Stephen M. Gardiner[1] & Catriona McKinnon[2]

Generationally Parochial Geoengineering: Early Warning Signs of a Basic Threat

'Geoengineering' has come to refer to massive technological interventions into fundamental earth systems on a planetary scale, often with the aim of counteracting human-induced climate change. Despite a burgeoning literature, some ethical issues surrounding geoengineering remain under-analyzed, barely identified, or in effect ignored. We are interested in one such issue, the threat of generationally parochial geoengineering (GPG): geoengineering that is dominated by the narrow, generation-relative concerns of a given generation engaging in the intervention, without due consideration for wider concerns, including especially the interests of later generations. In this paper, we develop the basic idea and identify some early warning signs in the current discourse, focusing on stratospheric sulfate injection, a form of solar radiation management. Our emphasis is on motivating the claim that generationally parochial geoengineering is a threat that should taken seriously at all levels of work on geoengineering, including research, development, and deployment.

[1] Professor of Philosophy at the University of Washington, Seattle. E-mail: smgard@uw.edu
[2] Professor of Political Theory at the University of Exeter. E-mail: c.mckinnon@exeter.ac.uk

> "There is a kind of parochialness in time. How many writers have there been who have expressed the aspirations of their own generation only?"[3]

1. Introduction

Despite a burgeoning literature, some ethical issues surrounding geoengineering remain under-analysed, barely identified, or in effect ignored. In this paper, we explore the threat of generationally parochial geoengineering ('GPG'): geoengineering that is dominated by the narrow, generation-relative concerns of a given generation engaging in the intervention, without due consideration for wider concerns, and especially the interests of later generations.[4] In our view, thwarting GPG ought to be a central concern of both the ethics of geoengineering, and any serious scientific, political or policy discussion. Unfortunately, this is not yet the case: existing proposals for geoengineering research and governance are largely silent on the threat, and some may even encourage it.

This neglect is lamentable, but also sadly predictable. It underscores the difficult context in which interest in geoengineering is emerging. The history of international climate policy is largely one of severe moral failure, which has now led to a climate emergency. Advocates for pursuing geoengineering aim to moderate the crisis, but tend not to dwell on the underlying nature of the problem that leads to it, nor its implications for their proposed solutions. This is a dangerous omission. Specifically, in our view the climate problem is best understood as a severe ethical challenge that Stephen Gardiner calls 'a perfect moral storm' (Gardiner 2011). On this analysis, two of the main drivers of moral failure are serious discrimination against the future (roughly, Gardiner's "intergenerational buck-passing") and the distortion of the ways we think and talk about climate change, often under the influence of narrow, short-term, and self-serving motives (roughly, Gardiner's "moral corruption").[5]

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[3] 1906 Academy 20 Oct. 391/2, cited by OED.

[4] This is not the first time the threat of GPG has been raised. Gardiner mentions it briefly in several places (e.g., Gardiner 2011a, 2011b, 2017). We aim to flesh out the concept and show that the threat is live in practice.

[5] Gardiner motivates the general idea of moral corruption by drawing on a passage in Kant (306). Based on that passage, he says that "moral corruption is: (a) a tendency to rationalize, which (b) casts doubt on the validity and/or strictness of moral claims, by (c) seeking to pervert their status and substance, and in doing so (d) aims to make those claims better suited to our wishes and inclinations, and (e) destroys the characteristics in virtue of which we respect them (e.g., what Kant calls their "dignity")" (307). He remarks that moral corruption "strikes at our ability even to understand what is going wrong in moral terms, by subverting moral discourse to other (usually selfish) ends" (305). While Gardiner does not take himself to be offering a precise definition of 'moral corruption', he takes his discussion to be "sufficient for present purposes" (Gardiner 2011, 303-307).

In this paper, we pursue the idea that geoengineering policies are at least as vulnerable to these drivers as more conventional strategies. In the first half, we explore the concept of generationally parochial geoengineering; in the second half, we identify some early warning signs in the current discourse in science and policy. Our focus is on motivating the claim that the risk of GPG should be taken seriously at all levels of work on geoengineering, including research, deployment, governance, and institution-building.

2. Context

Roughly-speaking, we take the term 'geoengineering' to refer to deliberate technological interventions into fundamental earth systems on a massive, typically planetary, scale.[6] Currently, such interventions are being proposed with the aim of counteracting human-induced climate change. While numerous techniques have been suggested, we will focus on stratospheric sulphate injection ('SSI'), the proposal to spray sulphate particles into the stratosphere in order to deflect a fraction of incoming sunlight back into space and so moderate anthropogenic warming.

We choose SSI for three reasons.[7] First, SSI is at the centre of current controversies. It is the focal strategy for geoengineering scientists, already prominent in public discussion, and likely to become more so as the climate situation deteriorates.[8] Second, everyone agrees that SSI is a paradigm case of geoengineering. Third, since SSI is a paradigm case, it is plausible that many lessons from our analysis will carry over to other forms of geoengineering (albeit with suitable modifications for differences in salient features and context). For the rest of the paper, then, assume that when we speak of geoengineering, we have SSI in mind.

One reason geoengineering is being discussed is the emissions crisis. The central goal of international climate policy, agreed over thirty years ago at the Rio Earth Summit, is to protect current and future generations against "dangerous anthropogenic interference with the climate system" (United Nations 1992). In Paris in 2015,

[6] Our definition is broadly similar to the Royal Society's (Shepherd et al, 2009), but does not include combating climate change as part of the definition.

