Linking Solar Geoengineering and Emissions Reductions:

Strategically Resolving an International Climate Change Policy Dilemma

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Abstract

Solar geoengineering may be able to significantly reduce climate-change risks, but raises sharp controversy. The leading cause of controversy is the concern that solar geoengineering's research, development, or use might inappropriately displace efforts to cut greenhouse-gas emissions. A possible response would be to strategically link the international policies of greenhouse gas emissions reductions ("mitigation") and solar geoengineering. Here we explore and expand on this idea, including by disaggregating states based on relevant characteristics, the incentives that various policy linkages could foster, and considering the processes of developing linkages. We explore potential linkage mechanisms and identify a combination that could effectively reduce mitigation displacement (if not increase mitigation), appears feasible, and would not be inconsistent with widely-held norms. In this, one or more states proclaim their right to deploy solar geoengineering if they meet their own mitigation targets and the rest of the world insufficiently mitigates. We identify possible challenges, including legitimacy, credibility, optimal size, relations among nonmembers, mitigation targets, and complexity, none of which seem insurmountable.

Introduction

Anthropogenic climate change poses large risks to humans, other species, and ecosystems. The leading response has been reducing greenhouse gas emissions, often called "mitigation," but this continues to be inadequate after almost thirty years of internationally coordinated efforts. Feasible future mitigation is unlikely to keep global warming within the internationally agreed-upon 1.5 to 2°C goal set in the 2015 Paris Agreement (United Nations Environment Programme 2019). Additional measures, such as adaptation and carbon dioxide removal (sometimes called negative emissions technologies), have received increasing attention and are now clearly necessary complements to manage climate change risks. However, there are convincing reasons to expect that these will collectively fall short of preventing dangerous climate change and its impacts.

An additional set of responses to climate change is solar geoengineering (sometimes called solar radiation modification or management (SRM)), a group of technologies that would intentionally alter the planet's shortwave (i.e. visible) radiative balance, usually by blocking or reflecting a small portion of incoming sunlight. The most studied method would mimic the natural cooling effect of large volcanic eruptions, whose ejected fine particles linger in the atmosphere for some months and block sunlight. Current evidence indicates that such stratospheric aerosol injection could effectively, rapidly, and reversibly reduce climate change; would necessarily be global in effect; would have low direct implementation costs; and would pose multiple serious physical risks and social challenges (National Research Councils 2015; Reynolds 2019). The Intergovernmental Panel on Climate Change (IPCC) says with "*high agreement* that [stratospheric aerosol injection] could limit warming to below 1.5°C," a very aggressive target (Intergovernmental Panel on Climate Change 2018:350; italics in original). Moreover, due to solar geoengineering's speed of action, it could manage climate change risks in the short term, which mitigation, carbon dioxide removal, and adaptation could not.

Solar geoengineering is controversial. The IPCC concludes that "public resistance, ethical concerns and potential impacts on sustainable development could render [solar geoengineering] economically, socially and institutionally undesirable" (Intergovernmental Panel on Climate Change 2018:317). One reason is that, given its low financial deployment costs and global effect, one or a few states could implement it independent of international consensus. This characteristics (and others) engender potentially complex international relations (Horton and Reynolds 2016). Yet the strongest, most consistent, and most influential concern is that its consideration, research, and development would lessen mitigation, a possibility that is here called "mitigation displacement." Despite a decade of serious discussion about solar geoengineering, there have been no proposals to minimize mitigation displacement that would, in our assessment, be both effective and feasible. After all, mitigation displacement would be caused by numerous actors' internal deliberations and decisions, now and in the future. Nevertheless, an approach that appears to have some potential to address the mitigation displacement concern would be to link mitigation and solar geoengineering in international policy-making, as previously suggested by Parson (2014).

This paper expands on proposed strategic linkages of mitigation and solar geoengineering policies, developing and assessing multiple informal qualitative linkage mechanisms. The first substantive section reviews the mitigation displacement concern and suggestions for minimizing it. We then briefly introduce issue linkage in general. The next section then clarifies our assumptions; systematically considers the relevant characteristics of states, which will be the actors of interest in solar geoengineering development and implementation; and puts forth some general features and limitations of mitigation and solar geoengineering policy linkages. The next three sections describes existing and new proposals: linking mitigation with the *research and development* of solar geoengineering, with decision-making regarding *whether to deploy*; and with that regarding *how to deploy*. We assess the proposals as to whether we expect them to effectively reduce mitigation displacement, be feasible, and not be inconsistent with widely-held norms. The conclusion summarizes, notes some limitations, and offers a few lines of further inquiry.

Mitigation displacement

As noted, the possibility that solar geoengineering's consideration, research, and development would lessen mitigation is the strongest, most consistent, and most influential concern.[1] An important early work by climate change researcher David Keith names the possible phenomenon “moral hazard,” an inaccurate but persistent appropriation of a term from insurance economics (Keith 2000). The mitigation displacement concern had a demonstrable impact as early as the drafting of a 1992 US National Academies climate change report (Institute of Medicine, National Academy of Sciences, and National Academy of Engineering 1992; Schneider 1996). Thereafter it was the primary basis for a taboo on solar geoengineering, resulting in the death of a 2001 proposal inside the US White House to support geoengineering research (MacCracken 2006:239). Today, the mitigation displacement concern remains a leading reason that solar geoengineering is subordinate within climate change policy discussions (Lawrence and Crutzen 2017).

