarding mitigation could be strategically linked with those of whether to deploy solar geoengineering. This was the first such linkage to be proposed: Gregor Betz suggested that solar geoengineering be used when and only if greenhouse gas emissions have been reduced to 90% of their 1990 levels (Betz, 2012, p. 484). Parson later called this *Reverse Linkage*, in which states collectively agree beforehand to not use solar geoengineering unless they achieve some agreed-upon level of mitigation (Parson, 2014, p. 105). Likewise, Lin says that deployment could depend upon states' adoption of specific mitigation measures or strategies (Lin, 2013, p. 710).

Parson inverts this in his *Plan B Linkage*, in which states may deploy solar geoengineering only if climate change impacts are severe (Parson, 2014, p. 105). In a way, this describes the default situation, in that if mitigation successfully prevents dangerous climate change, then solar geoengineering would be unnecessary and hopefully taken off the table. Thus, an explicit Plan B Linkage agreement might not be strictly necessary, but could nevertheless formalize a shared understanding, explicating the circumstances under which solar geoengineering would be considered, endorsed, or condoned.

As Parson notes, neither Reverse nor Plan B Linkage appear effective. They each require long term, likely transgenerational commitments and consequently would be subject to reneging. Reverse Linkage would be intertemporally noncredible, in which states collectively and implicitly threaten to withhold solar geoengineering if mitigation is insufficient—which would be the very circumstances in which it could be the most beneficial. Future decision-makers would probably back out of these old threats, not keeping their hands tied in this way. Knowing this, states' current leaders would not see this as a reason to bolster their mitigation efforts. In fact, Reverse Linkage could give states the perverse incentive to set unambitious goals in order to retain the right to use solar geoengineering. Plan B Linkage, as noted, changes little from the present course. Neither proposal would motivate states to mitigate substantially more.

To address some of these limitations, Parson suggests *Real-Time Linkage*, in which solar geoengineering would be implemented soon at a magnitude small enough to constrain its risks but large enough to generate useful knowledge and resolve some uncertainties. Its continuation would be made contingent on states' ongoing strong performance on mitigation. Although Real-Time Linkage surmounts intertemporal commitment problems, like Reverse Linkage, it would likely be a noncredible threat, in which leaders promise to stop pursuing solar geoengineering—a means to reduce climate change risks—if mitigation is insufficient. This might counterproductively cause states to simply set low goals.

All three of these linkages with whether to deploy—Reverse, Plan B, and Real-Time—speak of states only collectively. None of them would reduce mitigation's international collective action problem. States would collectively establish a mitigation goal, but each would be tempted to defect from cooperative efforts. One possible rejoinder is that goals could be set separate from and prior to linkage. Satisfying linear progress toward, for example, the Paris Agreement's 1.5–2°C goal could serve as the criterion. Yet the current absence of such linear progress suggests that the problem would persist under these linkages, as states would still bicker among themselves about how to distribute the burden and claim that they never intended to make linear collective progress toward long-term goals, but instead modest initial steps followed by accelerating progress. A second possible rejoinder to the collective action critique is that, as climate change increasingly manifests, all states would experience growing, shared impacts. However, whether this would be the case would be independent of linkage with solar geoengineering.

Given these limitations, I propose *Authority to Act Linkage*, in which one or more linkers proclaim their right to deploy solar geoengineering only if they meet their own mitigation goals *and* the rest of the world's countries have failed to meet theirs. Inversely, they commit to forego that right if *either* of these criteria are not met. The linkers would set these goals, for both themselves and the targets. Because the linkers would prefer to retain their option to use solar geoengineering without suffering reputational damage from reneging on a commitment, they would have the incentive to mitigate more. Assuming that targets do not want other states to use solar geoengineering, they too would have reason to increase their mitigation. The linkers would need to be those that perceive solar geoengineering as potentially beneficial and, if they were few, to also be dissenters. If they were more in number, then an international organization could have a role in facilitating the linkage's formation. This proposed linkage would have important benefits relative to the others: It would require neither transgenerational intertemporal commitments nor early implementation of solar geoengineering.