[7] The recent literature tends to use the broader term 'stratospheric aerosol injection' ('SAI'). One reason is that some scientists are now actively discussing using particles other than sulphates, including artificial particles especially engineered for the purpose. We prefer to stick with the narrower term, SSI, in part so as to leave open (for now) the question of whether a slide towards the broader term, SAI, raises further issues. Consider two examples. First, we are concerned that some forms of SAI involve introducing novel, artificial particles into a delicate part of the climate system. Second, we wonder about the implications of breaking the so-called "natural analogy" with volcanic eruptions. Among other things, neglecting such differences between SSI and SAI may facilitate moral corruption.

[8] See, for example: Crutzen 2006; Cicerone 2006; Gardiner 2007, 2011; Hamilton 2013; Keith 2014; Preston 2012, 2016; Gardiner, McKinnon and Fragniere 2021; Stephens et al. 2021; Biermann et al. 2022.

the international community declared that this requires "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C" (United Nations 2015; 2009; IPCC 2018). Unfortunately, the world is not close to meeting these goals through cutting greenhouse gas emissions, and time is fast running out. Indeed, some authorities claim that there is now 'no credible pathway to 1.5C' (UNEP 2022).

The emissions crisis helps to explain the appeal of radical geoengineering interventions. Advocates claim that SSI in particular can reduce the urgency of the crisis by moderating climate impacts and altering the political landscape. In a raw form, the initial standard arguments include: SSI will cool the planet quickly and relatively cheaply; SSI will "buy time" for more traditional mitigation efforts; in developing SSI we will be "arming the future" by equipping younger generations with technologies that can limit warming late in the century; and SSI provides a "last resort" to deploy in the case of a climate emergency.

Importantly, the initial arguments have been subjected to sustained scrutiny over a prolonged period.[9] Notably, some of the critical feedback aims to block the pursuit of SSI altogether, while some seeks instead to reshape it, particularly in a more just or ethical direction. Either way, we believe there should be a presumption against simply accepting the initial, standard arguments for SSI at face value, without further, more sophisticated development, and in particular without learning from the implications of engaging with the critics.

Despite this, in practice the standard arguments appear to be becoming highly influential as the emissions crisis continues to intensify. Notably, calls for pursuing SSI have now become mainstream in science and policy circles. For instance, recently a major report from the National Academies of Science, Engineering and Medicine advocated for a US research program, and the effort has garnered wider support from editorials in influential venues, such as *Nature* and the *Economist* (e.g., Economist 2021; National Academies of Sciences 2021; Nature 2021) as well as major think tanks, such as the Council on Foreign Relations (Patrick 2022)).

Indeed, we are concerned that SSI may soon become normalized, without much public discussion or serious deliberation, and with only marginal attention being paid to the social and political issues it raises (e.g., Gardiner 2010, 2020; Stephens et al. 2021; Biermann et al. 2022). One sign that this may occur is that large-scale deployment of another class of geoengineering technologies, carbon dioxide removal

[9] Critical voices include: Jamieson 1996; Gardiner 2007, 2010, 2011ab, 2013ab; Hulme 2012; Preston 2012, 2013, 2016; Hamilton 2013; Fragniere and Gardiner 2016; McKinnon 2019, 2020; McLaren and Corry 2021a; Gardiner, McKinnon, Fragniere 2021. The initial arguments for pursuing SSI also have their defenders (e.g., Svoboda 2012; Morrow and Svoboda 2016; Moellendorf 2014; Morrow 2020; Callies 2022).

(CDR), is already being *assumed* in mainstream scientific projections (e.g., IPCC 2018). Notably, this prominence is being given to CDR even though the main techniques being discussed are poorly understood and largely untested. Indeed, most are *highly speculative*: they either do not yet exist, or are in very early stages of investigation. Given this, large uncertainties hang over whether a massive deployment of CDR is likely to be feasible, on what timescale, and with what risks (e.g., Burns and Nicholson 2017).

3. Generationally Parochial Geoengineering

Over the last three decades, an established academic literature on the ethics of SSI has emerged.[10] This literature identifies a wide range of concerns. Prominent issues include that unethical forms will emerge that encourage or embody serious injustices, including procedural injustice, substantive injustice, and injustices centered on a lack of recognition of diverse values and populations. Some more specific ideas are that actual SSI is likely to be politically illegitimate, encourage moral hazards (such as mitigation deterrence), increase militarization, actively facilitate (or enhance the potential for) oppression by powerful actors, and pose risks to future generations.[11] In our view, this literature is valuable. However, some parts remain underdeveloped and often underappreciated. In this paper, we highlight the threat of generationally parochial geoengineering, a specific kind of intergenerational injustice that involves the *way* in which geoengineering is pursued, including the *kinds* of research programs, interventions or policies that find favor. In highlighting the threat of GPG, we hope to establish it more firmly as a central concern for geoengineering ethics and policy. While we do not believe that recognizing the threat should diminish or supplant other concerns, we also maintain that GPG should not be marginalized or set aside in favor of them. SSI raises many challenges. GPG should be considered in the core group. One reason is that minimizing discussion of GPG encourages intergenerational moral corruption.

[10] For a few examples, see previous footnote. Pamplany et al. 2020 provides a useful (though incomplete) survey of the literature, covering more than three hundred sources from 1996-2020; Fleming 2010 puts the discussion in a wider context. Notably, sometimes the discussion is subsumed under broader terms such as 'solar radiation management' (SRM), 'solar geoengineering' (SE), 'climate engineering', or 'geoengineering' in general. Even then, SSI is typically the focal point of discussion.