As the taboo on discussing solar geoengineering has weakened, mitigation displacement has received increasingly detailed scholarly attention. An early contribution by Benjamin Hale asserts that the concern is too ambiguous to be effectively supported or rebutted (Hale 2012:114). Some scholars who have considered mitigation displacement are worried. Albert Lin believes that mitigation displacement is likely and would be harmful because mitigation is the inherently preferable response to climate change (Lin 2013:711). Christian Baatz argues that mitigation displacement would increase the probability of sudden and sustained termination of solar geoengineering, which would have severe negative impacts (Baatz 2016). Duncan McLaren

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[1] This objection with respect to mitigation has not been limited to solar geoengineering. Early proposals to consider adaptation in the early 1990s were widely denounced for, among other things, diverting effort and attention away from essential mitigation efforts (Burton 1994:14). Adaptation became respectable in the late 1990s and early 2000s, as both responses were seen as essential. Carbon dioxide removal initially faced similar criticism, but is increasingly recognized as necessary to achieve widely endorsed climate targets. These technologies are now recognized in the Paris Agreement in its calls “to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases” and for “Parties [to] take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases” (Articles 4.1, 5.1).

asserts that mitigation displacement would interfere with the “broader climate policy goals such as climate justice” (McLaren 2016:600), although it is unclear in what contexts “climate justice” is a recognized policy goal. Other scholars are relatively sanguine (Morrow 2014; Reynolds 2015; Lockley and Coffman 2016; Halstead 2018; Wagner and Merk 2018).

As Hale noted, much confusion and disagreement over mitigation displacement arises from its ambiguity. The concern is that solar geoengineering somehow reduces mitigation, but any such change would be relative to an unobservable counter-factual. Some advocates of the concern have pointed to multiple studies of optimal integrated climate response, in which introducing solar geoengineering into the set of responses reduces the magnitude of mitigation and shifts it into the future (e.g. Klepper and Rickels 2012; Moreno-Cruz, Wagner, and Keith 2017). These results, however, regard changes in *optimal* mitigation, yet *actual* mitigation to date is much less than optimal. Solar geoengineering could displace optimal mitigation, but this tells us little about any effects on actual mitigation. In fact, raising solar geoengineering’s profile might increase actual mitigation. An awareness that such extreme measures are under consideration could cause the public and decision-makers to be more alarmed about climate change and support more mitigation, leading to a sort of mitigation facilitation.

Whether solar geoengineering would displace or facilitate mitigation is, to some extent, an empirical question. At least ten studies of opinion or behavior explore how people respond to the prospect of solar geoengineering (Shepherd, Caldeira, Haigh, Keith, Launder, Mace, et al. 2009; Ipsos MORI 2010; Mercer, Keith, and Sharp 2011; Integrated Assessment of Geoengineering Proposals 2014; Kahan, Jenkins-Smith, Tarantola, Silva, and Braman 2015; Wibeck, Hansson, and Anshelm 2015; Fairbrother 2016; Merk, Pönitzsch, and Rehdanz 2016; Wibeck, Hansson, Anshelm, Asayama, Dilling, Feetham, et al. 2017; Raimi, Maki, Dana, and Vandenbergh 2019; see Burns, Flegal, Keith, Mahajan, Tingley, and Wagner 2016). Notably, in almost all of these, respondents *increase* their assessment of climate change’s risk and/or their support for mitigation. In only one (Raimi et al. 2019) do the respondents become less worried about climate change or less willing to mitigate. Like all such studies, each of these has limitations. Most importantly, mitigation displacement regards how decision-makers will act in future circumstances, not how lay people presently claim that they would act or respond in experimental settings. Furthermore, mitigation and solar geoengineering are not the only responses, and they will interact in complex ways with carbon dioxide removal and adaptation.

Even if solar geoengineering does displace mitigation, it would not necessarily be harmful. Both responses reduce climate change and its risks, albeit in different ways and with dissimilar temporal profiles. If solar geoengineering were to substantially reduce climate change and only slightly displace mitigation, then climate change’s impacts would be less severe, perhaps enough to outweigh the effects of changes in mitigation’s climatic effects and its second-order benefits, such as the reduction of airborne particulates from coal combustion.

Although well-crafted policies could in principle manage displacement, describing how they could do so effectively and feasibly has proven elusive. Albert 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). David Morrow more moderately recommends ensuring diverse research, careful communication, and proactive engagement with the public and decision-makers (Morrow 2014). John Halstead argues for a research program that focuses, at least initially, on solar geoengineering’s governance and security issues instead of its environmental effects (Halstead 2018). Another approach to facilitating robust mitigation in the face of solar geoengineering is to strategically link international policies (Parson 2014), the topic of this paper.

Issue linkage

At the most general level, issue linkage is when two or more actors negotiate and perhaps agree to undertake (or refrain from) certain actions that relate to more than one issue. Issue linkage is one of the cornerstones of negotiation, collective decision-making, and cooperation, including in international domains (Sebenius 1983; Haas 1990; Oye 1993; Limão 2005; Johnson and Urpelainen 2012). Indeed, some scholars conceptualize international law as a marketplace in which states exchange jurisdiction in often-unrelated domains (Trachtman 2008). Linkages can take diverse forms, with the distinctions among categories blurry. They can increase the probability of a stable agreement or can make one less likely or brittle. Other purposes can be to provide an enforcement mechanism for an issue that lacks one or to help stabilize a fragile coalition. Linkages can increase states' welfares through mutually beneficial exchange or can decrease them through threats and coercion. They can be informal or formal, private or public, and implicit or explicit. The linked issues can be substantively related, or not. Linkage is similar to – but not synonymous with – side payments, which are welfare-increasing offers of concessions in one issue to those that would be worse off by an agreement or development in another issue.[2] Power, perception, and shared knowledge are all salient to linkage, as a state that desires linkage must sufficiently control the agenda in order to add an issue to negotiations that other states might see as outside of the current scope of discussion. Issues that are commonly and robustly linked can coalesce into an issue area in which policy mechanisms are mutually reinforcing.