Authority to Act Linkage could have multiple variants. For one thing, the linkers could claim that they have the *exclusive* right to implement solar geoengineering. Doing so would increase targets' incentives to mitigate but would require that the linkers enforce their exclusive authority, implying a need for them to be powerful. Second, the linkers could declare that their right to deploy solar geoengineering depends on whether the targets meet a *collective* mitigation goal or multiple *individual* ones. Third, an asserted exclusive right to implement solar geoengineering and individual goals among targets would allow the linkers to invite compliant targets to join the linkers' coalition, further increasing targets' incentives to mitigate. However, linkers might resist this as it would dilute their per-state influence. Fourth, with plural linkers, their goals could be collective or individual. Neither would surmount their collective action problem. But if the goals were individual, then the linkers could eject those that had not met them. However, this may be politically difficult depending on the states' identities and if the ejected noncompliant former linkers retained the capacity to implement solar geoengineering.

Authority to Act Linkage would face four interrelated challenges, the first of which is *legitimacy*. As a starting point, the linkers' perceived legitimacy would correlate with their number and international reputation. At one extreme, an Authority to Act pledge by a single state or a handful of them might be considered an illegitimate threat. At the same time, if they were particularly vulnerable to climate change, then their pledge (or threat) could carry moral weight. This would resemble Steve Rayner's suggestion that vulnerable states could threaten solar geoengineering as a type of civil disobedience, attempting to force global mitigation (in Morton, 2015, p. 348, 391). Alternatively, if the few linkers had well-established histories of aggressive mitigation, then their actions could likewise be seen as legitimate. Or if the founders were multiple and powerful, then not only would their political influence strengthen the linkage system and perhaps its perceived legitimacy, but their greater emissions—and thus potential mitigation—would constitute a large share of the global total.

Another factor relevant to legitimacy is how the targets view their own mitigation efforts, before and during the issue linkage. They might recognize that the imposition of Authority to Act Linkage would incentivize them to increase mitigation to a degree that benefits them. To the extent that their mitigation is insufficient due to its international collective action problem, then this linkage could push targets from a defecting equilibrium to a cooperative one. If the linkers mitigate enough—and especially if their goals were ambitious—while the targets did not, if solar geoengineering seemed to pose little risk, and if dangerous climate change impacts were imminent, then any subsequent solar geoengineering by the linkers might be considered legitimate, or at least more than in the absence of linkage. After all, in this case the linkers had done their part to make deployment unnecessary while the targets had arguably failed to do so. In contrast, if mitigation was already aggressive, solar geoengineering was understood as risky, and extant and expected climate change impacts were mild, then an Authority to Act assertion could be seen as unnecessary and illegitimate.

With respect to the variants of Authority to Act Linkage, a claimed exclusive right to implement solar geoengineering would be more assertive and face more stringent legitimacy expectations. In addition, allowing targets that meet their individual mitigation goals to join the coalition could reduce the linkage system's divisiveness.

The second challenge of Authority to Act Linkage is the commitments' *credibility*. Consider the four possible outcomes suggested by the goals of the two sets of states (Table 1). If linkers mitigate sufficiently to meet their goals and targets do not (quadrant C), then the implicit threat to deploy solar geoengineering would be credible, as it may benefit the linkers. Yet in the other three outcomes—all states meet their mitigation goals (A), targets do but linkers do not (B), or neither group of states do (D)—would the linkers actually refrain from solar geoengineering, as promised? Climate change impacts are more likely to be greater in the latter cases (that is, A < B < D). Among these outcomes, the linkers would be most tempted to renege and implement solar geoengineering if neither group of states sufficiently mitigates (D). And even if all states had met their goals, then impacts could still be severe due to climate surprises (such as higher climate sensitivity) and/or to unambitious goals (considered further below). This is the greatest limitation of Authority to Act Linkage.

The third challenge is the Authority to Act coalition's *optimal size*, a factor that is related to both legitimacy and credibility. On the one hand, fewer linkers could increase the linkage's effectiveness, as they could more readily overcome their own collection action problems and make decisions. Carried to an extreme, one could imagine a single state—perhaps a superpower with benevolent intentions—declaring that its future solar geoengineering deployment would depend on whether the rest of the world adequately mitigates. On the other hand, more linkers would increase the linkage system's legitimacy as their pledge would more closely resemble an international consensus. Yet too many linkers would come to resemble Reverse Linkage, which, as described in the previous section, suffers from a perverse incentive to set unambitious mitigation goals and a non-credible commitment to withhold potentially beneficial solar geoengineering in the face of climate change. There thus seems to be a trade-off between effectiveness and legitimacy, implying an optimal, moderate breadth of participation. However, if linkers had individual goals and could be excluded from decision-making or expelled if they failed to meet them, then a large coalition could be both legitimate and effective.