[11] Pamplany et al. identify two waves of research so far. The first is characterized by broader, multi-dimensional analysis; the second tends to focus on particular criticisms, most of which were already raised in the first wave, albeit often in less detail. Thus, the concerns listed in the text characterize both waves.

3.1. 'Parochialism'

In general terms, an approach or attitude is parochial if it is "limited or provincial in outlook or scope", or (more robustly) "concerned with only narrow local matters without regard for more general or wider matters".[12] In common parlance, 'parochialism' has come to have negative connotations, signaling a kind of disapproval. For example, the *Collins English Dictionary* characterizes the primary meaning of 'parochial' by saying: "If you describe someone as *parochial,* you are critical of them because you think they are too concerned with their own affairs and should be thinking about more important things". This negative sense of 'parochial' is the one we have in mind in putting forward our term, 'generationally parochial geoengineering' (GPG). GPG refers to geoengineering that is dominated by the narrow, generation-relative concerns of a given generation engaging in the intervention, *without due consideration* for wider concerns, including especially the interests of later generations of human and nonhuman life over the longer term. Thus, GPG involves *a lack of due consideration or proper regard* for wider matters, and in particular substantive and procedural ethical concerns. For instance, under many circumstances, GPG will entail a neglect of rights, justice, and well-being.

We see GPG as one member of a family of troubling parochialisms that could take hold in the geoengineering context, including nationally-parochial geoengineering, corporately-parochial geoengineering, culturally-parochial geoengineering and anthropocentrically-parochial geoengineering.[13] While all these various parochialisms deserve more attention, here we focus on generationally parochial geoengineering. One reason is that GPG remains underexplored, especially in the context of actual climate policy. Another reason is that many of those who stand to be damaged by GPG are politically disadvantaged and indeed often invisible, since they are not

[12] The generic form of parochialism can sometimes be ethically defensible, for instance when (i) the agent has a special responsibility towards the narrow concerns and (ii) others can be relied upon to promote and protect the wider ones. Thus, it is sometimes reasonable for local politicians to prioritise what will most benefit their constituents over (say) national goals. Still, much depends on assumption (ii). Without (ii), it is at best unclear whether those with special responsibilities are absolved of wider claims that might be made on them.

[13] Most obviously, *Nationally Parochial Geoengineering* is geoengineering that is concerned only with the narrow, national concerns of the country then engaging in geoengineering. For instance, country X may deploy the form of SSI that it believes best protects its own agricultural systems, but be indifferent to the severe droughts this inflicts elsewhere. Similarly, *Culturally Parochial Geoengineering* is geoengineering that is concerned only with the narrow culturally specific priorities of a particular dominant culture. For instance, forms of SSI may emerge that are oriented toward preserving Western consumer society, but indifferent to the needs of traditional tribal peoples and values that are central to their ways of life. One example might be SSI aimed at protecting only against a high temperature threshold (e.g., 2-2.5°C), where that does nothing to prevent the loss of small island nations or the Amazon rainforest.

yet born, or are too young to resist. Thus, we in the current generation have a special responsibility to raise concerns on their behalf that they cannot.[14]

3.2. An Illustrative Example

To illustrate GPG, let us sketch a stylized example that we take to be a paradigm case.

> *Elders-First Geoengineering*: Suppose that the current generation of political, economic, and scientific leaders in a powerful, advanced, consumerist society primarily represents and is constituted by those over fifty-five. Call this leadership class "the Elders", and the country they lead "Boomerland".
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> The Elders become concerned about climate change and the deteriorating situation. Given this, they decide to push ahead with SSI research, aiming to develop a deployable technology as soon as possible. However, rather than trying to limit future warming as such, the core intentions of the Elders are (first) to protect *their generation* from impacts that arise during their own lifetimes, and (second) to continue to enjoy their high consumption lifestyles. In other words, the only negative climate impacts that concern the Elders are those occurring over (say) roughly the next few decades. Consequently, they are drawn to the idea of a relatively short-term "technological fix" that does a reasonable job of holding off the worst effects of climate change for around (say) forty years. They therefore support restricted research and development targeted at interventions that fit this profile, and some forms of SSI look promising.
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> Unfortunately, it turns out that these forms of SSI also pose extreme risks to younger generations, including some alive late in this century but especially those around in the 22nd, 23rd and 24th centuries. These risks are more severe even than those of substantial climate change (e.g., because SSI encourages runaway climate change, or due to the possibility of termination shock amidst climate breakdown). However, the Elders are either indifferent to these later risks, or at least not highly motivated to prevent them. Notably, this is so even though other, more ethically attractive policies are available, including some that involve SSI done in a different way, or as part of a different portfolio of policy options. Alas, the Elders are simply not interested in alternatives, or in ethics; e.g., they are generationally ruthless, or self-absorbed, or cowardly (see below our discussion of the possible roots of GPG).

[14] The same holds for anthropocentric parochialism and some kinds of cultural parochialism.

> The Elders use their disproportionate power in society to push forward development of their short-term "geoengineering fix", and Boomerland ultimately ends up deploying their preferred form of SSI. As it turns out, this deployment does hold off the worst impacts until late in the century (as intended); however, it then unleashes increasingly catastrophic impacts over the next three centuries (as foreseen). Thus, while it protects the Elder generation, the policy ultimately causes suffering on a global scale, and in ways that are clearly ethically indefensible (by assumption). Humanity ultimately survives, but only barely.