It is not self-evident which issues can and should be linked. To a large degree, it depends on states' interests, capabilities, and knowledge. Relevant questions include: Under what conditions would linkage effectively and feasibly further (some) states' interests? Would the resulting coalitions be stable, and the threats and promises credible? What are a linkage's optimal form, substance, and the degree of legalization? Which states (or other actors) are necessary, and which are sufficient? Which ones can and should be excluded? Can beneficial linkages form more or less spontaneously or are catalytic international institutions necessary?

An example of effective issue linkage in a multilateral environmental agreement regards stratospheric ozone depletion (Benedick 1998; Parson 2003). In the 1980s, scientists and states were aware that emissions of certain substances were depleting stratospheric ozone, which protects organisms from harmful ultraviolet radiation. Like climate change, these emissions' mitigation was a global, multiplayer prisoner's dilemma and presented a difficult collective action problem. Unlike climate change, the vulnerable states – industrialized ones at the high latitudes – were also the high emitters. The less vulnerable ones – developing ones at the low latitudes – had little incentive to reduce their emissions of ozone depleting substances. However,

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[2] Specifically, there can be side payments without linkage – such as simple grants of valuable resources – and linkage without side payments – such as coercive threats.

once the vulnerable states linked emissions cuts with promises of financial assistance and the transfer of alternative technologies to the less vulnerable ones, broader and deeper cooperation became possible. These promises were supplemented with threats of trade restrictions. This tactical linkage was formalized in the Montreal Protocol, which further links by prohibiting parties from importing from nonparticipating states products that contain or are made with controlled ozone-depleting substances. All states now participate in the Protocol, and stratospheric ozone is recovering.

In contrast, issue linkage in international climate change policy has been elusive. To some degree, promises of financial assistance and technology transfer from industrialized have catalyzes climate action in developing countries. More specifically, industrialized states tactically linked trade by offering World Trade Organization membership to Russia in exchange for its ratification of the Kyoto Protocol, pushing the agreement into effect. Not only was this linkage not formalized, it was never officially acknowledged (Arvedlund 2004). However, further substantial linkage has generally been absent from climate change negotiations. A key reason is that historical greenhouse gas emissions are dominated by states that are relatively less vulnerable to deleterious impacts. It is unclear what the poorer, vulnerable states could offer to the high emitters that would induce additional mitigation. Scholars and, to a lesser degree, international negotiators have considered linking mitigation policy with international trade (Kemfert 2004; Nordhaus 2015) but with little progress to date. Solar geoengineering may offer possible linkages to increase mitigation.

Context for linkage of solar geoengineering and mitigation policies

Mitigation and solar geoengineering are two major response types, along with carbon dioxide removal and adaptation, to climate change. Interactions between them present opportunities for linkage that have not yet been well explored. Ideally, such linkage could harness solar geoengineering’s characteristics to enhance mitigation.

In the case of climate change, and especially solar geoengineering, the relevant actors are states. They are the primary locus of international mitigation efforts, would insist on control of solar geoengineering deployment, and in general are the source and subjects of international cooperative agreements. Such agreements, often but not always legal in form, can sometimes manage and surmount global collective action problems such as mitigation.

We treat states here as unitary decision-makers who act rationally in pursuit of their diverse interests, bounded by their limited capacities and resources. We recognize the limitations associated with this rational actor model. In reality, substate actors and politics are often important but are bracketed here. Our starting point is states' present and near-term interests, capacities, and positions. For example, states are embedded in various international institutional and legal regimes. We 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.

We assume that each state is already at its *local* equilibrium of mitigation, in that their leaders have undertaken policies that balance mitigation's marginal domestic benefits (local reduction of climate change impacts, local second order 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). Importantly, a local equilibrium is not necessarily locally optimal. For example, the local equilibrium might be suboptimal due to rent seeking by politically influential, entrenched industries. Also, because mitigation is a global collective action problem, local equilibria are collectively suboptimal. This is because, as a nonexcludable global public good, mitigation's marginal benefits would be distributed across the world while most marginal costs would be borne domestically. In other words, states typically defect from global cooperation in mitigation.

Linkage can capitalize on states' variation to increase incentives to mitigate. Because we wish to be parsimonious in the states' dimensions of variability, we do not emphasize some that seem salient, such as international influence, wealth, and vulnerability to climate change. The first relevant dimension of states' variance is their willingness to undertake additional local mitigation and to induce it elsewhere. States differ in the amount of additional mitigation that an external change in their circumstances – such as a side payment – would produce. Specifically, such an incentive would change decision-makers' calculus regarding what is locally optimal. Some states would find additional mitigation relatively more difficult, expensive, or politically unpopular, at the margin, whereas others could do so easily and cheaply. In economic terms, this is akin to a mitigation supply curve. Likewise, states differ in how much they would be willing to sacrifice in order to increase total mitigation. Some are willing to offer much to induce mitigation elsewhere, and others may be close to agnostic. Again in economic terms, one can think of a mitigation demand curve.