The *stringency of the mitigation goals* is another issue. Mitigation goals would be shaped by the linkers' motivations. If the linkers genuinely preferred mitigation, then they would set reasonable goals: high enough to increase mitigation but not too high that the states could not achieve them. If perceived legitimacy was considered important—as it likely would be—then linkers might set particularly ambitious goals for themselves and modest ones for others. In contrast, if they actually preferred solar geoengineering and sought a means to use it with a veneer of legitimacy, then they would declare unambitious mitigation goals for themselves and very ambitious ones for others. If the targets recognize this, they could reject the linkage. In this case, the international political landscape would, in principle, return to roughly where it was prior to the attempted linkage. However, the linkage attempt could alter states' relevant preferences, discussed further below.

A fifth and final issue is *potentially problematic relations among targets*. To prevent presumably unwanted solar geoengineering, targets would strive to meet their mitigation goals. If their goal was a collective one,

Table 1. Four possible outcomes of Authority to Act Linkage.

	Linkers mitigate	Linkers do not mitigate
Targets mitigate	[A] *Linkers pledge to not deploy*. Promise is credible, at least if goals are ambitious and climate change is not worse than expected.	[B] *Linkers pledge to not deploy*. Promise is questionable, especially if climate change is worse than expected.
Targets do not mitigate	[C] *Linkers retain right to deploy*. Implicit threat is credible.	[D] *Linkers pledge to not deploy*. Promise is relatively the least credible.

then individually they would wish to bear as little burden as possible, that is, to free ride on others' efforts. On the other hand, the prospect of solar geoengineering—with its attendant and immediate risks, uncertainties, and chances of disruptive international projections of power—might provide the motivation to overcome their collective action problem as well as other barriers to greater mitigation. Alternatively, if target states' mitigation goals were individual ones set by the linkers, then they would not face a collective action problem. However, once most of them satisfied their goals, then the remaining targets would gain negotiating leverage over the others. Indeed, holding out to extract a greater share of the social surplus through credible demands for side payments is probable, especially if some remaining targets are agnostic whether solar geoengineering is implemented.

Linkage with how to deploy

Finally, international policy for mitigation could also be strategically linked with that for how to implement solar geoengineering. Parson put this forward in *Pay to Play Linkage*, in which only those states that meet their mitigation goals may participate in collective decision-making regarding ongoing solar geoengineering, particularly setting its parameters such as magnitude. He originally suggested real-time Pay to Play Linkage, in which mitigating states would gain access to decision-making. Although this would overcome the problem of intertemporal commitments of uncertain credibility, in order to offer a genuine incentive, this would require immediate solar geoengineering deployment, if only at a low magnitude. Pay to Play Linkage could alternatively be intertemporal, in which current mitigation policies allow a voice in later decision-making.

Pay to Play Linkage resembles Authority to Act in many, but not all, ways. The linkers would need to expect that solar geoengineering would be used (if it had not already) and that it would benefit them. They would offer to share their decision-making authority, which is costly to them through its dilution. The number of linkers could range from a single state to many. If few, the states would need to be dissenters, and if more, an international organization could help launch the linkage. Because the linkers would invite compliant targets to join them in asserting an exclusive right—in this case to set parameters—the mitigation goals would be individual ones. This means that targets' mitigation efforts would not have a collective action problem. Furthermore, legitimacy would also be salient yet less demanding because the Pay to Play linkers' asserted right would be more modest. And the linkers' threat to exclude those that do not meet their mitigation goals might not be credible if the coalition were small and politically weak, and states' preferences regarding the deployment parameters diverged widely.

In contrast, some issues substantially differ between the Authority to Act and Pay to Play Linkages. Here, founding linkers would relinquish less when they offer to expand the decision-making group. The optimal number of linkers would be large, as this would strengthen legitimacy while not presenting the counterproductive incentives and potentially noncredible commitments of a large Authority to Act coalition. Moreover, the Pay to Play linkers could not as readily use the linkage as an ulterior vehicle to legitimize solar geoengineering. The targets would face neither a collective action problem, because their mitigation goals would be individual, nor a holdout one, because the final states to mitigate have no leverage over others. On the other hand, this means that targets would lack incentives to facilitate each other's mitigation.