The purpose of the stylized *Elders-First* example is to sketch a paradigm (and thereby uncontroversial) case of a geoengineering scenario that would be rejected by any reasonable moral or political philosophy. For instance, one might say that, other things being equal, any generation acting as the Elders do is (at best) reckless with respect to the basic rights, interests, and needs of future people, and (at worst) engaged in deliberate aggression against them. We expand on this thought shortly. Before doing so, let us explore the richness of the notion of GPG.

3.3. A Big Tent

'GPG' refers to geoengineering that is dominated by the narrow, generation-relative concerns of a given generation engaging in the intervention, without due consideration for wider concerns, including especially the interests of later generations of human and nonhuman life over the longer term. This characterization leaves much open. Since instances of intergenerational parochialism might vary along various dimensions, GPG is a "big tent". To illustrate this, consider just four such dimensions.

First, GPG might involve different *agents*. Some salient possibilities include that the parochial generation may be: the current generation of political leaders (e.g., those controlling the corridors of power over a few election cycles, or those presiding over a despotic reign); or the current generation of social decision-makers (e.g., those in positions of power aged 40–80, who largely determine the political leaders); or the current generation as a whole (e.g., in a highly democratic state).

Second, the *time-frame* over which generational parochialism is operative can vary. For instance, those over 55 may favor SSI that holds off the worst impacts of climate change for, say, 40 years, whereas those over 35 may prefer 60 years, and those over 15 years old may prefer 80 years. Alternatively, perhaps the relevant group is all those alive now, who would like to protect their own children and so prefer technologies that defer truly nasty climate damages for 100–150 years. Although

these time-frames are very different, the basic dynamic of generational parochialism remains.

Third, the *epistemic* conditions of the relevant agents might diverge. For instance, while generationally parochial SSI may arise under *active awareness* of consequences for the longer-term future, it may also occur under limited knowledge or even ignorance. Notably, these do not automatically excuse the parochialism. For example, the epistemic deficits may themselves result from indifference, including a failure even to investigate the relevant implications of SSI beyond a few decades. Under many circumstances, this would amount to intergenerational negligence by the current generation.

Fourth, GPG may have various *roots*. For instance, one salient possibility is that a given generation is *ruthless*: it strongly prefers to advance its own interests, and does not care about the burdens this imposes on future generations. Alternatively, a generation may be *self-absorbed*: it is so focused on what happens to itself, in its own time, that it fails even to seriously consider what happens to its successors. Another potential root is *cowardice*: the generation lacks the moral courage to make the necessary choices on behalf of the future, perhaps because these choices would demand more of it than geoengineering. Importantly, all of these possibilities are dangerous, not least because they open the door to injustice, perhaps of severe forms.

Considering the various dimensions of temporal parochialism, GPG clearly covers a wide range of possible scenarios. Putting a few variables together, we can identify some variants of the paradigm case that may serve as useful touchstones. Among the more obvious are:

- *Last Dance Politicians*: A senior generation of political leaders (e.g., those aged 65 and over) pursues SSI that it hopes will hold off the worst impacts of climate change "on their watch" and immediately afterwards (e.g., for 20–30 years), even with the awareness that their intervention will likely make the situation much worse thereafter.

- *Greedy CEOs*: The current generation of corporate leaders pursue SSI that would hold off the worst impacts of climate change for a few decades and so preserve their power and profits, showing no interest in the impacts thereafter.

- *Generational Elite Capture*: The current generation of social decision-makers (e.g., those in positions of power aged over 45) pursues SSI that holds off the worst impacts for 50 years and fails to investigate the implications for later generations.

Among the less obvious, but still highly salient, scenarios are:

- *Those We Love Now*: The current generation of social decision-makers (e.g., those in positions of power aged over 45) pursues SSI that holds off the worst impacts for itself and its children (say, for 80–120 years), but fails to investigate the implications for later generations.

- *An Unholy Alliance Against the (Further) Future*: Young adults and particularly vulnerable communities cooperate with older generations in backing a climate policy (a) that pursues SSI to hold off the worst in the short-term when the older generations are around to benefit (e.g., 30–40 years), (b) in exchange for medium-term adaptation measures that help to protect the current young over much of their lifetimes (e.g., 50-60 years), (c) while accepting that this approach worsens impacts in the further future (e.g., after 80 years).

- *An Intergenerational Arms Race*: A succession of generational agents each seeks to postpone negative climate effects that would fall on themselves by shifting the worst impacts to the future. The cumulative effect of all this buck-passing is to compound those negative effects on some generations in the further future, dramatically driving up the risk of eventual catastrophe, perhaps to the point where it is inevitable (cf. Gardiner 2011b, chapter 6).

3.5. Normative Roles

A further aspect of the richness of the GPG analysis concerns the variety of roles it can play in normative contexts. To begin with, in our view, generational parochialism is a *generic ethical challenge*, to which any ethical tradition will want to respond. Notably, neither the definition nor the cases mentioned above specify the precise normative content of the ethical concern raised by GPG (e.g., by fleshing out the central idea of failing to give 'due consideration' to wider, intergenerational concerns). For instance, the worry that GPG identifies is not indexed to a specific set of normative concepts (e.g., human dignity, impartiality, rights, equality, sufficiency, just savings), nor associated with a particular ethical tradition (e.g., Kantian ethics, utilitarianism, virtue ethics, ethics of care). Instead, the background idea is that GPG is and ought to be a cause for concern *whichever* normative framework or ethical tradition one favors.[15] For example, GPG can be objected to as a failure of impartiality, a lack of respect for future human rights, or a failure to secure conditions

[15] Some may reject this burden. Perhaps they reject intergenerational justice or ethics in general (e.g., because they maintain that self-interest is the only or overriding concern), or perhaps they believe that

sufficient for future people to flourish, or all of these at once. Deciding which is the right approach is an important task within intergenerational ethics, but the concept of GPG does not presuppose a particular answer. This is a matter for deeper theory.