States' supplies of and demand for mitigation are related. Those that strongly desire more total mitigation are willing to offer concessions in other issue areas to induce mitigation elsewhere. Those states that could easily and cheaply mitigate more are willing to accept such concessions. In other words, there is or can be an international market for mitigation, or at least a shadow market. This market has eager potential buyers and sellers of additional mitigation, and states that are roughly neutral in both regards. For simplicity, the terms "buyers" and "sellers" are used henceforth. In the linkage proposals below, buyers offer a promise or make a threat with the intention of increasing mitigation among sellers.

Like international cooperation in general, this mitigation market functions inefficiently due to high transaction costs. The international community frowns upon overt financial side payments (although climate finance is a growing domain of what often amount to financial side payments). Most international cooperation is instead barter. As in typical bartering, potential buyers and sellers may not be able to identify a common issue to trade for additional mitigation. For example, a buyer might be willing to offer military assistance, while a seller might already have sufficient military capacity and seek instead greater access to intellectual property. This market is made even more inefficient by the information asymmetries that results from states' secrecy and misinformation in signaling their capacities and interests. Buyers and sellers can consequently remain unaware of potential matches among them.

States' preferences regarding solar geoengineering also vary. Unlike those of mitigation, these cannot be expressed as a single dimension because preferences concerning *whether* and *how* to use it are distinct. Regarding the former, there is an international rejection – both explicit and implicit – of using solar geoengineering at this time. Furthermore, any uni- or minilateral implementation contrary to international consensus would presumably be met with opprobrium. Therefore, in the absence of a global consensus to do so – which seems improbable for the near future – a state that wished to deploy solar geoengineering would need not only financial resources and technical capacity, but also the international clout and willingness to act contrary to the wider international community. Some states that might wish to use solar geoengineering would restrain themselves to maintain a positive reputation and to avoid retaliation, whereas others – such as superpowers and those on the fringes of the international order – would be quicker to take actions contrary to the apparent consensus. Domestic politics regarding both acting in line with the international community and solar geoengineering itself would presumably contribute to a state's position on this spectrum. Again for simplicity, the terms "conformers" and "rogues" respectively are used henceforth. Only a handful of states have the requisite financial resources, technical capacity, and political will to be true rogues. Yet there also some modest rogues that could or would not act alone, but might as part of a broader coalition. Furthermore, some states may be averse enough to solar geoengineering that they would be willing to offer side payments to rogues to prevent its use. Conversely, rogues may be able to use a credible threat of deployment to extract side payments.

Regarding *how* solar geoengineering would be used, it would possess several parameters such as which technique and materials are utilized as well as the interventions' timing and location. For simplicity, we focus on only the most important parameter: the amount of incoming shortwave radiation that is reflected, blocked, or released from the earth.[3] States would vary in their desired intensity of solar geoengineering. We can describe them as "high-intensity" and "low-intensity" preferring states. In the absence of hypothetical counter-solar geoengineering (Parker, Horton, and Keith 2018; Heyen, Horton, and Moreno Cruz 2019), its intensity is cumulative: states could increase but not decrease it. Thus, it could feasibly be done at a level greater than preferences of low-intensity states, or even of the average one. Some states might be willing to offer side payments for others to refrain from or to reduce their solar geoengineering. Here, too, an international market could develop.

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[3] This would be measured as negative radiative forcing, in units of power per area, such as watts per square meter. In the case of stratospheric aerosol injection, this intensity would be roughly proportional to the mean aerosol optical depth.

Potential linkage with research and development

We now consider possible strategic international linkages of mitigation and solar geoengineering policies. In all of these, buyers make a promise or threat concerning solar geoengineering in order to increase sellers' mitigation. We proceed here in a quasi-chronological sequence from linking mitigation policies with those for solar geoengineering *research and development*, for *whether to deploy*, and for *how to deploy*. In all cases, we ask whether it can be expected to decrease mitigation displacement (that is, to increase mitigation relative to no linkage), appears feasible (that is, to appear beneficial for the required states to join and to punish violators), and would not be inconsistent with widely-held norms.

Albert Lin suggests that states make investments in solar geoengineering research and development (or similar other steps) dependent on analogous steps in mitigation and adaptation. In his view, linkage could be undertaken via informal or legalized commitments, but the mitigation and adaptation measures should consist of "upfront and verifiable action" to prevent later reneging (Lin 2013, 710). This amounts to asserting that states should have stronger preferences for mitigation and adaptation and lesser ones for solar geoengineering research and development. He offers no mechanism for changing their interests nor the incentives that they face.

Buyers of additional mitigation could offer sellers the opportunity to participate in solar geoengineering research. 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 programs. 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). Furthermore, R&D Linkage would send international signals that those states that are researching and developing solar geoengineering also prioritize mitigation and that the endeavor is founded on transparency and cooperation, not secrecy and desired relative advantage. As a specific example, developing countries might be suspicious of industrialized countries' intentions. To increase international trust, the latter could finance cooperative solar geoengineering activities with the former. In the process, the industrialized countries might expect a some additional mitigation by the participating developing countries. Finally, potential sellers 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 further increase their motivation to join.

This linkage mechanism has several limitations. First, from the sellers' perspective, joining a research and development coalition is of limited value. Solar geoengineering, and thus its research and development, is still uncertain. In terms of direct financial benefits, joining an international research program might be worth tens of millions of US dollars for a single state, which appears insufficient to induce substantial additional mitigation. This is especially the case among the relative wealthier sellers.