Like the other proposals, Pay to Play Linkage would face challenges to its effectiveness. First, a solar geoengineering programme would need to be undertaken or at least widely perceived as likely in the future. Second, targets would be motivated to mitigate more only if their preferences regarding deployment's parameters differed significantly from those of the existing linkers. If a target had similar preferences as the average linker (Ricke et al., 2013), then it would have only modest reason to join, as doing so would have little effect on the outcome. On the other hand, a target might be uncertain about the alignment between its preferences and those of the linkers, especially in the early period of the linkage. Moreover, participation would offer nonmaterial benefits, such as international status. Third and finally, in the presumed absence of counter-solar geoengineering, Pay to Play Linkage would be asymmetrical, having more appeal to targets that are low-magnitude and conformers. In these circumstances, they would mitigate more to prevent solar geoengineering at a level greater than their preferences. If instead the targets were high-magnitude or dissenters, then they would simply undertake additional deployment themselves. That is, Pay to Play Linkage requires the linkers and targets to have specific characteristics, and its appeal to the latter group could be limited.

Conclusions

The strongest, most widespread, and most influential concern of solar geoengineering is that it could obstruct mitigation. Here, I discussed several possible linkages of international mitigation and solar geoengineering policies aimed toward reducing mitigation obstruction. Notably, the three categories of linkage—with research and development, with whether to deploy, and with how to deploy—are not mutually exclusive. Indeed, a serial combination of R&D, Authority to Act, and real-time Pay to Play Linkages could be particularly effective. In this article, I explore particularly issue linkage in which some parties—the 'linkers'—unilaterally attempt to force linkage on other parties—the 'targets.' I encourage other scholars, thought leaders, and policy-makers to consider these and other linkages.

Of the linkages considered here, I believe that Authority to Act has substantial potential to increase mitigation while being consistent with states' apparent interests to join, comply, and enforce any agreement. In this, linker(s) proclaim their right to deploy solar geoengineering only if they meet their own mitigation goals *and* the rest of the world's countries have failed to meet theirs. Authority to Act Linkage could be announced by a small coalition of powerful, influential, or climate-vulnerable states, or by a larger group facilitated by an intergovernmental organization. Under this, linkers and targets would both have incentives to increase their mitigation. The linkage would be self-enforcing, in that it would be in some states' interests to initiate the issue linkage. Linkers would also be motivated to eject defectors and free-riders because doing so would increase the remaining linkers' influence in decision-making. If targets' goals were individual, not collective, then the Authority to Act group could expand through targets' compliance while facing a reduced international collective action problem. Neither intertemporal commitments nor early solar geoengineering deployment would be necessary. There are also plausible paths toward its development. None of the above-discussed challenging issues—legitimacy, credibility, size, relations among targets, and stringency—are necessarily prohibitive. Instead, their seriousness would depend on the particular climatic, scientific, political, and ideational contexts. These contexts are presently difficult to forecast because of solar geoengineering's associated uncertainties, particularly that of states' preferences.

Three limitations of linking international mitigation and solar geoengineering policies must be recognized. Like most discussions of solar geoengineering's governance challenges and possible responses, the exploration and assessment here are necessarily speculative. The matter at hand—mitigation obstruction—itself remains speculative and perhaps indemonstrable. Furthermore, most of the linkages here are peculiar in that they are noncooperative, are potentially in the targets' interest, and link within the climate change issue area, rather than beyond it to trade issues or side payment. The limited empirical evidence of issue linkage's effectiveness may consequently not offer robust guidance. Also, no linkage or other proposal to manage mitigation obstruction can surmount the epistemic barrier of measuring such obstruction, as most causal processes and any counterfactual baselines are unobservable.

As another limitation, the proposed linkages rest on the assumption that states' preferences regarding the two response options are related, which might not be the case. Some states—which could be superpowers—might simply resist or undertake solar geoengineering independently of mitigation and climate change impacts. Alternatively, actual mitigation might be so strongly shaped by other forces, and states' preferences regarding solar geoengineering so weak, that the former is not sufficiently influenced by the latter. This possibility is made more complex when one removes the assumptions of the rational actor model employed here. In reality, preferences of the public, scientific experts, and powerful substate actors could diverge from the state's apparent interests. These actors could embrace or reject solar geoengineering and mitigation in surprising ways. And solar geoengineering and mitigation policies operate on different timescales. While this has the benefit, noted above, that solar geoengineering's short-term impacts and risks could motivate states, their divergent timescales may also make linkage difficult.