We cast our net widely for a reason. We take the ability of an ethical framework to confront the tyranny of the contemporary to be a *condition of adequacy* for that framework, and one through which rival traditions might be compared and judged. In other words, we see avoiding generational parochialism (here in the context of geoengineering) as a test for ethical theories in the same way that endorsing universal suffrage is a test for theories of democracy. Approaches to ethics will want to show that their central concepts are well-suited to make sense of and neutralize the intergenerational threat. If a given approach directly encourages GPG, then it is in trouble.[16]

Nevertheless, our concern in this paper is elsewhere. We aim to make the case that there are good reasons to treat GPG as a *live threat*: given how actual discussions of SSI have been evolving, there are serious concerns that the situation is primed for GPG to emerge. Given this, our focus is on what one might call "providing *guidance against temptation"*. We wish to alert relevant parties (e.g., scientists, policymakers, the public at large) to the general threat of GPG, to help them recognize ways in which more concrete practices may encourage GPG, and to point out some places where generational parochialism may already be creeping in. Our hope is that increased awareness will act as a *first line of defence* against GPG, and so help to forestall or pre-empt the worst excesses. That being said, we are not optimistic that awareness will be enough by itself. In our view, further, institutional defences will ultimately be required to check GPG, some of which are likely to involve radical shifts away from the status quo (e.g., Gardiner 2014a, 2019; Gonzalez-Ricoy and Gosseries, 2016; McKinnon 2017, 2021; see below).

This focus on providing guidance against temptation has implications for how one should understand the kinds of evidence we are looking for, and how that evidence should be treated, when we turn to early warning signs. Since we intend simply to make the case that there are good reasons to regard GPG as a live threat, we are looking for grounds for *reasonable suspicion* that there is a risk of GPG emerging. Identifying early warning signs can serve to put us on our guard by suggesting that there is *an initial case to answer*.

Importantly, this focus is very different from that of *convicting* particular agents

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it is never inappropriate for the current generation to ignore the concerns of other generations. We find such views unpalatable. In any case, we leave them aside here.

[16] This claim is not inconsequential. For instance, some will argue that conventional cost-benefit analysis – i.e., that based on projections of current market prices, and employing standard positive discount rates, such as 5% - fails the test.

of GPG. Although such criticism might be of interest in the future, especially to future generations, this is not our purpose here. Rather than censure, our primary aims are redirection, resistance and reform. It is largely our generation that needs to act, and not succumb to the temptation of intergenerational buck-passing. Since we are the ones implicated, much of the point of identifying GPG is to influence our behaviour, by showing us what is at stake and putting us on our guard, and to prompt institutional reform. Conviction and censure are not necessary to achieve this; moreover, they may end up being beside the point, as they are likely to come too late.

One important consequence of the focus on redirection and reform is that we should not be fixated on satisfying the high standards of proof that are often taken to be needed for the purposes of conviction or blame. Instead, we can be content with much lower levels of evidence. In particular, we are interested in evidence that is *sufficient to activate a duty to protect* the future against the predictable threat of GPG. In light of this, we should not, for example, direct our attention to trying to establish that GPG is present "beyond reasonable doubt". Instead, noticing that there is a reasonable suspicion of GPG, or even merely a lurking danger, can be enough. This level of awareness should be sufficient to put those working on geoengineering interventions on their guard to look out for signs of GPG, and help them to develop a sensitivity for problematic practices or assumptions that may facilitate GPG. For example, it can make them alert to potential blind spots or implicit biases in geoengineering research or policy. Reasonable suspicion of GPG also helps to ground the wider case for institutional reform, and to suggest that a specific goal of such reform should be to confront GPG. In this way, there are parallels between raising awareness of the threat of GPG and confronting other social problems, such as subtle forms of gender bias or institutional racism.

Our fourth point is that (perhaps surprisingly) investigation of GPG can be worthwhile even if our initial arguments fail to establish that there is already a case to answer. For active engagement with the possibility of GPG itself heightens awareness in ways that make it less likely that generational parochialism will emerge in the future. Once relevant groups, such as scientists, policy professionals, government officials, institutional reformers, and the general public, start checking geoengineering proposals for the possibility of generational parochialism, this encourages a positive feedback loop whereby GPG is more likely to be confronted at all levels, including at the earliest stages and in foundational assumptions. Thus, paradoxically, it can turn out that highlighting the threat of generational parochialism can be successful in providing guidance even if no actual instances of GPG are ever shown to have occurred. Indeed, in some ways that is the best-case scenario for the project as well as for humanity.

Our fifth and final point about the normative character of GPG and our interest

in it is more substantive. Despite all this modesty, it is true that our own concern about GPG emerges from a particular mindset about the appropriate ends and framing of geoengineering policy. Most centrally, in the background is our belief that ultimately (if pursued) SSI should be seen and assessed as a global, intergenerational, ecological, and ultimately ethical project: one aimed at protecting the interests of humanity (and nonhumans) at large across generations, in accordance with appropriate ethical norms, including norms of justice.[17] This mindset invites the further claims that research and governance should be developed in an ethically responsible way, keeping the global project in mind. Among other things, this suggests that research should also be aimed at protecting the concerns of humanity at large across generations, and that governance should be appropriately responsive to the interests and rights of people globally and intergenerationally (e.g., Gardiner and Fragniere 2018). In light of all this, a focal question for us is "How would future generations view the current pursuit of SSI?"