Second, those potential sellers for which an offer to participate in research and development would have the greatest value are largely developing countries. This leads to two drawbacks, although neither of them seem prohibitive. For one thing, those countries mostly lack strong institutional and human capital for research and development. They may thus not be in a position to substantially contribute to the research and development, although the buyers' purpose may not be to gain new valuable research and development partners but instead to increase mitigation. For another thing, developing countries might consider such an offer as neocolonialist, in which wealthy industrialized countries extract concessions from poorer developing ones if the latter wish to join the formers' coalition. At the same time, developing countries may not see it as fundamentally distinct from current climate change policy linkages, such as the sometimes-implicit contingency of developing countries' mitigation efforts on technology transfer and climate finance from industrialized ones.

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 buy and sell additional mitigation via such linkage. On the other hand, those states that are skeptical or even opposed to solar geoengineering may value having input into research and development programmatic decision-making.

Finally, a conditional offer to participate in a research and development program implies a threat to exclude those states that do not increase their mitigation, which would be contrary to widely-shared scientific norms of cooperation and transparency. Although national and closed research and development is not uncommon in contested domains, cooperation and transparency are especially important in solar geoengineering (Rayner, Heyward, Kruger, Pidgeon, Redgwell, and Savulescu 2013; Craik and Moore 2014). In fact, the proposal could backfire on the founding buyers: 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.

A variant of R&D Linkage would take a harder line, making the above implicit exclusion explicit. In this *Nonproliferation Linkage*, those mitigation buyers that develop solar geoengineering allow access to the requisite technical knowledge and materials only to those sellers that mitigate more. This would increase both the incentive to join the club and the cost of not doing so. Nonproliferation Linkage would face several limitations, including most of those for R&D Linkage: solar geoengineering's uncertainty reduces the value of joining, the pool of interested states might be small, and it would run counter to scientific norms of transparency. Furthermore, knowledge and materials are difficult to control. In response, the buyers that found the linkage could also stipulate that, in order to join the club, the sellers would also need to commit to not share the salient information with nonmember states. Yet enforcing such a commitment would be challenging, as the sellers who acquire them could share them with other states, possibly surreptitiously. Moreover, other states outside the Nonproliferation Linkage club could develop or acquire the knowledge on their own. It also remains uncertain whether solar geoengineering would require a few unsubstitutable and unreplicable forms of expertise or materials that the developers could control and use as leverage, whether it would consist of numerous substitutable and replicable means and methods, or whether it would use easily accessible knowledge and materials.

Neither of these suggested linkages with solar geoengineering research and deployment is very promising. The relative increase in mitigation would be small, as the linkages might not appeal to many states and might offer little through joining. Moreover, they may be seen as contrary to the transparency that such a contentious avenue of research arguably warrants.

Potential linkage with whether to deploy

Policies regarding mitigation could also be strategically linked to those of solar geoengineering deployment. In this section, we consider linkages with whether to deploy, and in the next with how. Such a form of linkage was the first proposed. Gregor Betz suggested that actors, before undertaking solar geoengineering research, commit to implement it only when and if greenhouse gas emissions have been reduced to 90% of their 1990 levels (Betz 2011). Parson later called this *Reverse Linkage*, in which states agree beforehand to not use solar geoengineering unless they achieve some agreed-upon level of mitigation (Parson 2014).

Lin put forth what amounts to the opposite contingency, in which deployment would depend upon states' adoption of specific mitigation measures or strategies (Lin 2013:710). Parson's *Plan B Linkage* is similar but more robust, in that states may deploy solar geoengineering only if climate change and its impacts are severe (Parson 2014). In a way, this describes the default situation, in that if mitigation (as well as carbon dioxide removal and adaptation) successfully prevents dangerous climate change and its impacts, 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 implementation would be considered, endorsed, or condoned. The resulting lessened expectations of future conflict could reduce political barriers to serious research of solar geoengineering.

As Parson noted, both *Reverse Linkage* and *Plan B Linkage* would not be effective (Parson 2014). They each require long term, likely transgenerational commitments and thus could constitute "cheap talk" and be subject to reneging. Reverse Linkage would be an noncredible threat, in which states collectively implicitly threaten to withhold solar geoengineering if mitigation is insufficient – which would be the very circumstances in which it could most reduce impacts. Future decision-makers would likely renege on 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. Plan B Linkage, as noted, changes little from the present course. Neither linkage substantially increase states' incentives to mitigate greenhouse gas emissions. In fact, Reverse Linkage could give states' the perverse incentive to set unambitious targets in order to retain the right to use solar geoengineering.

To address some of these limitations, Parson suggested *Real-Time Linkage*, in which solar geoengineering would be implemented soon on a scale that would be small enough to limit risks but large enough to generate useful knowledge and resolve some uncertainties. Its commencement and continuation would be made contingent on states' ongoing strong performance on mitigation and other climate responses. But while Real-Time Linkage surmounts commitment intertemporal problems, it still leaves the condition for continuance or cessation as a collective target, whose satisfaction would be a global collective action problem. Furthermore, Real-Time Linkage would likely be a noncredible threat, in which leaders promise to stop pursuing solar geoengineering – a means to reduce climate change and its risks – if mitigation is insufficient. Like Reverse Linkage, this might cause states to simply set low targets.