Removing this rational actor assumption points to a harmful possible outcome. Steps toward linking international policies for mitigation and solar geoengineering could create and reinforce beliefs that the two responses to climate change are mutual substitutes, perhaps *furthering* mitigation obstruction. If so, then a failed attempt might not return the international political landscape to its prior state but instead to an unwanted one. This potential counterproductive effect should be taken seriously.

Third, targets and other observers may have reservations because most of the linkages discussed here, including those that appear to have the greatest potential, are noncooperative. However, not all noncooperative linkages are normatively undesirable. For one thing, they can help targets overcome barriers to their own objectives. In this case, noncooperative linkage could enable greater mitigation, recognized by targets as beneficial but prevented by international collective action, domestic resistance, and other obstacles. For another thing, not all noncooperative linkages are threats to reduce welfare. According to Thomas Schelling, 'a promise is costly when it succeeds, and a threat is costly when it fails' (Schelling, 1960, p. 177). For example, linkers would bear a cost of a successful Authority to Act linkage by foregoing their right to use solar geoengineering to the same extent as before the attempted linkage. Also, the linkers in the noncooperative proposals would not necessarily be one or a couple superpowers that are imposing their will on weaker states. While that is one possibility, solar geoengineering's apparent low financial and technical barriers to entry may allow other scenarios as well, including those in which the linkers are highly vulnerable to climate change or are numerous, seeking to bring mitigation laggards up to speed. How targets and other observers would perceive a noncooperative linkage, including with respect to its legitimacy, would be context-dependent. Finally, and relatedly, noncooperative threats are not necessarily illegitimate and states make them regularly. As one example, linkers sometimes threaten trade sanctions if targets fail to comply with human rights agreements, standards, and norms.

This article is by nature incomplete, and I suggest a few lines of possible future inquiry and, along the way, point out other limitations of the current exploration and assessment. I have offered important characteristics of states regarding mitigation and solar geoengineering: desiring versus being willing to provide additional mitigation, self-restraining to maintain a positive reputation and avoid retaliation versus more quickly taking actions contrary to the apparent consensus, and preferring more or less solar geoengineering. How mitigation and solar geoengineering policies could be linked depends in part on how these characteristics correlate. For example, one reasonable hypothesis is that linkers desire less severe climate change impacts and thus would usually prefer a greater magnitude of solar geoengineering.

My descriptions remain qualitative, informal, and somewhat vague, which may be satisfactory for an initial exploration and assessment. In the future, quantitative, formal models could identify potentials, limitations, and risks of these and other possible linkages. Another qualitative route would be to remove the rational actor model and instead focus on power and ideas. For example, in his foundation work on linkage, Ernst Haas describes how political leaders' goals and experts' beliefs about knowledge interact to create sharply diverging domestic political landscapes (Haas, 1980, pp. 376–385). In the case of solar geoengineering and mitigation, these goals and beliefs may vary widely among and within states as well as across time.

In addition, I consider linkages between policies for only mitigation and solar geoengineering, even though climate action also includes adaptation, finance, loss and damage, technology transfer, and more. More complex linkage proposals among these domains could further enhance mitigation.

Finally, as noted, some of the issue linkages discussed here are noncooperative yet are potentially in the targets' interest. These might be called *paternalistic* linkages. Paternalism has been well-explored in domestic and, to a lesser extent, international politics (e.g. Barnett, 2012). However, paternalistic issue linkage has not been substantially investigated here or elsewhere, but perhaps should be part of future research.

Although I propose these linkages of mitigation and solar geoengineering policies to address the mitigation obstruction concern, this might ultimately not turn out to be the most important manifestation of obstruction in climate change policy. Instead, climate change's expected impacts appear increasingly severe and mitigation continues to be grossly insufficient, yet solar geoengineering remains outside the bounds of 'polite conversation' within the global climate policy discourse. This may be evidence of *solar geoengineering obstruction*, in which an unwavering—and to a degree, understandable—prioritization of mitigation as the sole means to reduce climate change obstructs serious evaluation of solar geoengineering's potential and limitations. This obstruction warrants additional consideration.

Notes

1. ‘Mitigation obstruction’ is not fully precise with respect to CDR, as ‘mitigation’ technically includes CDR (Honegger et al., 2021).
2. Scholars’ definitions and terms vary. I am agnostic among them, only using some here for clarity and internal consistency.
3. Although many other scholars exclude unilateral efforts from issue linkage, the three scholars cited include it.

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