In the following sections, we turn to this question. Before doing so, however, we want to note one caveat. Our endorsement of a global, intergenerational, and ecological perspective on the appropriate aims of geoengineering is very different from an alternative mindset that claims that geoengineering should be seen as a nationalist project. We do not begin from the place of "America First SSI" or "China First SSI" or "Russia First SSI", and so on. Presumably, it is *possible* that such alternative beginnings may lead to ethically-acceptable outcomes at the global and intergenerational level. However, we are not focused on mere possibility, but on *plausibility*. Importantly, such plausibility would need to be shown, not simply assumed.

Sadly, we are pessimistic. One reason arises due to concerns about competing geoengineering interventions and counter-interventions, multiple-invocations of rights of self-defence, and the prospect of a geoengineering arms race that might be even more dangerous than severe climate change itself (e.g., Gardiner 2013a). However, another reason (particularly salient for this paper) is that nationalistic geoengineering is also vulnerable to GPG. It is not hard to imagine that some nationalistic forms of SSI may be beneficial for the first generation or two of (say) Chinese, Russian, or American leaders deploying it, but much worse for future generations *of those same peoples*. Thus, true nationalists – those who genuinely care about the *long-term* interests of their own countries, and not just about a few fellow nationals alive now – should also have serious concerns about GPG.

[17] See, for example, the first Tollgate principle for governing geoengineering (Gardiner and Fragniere 2018).

4. Specific Early Warning Signs

Let us now look at some specific ways in which the existing scientific and policy literature may encourage GPG, including by obscuring, disguising, or even actively facilitating it. Again, our focus will be on suggesting reasonable suspicions and a case to answer (not on conviction or blame). Again, the overall aim is to encourage a mindset fit to minimise the risk of GPG at various levels (including research decisions, norms, and institutional reform).

4.1. Research

We begin with the framing of research questions in various venues, including models, scenarios, and so on. For instance, climate and earth system models simulate interactions between the various drivers of climate change in order to heighten understanding of the climate system and project future climate change; geoengineering models do the same thing for SSI. Similarly, integrated assessment models simulate interactions between physical and social systems. Almost all current research on SSI takes the form of modelling and scenario building. Yet several common features of these exercises give cause for concern.

Sign 1: Short Time-horizons

The first is the number of years into the future for which models are typically run. The effects of SSI are likely to play out over a very long time-period, of the order of at least many decades, probably several centuries, and possibly thousands of years (e.g., IPCC 2014, 73–74). Yet the overwhelming majority of models have a much shorter time-horizon. For instance, in physical science the models typically focus only on the *next 10-50 years* when estimating the impacts of SSI (Kravitz and et al 2014; Eastham et al. 2018) and a few extend the horizon *only to 100 years* (e.g. Moreno-Cruz and Keith 2013).

This emphasis on short time-horizons also appears to be present in common choices of scenarios for policy analysis. For example, the editors of a recent collection on geoengineering scenarios – two leaders in the field – assert: "to be useful, ... creators and users must judge the scenario, or a similar pattern of events, as sufficiently likely to merit their attention and consideration in planning", yet they go on to say that **"***all [scenarios* in this collection] were set in the year *2040*" (Parson and Reynolds 2021, 5–7, emphases added).[18] Another example comes from conventional economic analysis. Referring to the dominant economic model (DICE), a

[18] They add: **"**This date was chosen to be near enough that scenarios are not dominated by vast technological or socio-political transformations and their relevance for near-term decisions is clear, while also being distant enough that greatly strengthened social and political forces promoted solar

recent paper on the economics of geoengineering states: "As with most applications of DICE, we are not interested in the very long run" (Belaia et al. 2021).

These choices of relatively short time-frames for research in science, economics and policy provide *prima facie* evidence that mainstream efforts to understand SSI are likely to be preoccupied with impacts on current adults and, at most, their children. It is easy to see why a focus on short time-frames encourages GPG; one might even say that it is a hallmark of GPG. By contrast, an ethical approach to geoengineering appears to require projections over much longer time-frames. If SSI is to have major impacts over many generations across the entire planet, how can research time-frames of only a few decades or even a century be appropriate? Surely there is a case to answer.[19] (See section 4 for further discussion.)

Importantly, there is also reason to think that a longer-term perspective might make a substantial difference. Notably, a recent publication that operated over the much longer time frame of a thousand years suggested a major effect on La Nina events which the lead author, Dr Abdul Malik, said would "strongly impact temperature, precipitation, floods and drought patterns across the globe" (Malik et al. 2020). As a result, Professor Joanna Haigh, co-author and former Co-Director of the Grantham Institute, declared: "The results of this study indicate that solar geoengineering can in no sense be viewed as a sensible rescue plan due to the potential to severely impact on temperature, precipitation, floods and drought patterns across the globe" (Ibbott 2021). We ourselves are not making any such claim – in part because it may be too early to reach such a conclusion.[20] Our point is simply that this new work underscores the importance of considering much longer timeframes than is usual, especially when framing research questions (in modelling, scenario building, and elsewhere). This would be a basic, first line of defence against GPG.