All three of these linkages – Reverse, Plan B, and Real-Time – speak of states as a single, unitary block, when they actually are numerous with diverse interests and capabilities. None of them would resolve mitigation's international collective action problem. Consequently, states would need to establish a mitigation target, but each would be tempted to defect from cooperative efforts, that is, to free-ride. If their targets were internationally negotiated and collective, then each would work to minimize their expected mitigation. If the states proposed the targets themselves, then they would be unambitious. A possible rejoinder is that targets could be set separate from and prior to a linkage agreement. Satisfying linear progress toward already-established long-term targets, such as the Paris Agreement's 2°C goal, could serve as the criterion. Yet even this has its shortcomings. States could claim that they never intended linear progress toward long-term targets, but instead modest initial steps followed by accelerating mitigation. A second possible rejoinder to the collective action critique of these linkage proposals is that, as climate change increasingly manifests, all states would experience growing, shared impacts. Yet it remains unclear whether this would be enough to break a collective action logjam. Ultimately, international climate change policy must take advantage of states' variation, not ignore it (Nordhaus 2015).

Given these limitations, we here propose *Authority to Act Linkage*, in which one or more buyers proclaim their right to deploy solar geoengineering only if they meet their own mitigation targets *and* the rest of the world has failed to meet its. The founders of the linkage system would set these mitigation, for both themselves and the other states. Because the members would prefer to retain their option to use solar geoengineering without suffering reputational damage or reneging on a commitment, members would have the incentive to mitigate more. Nonmembers would have incentives both to mitigate and to facilitate it among other states to make deployment less likely. This assumes that they do not want, or at least not when it would be controlled by other states, an assumption that may not hold for all nonmembers. The members of an Authority to Act system would be those that perceive solar geoengineering as potentially beneficial and that could mitigate significantly more. If the founders were few, then they would also need to be "rogues." If they were moderate to great in number, then an international organization could have a role in facilitating the system's formation.

Authority to Act Linkage could have multiple variants. For one thing, the members could claim that they have the *exclusive* right to implement solar geoengineering, or they might not claim so. Doing so would increase nonmembers' incentives to mitigate emissions but would require that the members enforce their claimed exclusive authority over other states that might have deployment ambitions, implying a need for the founding members to be powerful. Second, the members could declare that their right to deploy solar geoengineering depends on the other states meeting a *collective* mitigation target or multiple *individual* targets. Third, individual targets among nonmembers and an asserted exclusive right to implement solar geoengineering would allow the founding members of linkage system to invite those nonmembers that satisfy their targets to join, further increasing incentives to mitigate. However, some members might resist this, as it would dilute their per-state influence. Fourth, the members' targets could likewise be a collective one or a set of individual levels. If they were individual, then the members could eject those that had not met them, although this may be politically difficult. Finally, members could promise to relinquish their right to use solar geoengineering if *either* they fail to meet their targets *or* the rest of the world sufficiently mitigates, or they might be ambiguously silent on this matter. In this way, the founders' promise would be, in game theoretic terms, a commitment strategy: they voluntarily decrease their payoff from a less preferable outcome in order to make a more favorable outcome more likely.

Authority to Act linkage would face several potential challenges, the first of which is *legitimacy*. As a starting point, its perceived legitimacy would likely correlate with its breadth and diversity of participation. At one extreme, an Authority to Act pledge by a single state or a handful of them might be considered an illegitimate threat that is contrary to widely-shared norms. At the same time, if these few states 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 wider and deeper global mitigation (in Morton 2015:348, 391). Alternatively, if the few founders were hegemons, 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.

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, a mechanism allowing for nonmember states that meet their individual mitigation targets to join the exclusive club could reduce the linkage system's potential divisiveness.

To a large degree, the perception of and demands for legitimacy would depend on the climate change context. If the members mitigated enough – and especially if their mitigation targets were ambitious – while the nonmembers did not, and if dangerous climate change impacts seemed imminent, then any subsequent solar geoengineering deployment on their part could be considered legitimate. After all, in this case the members had done their part to make deployment unnecessary while other states had arguably failed to do so. Some nonmember states might publicly condemn it while privately praising it. In contrast, if mitigation, carbon dioxide removal, and adaptation were already aggressive; solar geoengineering were understood as risky; and extant and expected climate change impacts were mild, then an Authority to Act assertion could be seen as an illegitimate power grab.

The second challenge of Authority to Act Linkage is the commitments' *credibility*, particularly as perceived by the nonmembers. This is relevant especially in the variant in which coalition members promise to not use solar geoengineering if they fail to meet their targets or other countries sufficiently mitigates. Consider the four possible outcomes suggested by the two criteria (see Table 1). If members reduce their emissions and nonmembers do not (quadrant C), then the coalition's implicit threat to deploy solar geoengineering would be credible, as it may benefit its members. (This would apply also in the variant without the promise.) But in the other three possibilities – all states mitigate (quadrant A), nonmembers do but members do not (quadrant B), or no states do (quadrant D), then would the coalition actually refrain from solar geoengineering, as promised? Clearly, climate change impacts are more likely to be greater in the latter cases (i.e., A < B < D). The members would be tempted to renege and implement solar geoengineering. And even if all states had met their targets, then impacts could still be severe due to climate surprises (such as higher climate sensitivity) or to unambitious targets.

Table 1. Four possible outcomes of Authority to Act Linkage with a promise to not use.

	Members mitigate	Members do not mitigate
Nonmembers mitigate	[A] Members pledge to *not* deploy: Promise is credible *if* targets are ambitious and climate change as expected or milder	[B] Members pledge to *not* deploy: Promise is questionable, especially if climate change is severer than expected
Nonmembers do not mitigate	[C] Members retain right to deploy: Implicit threat is credible	[D] Members pledge to *not* deploy Promise is noncredible

The third potential challenge is the Authority to Act coalition's *optimal size*, a factor that is related to both legitimacy and credibility. On the one hand, few members could increase the linkage system's effectiveness, as a smaller number could more readily make decisions, including those that would be expected to increase nonmembers' mitigation. Carried to an extreme, one could imagine a single state – perhaps a benevolent hegemon – declaring that its future solar geoengineering deployment would depend on whether the rest of the world adequately mitigates. On the other hand, more members would increase the linkage system's legitimacy. Yet too many members would come to resemble Reverse Linkage, which as described in the previous section, suffers from a perverse incentive to set unambitious mitigation targets and a non-credible commitment to withhold potentially beneficial solar geoengineering in the face of climate change. There thus appears to be a tradeoff between effectiveness and legitimacy, implying an optimal, moderate breadth of participation. This situation could be avoided if members had individual targets are were excluded from decision making or fully expelled if they failed to meet them.

A fourth issue is potentially problematic *relations among nonmembers*. To prevent presumably unwanted solar geoengineering, nonmembers would strive to meet their mitigation targets. If their target was a collective one, 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 might provide the motivation to overcome their collective action problem. Moreover, a sharp discontinuity in their payoffs, in which surpassing a threshold would significantly improve their welfares, can transform a difficult collective action problem. Specifically, a cooperation problem can become an easier coordination one, in which the issue is merely deciding which state(s) will additionally mitigate to put them collectively beyond the threshold. Side payments can facilitate resolving this issue. Alternatively, if nonmember states' mitigation targets were individual ones set by the members, then they would not face a collective action and free rider problem. However, once most of them satisfied their targets, then the remaining nonmembers 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 nonmembers are agnostic whether solar geoengineering is implemented.

The *stringency of the mitigation targets* is another issue. One way to consider the variant of the Authority to Act linkage with the promise to forego is as a market in which the buyers offer to abandon their right to use solar geoengineering. An efficient market would require, among other things, multiple buyers and sellers. Yet as described above, either the sellers are a collective block, or a final nonmember buyer could hold out. In these cases, the sellers could act as a cartel or a monopoly respectively. Such a situation could also result in the variant in which mitigating states may become a member, and a particular state was known to be essential for this. For example, a hegemon might be needed for legitimacy, or a high-intensity "rogue" to prevent it from deploying solar geoengineering on its own accord. To the extent that buyers and sellers would negotiate, it would resemble a bilateral monopoly, in which there is both one buyer and one seller. This could result in protracted negotiations characterized by bluffing, brinksmanship, and a significant chance of failure. Multiple competing Authority to Act coalitions would not offer a solution, given solar geoengineering's global effect and that some members might assert the exclusive authority to implement

Regardless, mitigation targets would be shaped by the members' motivations, which could not be reliably perceived. If the members genuinely preferred mitigation, then they would set reasonable targets. If perceived legitimacy was considered important, then members might set ambitious targets for themselves and modest ones for others. On the other hand, if they preferred solar geoengineering – perhaps covertly – and sought a legitimate means to deploy it, then they would declare modest mitigation targets for themselves and very ambitious ones for others.

The final challenging issue regarding the Authority to Act linkage is *complexity*. One could make the case this proposed linkage exceeds what is typical of international cooperation, especially that which is legal in nature. Yet the Authority to Act pledge need not be codified in a treaty but could instead be merely the members' declared policy. Furthermore, any codification would not be more complex than existing agreements found in issue areas such as international trade.

Despite these challenges, we believe that Authority to Act linkage holds potential to reduce mitigation displacement. Both members and nonmembers would have significant incentive to increase their mitigation. It would be self-enforcing, in that it would be in members' interests to eject defectors and free-riders because doing so would increase members' relative influence in decision-making. It is not necessarily contrary to widely shared norms, although in some conditions it could be seen as an illegitimate threat. Furthermore, none of the five potentially challenging issues that we identify – legitimacy, credibility, optimal size, relations among nonmembers, stringency of the mitigation targets, and complexity – seem insurmountable. Among the numerous possible variants and scenarios may be some that would be effective and satisfactory.

Potential linkage with how to deploy

Finally, international policy for mitigation could also be strategically linked to 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 targets may participate in collective decision-making regarding solar geoengineering, particularly setting its parameters such as which method and materials to use, when and where to intervene in the climate, and at what intensity. Parson originally suggested real time Pay to Play linkage, in which mitigating states would gain access to decision-making regarding ongoing solar geoengineering. 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. Pay to Play linkage could alternatively be interporal, in which current mitigation allows a voice in later decision-making.

Pay to Play Linkage resembles Authority to Act in many, but not all, ways. The founding states would need to expect that solar geoengineering would be used (if it had not already) and that it would benefit them. They would be buyers of additional mitigation, offering to share their decision-making authority, which is costly to them through its dilution. The coalition's membership could range from a single state to many. If few, the states would need to be "rogues," and if more, an international organization could help form the coalition. Those states that might mitigate more to join would be sellers. However, because the members would necessarily need to assert an exclusive right – in this case to set parameters – the mitigation targets would be individual ones, not collective. This means that nonmembers' mitigation efforts would not have a collective action problem within the linkage system. Furthermore, legitimacy would also be salient but less difficult because the Pay to Play members' asserted right would be more modest. And the coalition's threat to exclude those that do not meet their mitigation targets might not be credible if both 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 members, if powerful, could retain the explicitly claimed or implicit authority to decide whether to deploy solar geoengineering. As such, they are relinquishing less when they offer to expand the decision-making group. The coalition's optimal size would simply be large, as this would strengthen legitimacy while not presenting the perverse incentives and potentially noncredible commitments of a large Authority to Act coalition. Although the mitigation targets could still be inefficient due to bilateral monopoly and other market failures, the Pay to Play coalition members could not use the linkage as a ulterior vehicle to legitimize solar geoengineering. The states that are external to a Pay to Play coalition would face neither collective action, because their mitigation targets would be individual, nor holdout problems, because the final states to mitigate have no leverage over others. On the other hand, this means that nonmembers would lack incentives to facilitate each other's mitigation.