Sign 2: Fast-start Focus

A second feature of mainstream modelling and scenario-building is the choice of starting-points for deployment. In our view, there are good reasons to believe that *any responsible* development of SSI would take at least a few decades of testing, impact assessment, and institution building, and perhaps longer. Consider, for instance, testing. Some claim that "some climate response tests, such as those attempting to detect changes in regional climate impacts, may not be deployable in time periods relevant to realistic geoengineering scenarios". One reason is that "any

geoengineering would be plausible" (Parson & Reynolds 2021, 7). For discussion, see section 4 below.

[19] Some in the geoengineering research community have argued that a short- to medium-term focus in modelling is preferable to a longer-term focus in order to generate information needed by lower- and middle-income countries in their adaptation efforts (e.g., Nissan 2019). Our response is that such modelling can perfectly well co-exist with modelling that has a much longer-term focus.

[20] For instance, this is only one study and involves a large forcing (of quadrupling C02).

deployment scenario in time scales relevant to averting the 1.5C or 2C targets would likely have to proceed with low certainty about regional impacts" (Lenferna et al. 2017).[21] Given the issues surrounding responsible deployment, there are reasonable grounds for saying that, other things equal, *any deployment coming in the next couple of decades is likely to be irresponsible, scientifically and ethically*. Instead of a well-considered intervention backed by the best science, such a deployment is at considerable risk of becoming a *high-stakes, high-risk gamble* in a situation characterized by high levels of ignorance and uncertainty.

More generally, we have some concern that requirements for responsible deployment may turn out to be sufficiently robust that they call into question the very possibility of ethically attractive or even minimally decent forms of SSI becoming available on a reasonable timescale. For instance, although being ready to deploy SSI in a responsible fashion in 2100, 2150 or 2200 would presumably be a major scientific and social achievement, it would not answer the purpose for which many are advocating it now: to avoid breaching the 1.5°C, 2.0°C and other thresholds this century.

A number of reasons underlie such worries. Let us highlight two. The first is that research is still in an early stage of development, such that models remain quite primitive in comparison to the intervention being proposed. For instance, until quite recently, most of the modelling that had been done was essentially of "turning down the sun": reducing incoming radiation at a uniform rate. This is some distance from understanding human attempts to inject aerosols into the stratosphere, and the interactions of those attempts with overall Earth systems over a long period of time. In the last few years, models have moved forward to examine some aspects of injections themselves (e.g., how it matters whether they are done at the equator or other latitudes). Nevertheless, a robust literature is yet to emerge on key issues (e.g., NASEM 2021, chapter 6), such as realistic interventions in the stratosphere at relevant scales, their interactions with broader systems (e.g., other parts of the atmosphere, terrestrial ecosystems), and their long-term consequences. Indeed, this is a central reason for advocating for more scientific research, including research which goes beyond modelling.

The point that there remains considerable work to be done is a simple one, but no less important for that. It underlines the possibility that, ultimately, the gap between where we are scientifically and where we would need to be in order to be justifiably confident in deployment may yet prove so large as to make SSI an unrealistic option over the time period being considered by most policy-makers, and perhaps for even longer.

[21] One of us (Gardiner) is a co-author on that paper.

The second, perhaps more important, reason for concern is that models can take us only so far. At some point, field testing will be needed. Plausibly, this will take at least a couple of decades, and probably significantly longer. Most notably perhaps, establishing a firm evidence base for the safety of SSI is likely to be a challenging task, scientifically and technologically.

One factor is that testing most allow sufficient time for signals to emerge from the overall noise of the climate system. This is especially so if we need to work with a modest injection, rather than a more dramatic forcing, which seems highly plausible given that any actual high magnitude test in the stratosphere will affect people on the ground in significant ways, and so would amount actually to doing geoengineering, rather than simply testing it.

Another factor is that researchers should be interested in the *longer-term effects* of SSI interventions, and robust indicators of these will likely take a while to emerge. Such issues strongly suggest that establishing a firm evidence base will not be a quick process. Yet proceeding to full deployment without a firm evidence base seems very risky, and may even count as reckless and negligent.[22]

Interestingly, concerns about the early stage of research and the demands of responsible testing may be amplified if novel, specially engineered particles will ultimately be used for deployment.[23] One reason is that the move away from sulfates (in SSI) to other, and especially novel particles, may compromise the "natural analogy" with volcanic eruptions, perhaps to breaking point. Another reason is that the implications of introducing novel particles into planetary systems are likely to be more difficult to predict. This is perhaps especially so when one considers the effects on sensitive parts of the atmosphere and on fragile ecosystems on the ground.

Give all this, it is striking that most existing research focuses on quick deployment scenarios. For instance, geoengineering models typically envision a (very) fast

[22] Something depends on how demanding the standards being imposed on testing are, and these may vary in comparison with the risks posed by climate change itself. In our view, this is an ethical issue. However, we cannot pursue it here.

[23] The prospect of creating *specially-engineered, artificial nanoparticles* to inject into the atmosphere was raised by David Keith in 2010: "engineered nanoparticles could exploit photophoretic forces, enabling more control over particle distribution and lifetime than is possible with sulfates, perhaps allowing climate engineering to be accomplished with fewer side effects" (Keith 2010). A 2018 article from Keith's group considers manufacturing "engineered micron-scale particles" with "high radiative efficiency", perhaps "coated with a thin (<10 nm) metal layer" (Parker, Horton, Keith 2018). A 2021 article from another group states: "Even though aerosol injection into stratosphere is one of the most promising solar geoengineering techniques, sulfate aerosols, which are suggested for such an application, show significant drawbacks such as infra-red (IR) absorption and ozone degradation. The development of new materials for such application that would exhibit substantial up-scattering, with non-IR absorption to allow a cooling effect are needed. Here, a novel composite material comprised of diamonds dispersed in a silica aerogel network is investigated and compared to pure silica aerogel." (Vukajlovic et al 2021; emphasis added).