It seems doubtful that a Pay to Play coalition would on its own have substantial influence over states' mitigation. If the average preferences of the existing and a potential member are similar, then the latter would see little value in joining because doing so would have little effect on the outcome (Ricke, Moreno-Cruz, and Caldeira 2013). Additional states would thus mitigate more to join the coalition only if their preferences regarding deployment's parameters differed significantly from those of the coalition's existing members. Furthermore, in the presumed absence of counter-solar geoengineering, Pay to Play linkage would have more potential if the nonmembers were low-intensity states and international cooperators. In these circumstances, they would mitigate more to prevent solar geoengineering at a level greater than their preferences. If instead the they were high-intensity states and "rogues," then the nonmembers would simply undertake additional deployment themselves. In total, it requires the founding and prospective members to have rather specific characteristics, and its appeal to the latter group could be limited.

Conclusion

The most widespread concern of solar geoengineering is that of mitigation displacement. Here, we discussed several possible linkages of mitigation and solar geoengineering policies. In truth, the distinctions between them are not sharp, and one could imagine how one linkage mechanism could evolve into another. Nevertheless, some appear to have more potential to satisfy our objectives of increasing expected mitigation, being feasible, and not being inconsistent with widely held norms.

Of the potential linkages considered here, we believe that Authority to Act has the greatest potential. There also appears to be a possible path toward its implementation. It could be announced by a small club of powerful, influential, or climate-vulnerable states. If targets are individual, not collective, then the group could expand through mitigating nonmembers joining. This individualization would also address collective action problems. Moreover, a combination of

Authority to Act and Pay to Play linkages could be particularly effective. In this, a nonmember's satisfactory mitigation would allow access to decision-making regarding both whether and how to use solar geoengineering. This could utilize two tiers of individual targets for nonmember states: a modest one for Pay to Play and a more ambitious one for Authority to Act. We encourage other scholars, thought leaders, and policy makers to consider these linkages.

The limitations of linking mitigation and solar geoengineering policies in general must be recognized. Perhaps most importantly, these rest on the basic assumption that states' preferences regarding the two response options are related. This might not be the case. States – some of which could be hegemons – might simply resist solar geoengineering independent of mitigation and, indirectly, climate change impacts. Alternatively, their actual mitigation pathways might turn out to be so strongly shaped by other forces that solar geoengineering policies are not influential. For another thing, mitigation and solar geoengineering policies operate on different timescales that may make them difficult to link. The effects of the former are delayed, in that new policies require some years before lower emissions are evident, whereas decisions regarding solar geoengineering research and development, whether to deploy, and how to deploy are mostly experienced quickly. This suggests that linkage might be with policies that are expected to result in mitigation, with some sort of subsequent mechanism to assess their actual results. Finally, we assess the proposed linkage mechanisms on the basis of, among other criteria, the extent to which we expect them to increase mitigation relative to some (unobservable) baseline. This does not directly address the concern regarding mitigation displacement, which occurs in numerous conscious and subconscious decision-making processes. This might simply be an intractable problem.

This article is by nature incomplete, and we suggest a few lines of potential further inquiry. First, we have offered three important characteristics of states regarding mitigation and solar geoengineering: buyers and sellers of additional mitigation, cooperators and "rogues", and low- and high-intensity preferers. How mitigation and solar geoengineering policies could be linked depends in part on how these characteristics correlate. One reasonable hypothesis is that buyers of additional mitigation desire less climate change and thus would usually prefer a greater intensity of solar geoengineering. Although such a correlation can be expected, there are a few reasons why it would be imperfect.[4] Another hypothesis that seems reasonable, at least initially, is that high-intensity states would be more willing to deploy it despite potential international condemnation. However, we are less confident regarding this suggestion. In the current political landscape, states that are willing to act contrary to the international community's wishes appear only weakly correlated with climate change vulnerability.

Second, and related, although we address, to some extent, how linkages of mitigation and solar geoengineering policies could form, our consideration remains limited because we do not specify countries. Subsequent analyses could identify which actual states are likely to act and which might resist. They could also be made more salient – and complex – by removing the assumption that all states seek to return the global climate to closer to preindustrial conditions.

Third, our descriptions remain qualitative, informal, and somewhat vague. Although this is satisfactory for an initial exploration, formal models could help identify potentials, limitations, and risks of these and other proposed linkage mechanisms.

Fourth, we consider linkages between policies for only mitigation and solar geoengineering, yet climate action also includes adaptation, finance, and carbon dioxide removal. More complex linkage proposals among policies in all these domains could further enhance mitigation.

Finally, we introduce a framework for understanding issue linkage in climate change as an mitigation market. This could have applicability beyond solar geoengineering. For example, can well-established market failures explain why there is so little issue linkage in the climate change policy space?

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[4] For one thing, mitigation prevents climate change globally whereas solar geoengineering – as it is presently understood – would be more effective at low latitudes. Second, a state with a strong "green" environmental voting base might prefer more mitigation yet be hostile to solar geoengineering. Third, states might prefer one response over others for strategic reasons.

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

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