start for SSI, in *only 10-25 years*. One reason for this is that, back in 2010, the original paper from the influential Geoengineering Model Comparison Project ('GeoMIP') assumed deployment would begin in only ten years, in 2020:

> "[The experiment] assumes an RCP4.5 scenario...but with additional stratospheric aerosol added *starting in the year 2020, which is a reasonable estimate of when the delivery systems needed to inject the aerosols might be ready.*" (Kravitz et al. 2011, 164, emphasis added)

The lead author, Ben Kravitz, tells us that this paper had significant influence on modelers and high-level reports:

> *"Numerous climate modeling studies have since begun their simulations in 2020* thanks to GeoMIP's precedent. Many of these geoengineering studies that show a start date of 2020 *are highlighted in reports at national and international scales."* (Kravitz 2020)

As we have indicated, we believe that the timeframe of a mere decade was unrealistic for responsible SSI back in 2010, and there are good reasons to think a fast-start focus remains so today. Kravitz has subsequently been admirably frank about the problems with the decadal modelling, given the state of the science. He also worries more generally about the framing effects, especially in influencing policymakers: "statements from the world's largest geoengineering research effort influence how ideas are shaped and discussed, not just among the scientific community, but also in society and politics". He cringes at the thought that they "might be used as part of a justification for any potential deployment" (Kravitz 2020).

Still, the fast-start focus continues to be present in the literature.[24] For example, a recent article from a top modelling group focused on 2035, choosing it as the start date for most scenarios, and so *only a 13-year time-frame* from publication. For the sake of assessing sensitivity, it also considered 2045 for other scenarios, and so a *23-year time-frame* (MacMartin et al. 2022). Similarly, an assessment of SSI with the goal of protecting the West Antarctic Ice Sheet published in 2015 envisioned deployment in 2035, which was then a *20-year window* (McCusker et al. 2015). In short, it seems common – in fact, the norm – to model for SSI starting in just 10–25 years.

[24] This may be simply because the papers were written before Kravitz's warnings. Moreover, again, we are not aiming to blame researchers, but only to point out how the state of the discussion tends to encourage GPG.

This makes us worry about the lurking threat of GPG. The fast-start focus seems puzzling if one were intent on pursuing an ethically responsible form of geoengineering that aims at the good of humanity as a whole over the very long-term. For one thing, concentrating on a timeframe of only a decade or two to deployment seems highly ambitious given the likely constraints on responsible development coming from (among other things) the need for testing, impact assessment, and institution-building mentioned above. Even more importantly, it is odd to focus *solely* on a 10–25 year window. In general, our recommendation would be that a genuinely intergenerational geoengineering research program should consider a *range* of time-frames for deployment, stretching out into the future. For example, such a program would take seriously preparing for deployment in different time periods, such as 2050-60 or 2070-80 or 2090-2100 or 2110-2120, as well as 2035-2045. Similarly, although investigating SSI to protect the 1.5°C limit makes some sense, it seems problematic, given the state of the science, to make it the *only* scenario considered. After all, perhaps by the time responsible SSI is likely to be ready for deployment, 1.5°C has already been left behind. Thus, an ethical research program would also consider SSI at different temperature thresholds, such as 1.7°C, 2.0°C, 2.2°C.

Disturbingly, the fast-start focus becomes more plausible under GPG. On the one hand, perhaps fast-tracking deployment by ignoring the need to test, assess and build institutions makes some sense if the overwhelming concern is with protecting a smaller group within the current generation. For instance, such a group may be satisfied to proceed if they have decent grounds to assume that any negative impacts would be manageable for a couple of decades or so, even if they may be catastrophic later on, or if the group is not so concerned about their personal longevity and so willing to "roll the dice".[25]

On the other hand, ignoring pathways to responsible geoengineering would also be intelligible if the pursuit of SSI were being endorsed by the parochial generation only for appearances' sake. Touting geoengineering might function as yet another "dangerous illusion" calculated to give the impression that an older generation is doing something about climate change even as it continues to drag its feet about more conventional changes that would clearly make a difference.[26] Deflecting

[25] Another possibility is that fast-tracking deployment may expose the current generation to higher risks of severe negative side-effects than the future. This might encourage the opposite of GPG: the current generation might choose to take on the burden of such risks in order to protect the future, and perhaps even to compensate (in part) for its own bad behavior in not combatting climate change more effectively earlier and in other ways (for this kind of suggestion, see Gardiner 2010, 293). Still, this scenario seems unlikely under current geopolitical realities.

[26] Gardiner calls Kyoto, Copenhagen and Paris "dangerous illusions" of this sort (Gardiner 2004b; 2011; 2022a).

attention from its failures may be another way to "buy time" for such a generation – not for decarbonization or adaptation, but to hold off the disapproval of the younger generations who will be left carrying the can.

More generally, it is easy to see why *only* SSI with a fast-start focus would be of direct interest to an older parochial generation. Since it seeks to protect itself, not the longer term, techniques that would take multiple decades to develop would not be relevant to a buck-passing generation, even if these technologies held the promise of protecting later generations. Consequently, we might see a parochial generation discourage, ignore or veto research on promising forms of geoengineering which would not be available until, say, 2060 or 2075 or thereafter. Instead, they would push for investment in much more messy and speculative interventions that could be deployed in the next couple of decades. Again, the threat of GPG opens our eyes to many risks.

We conclude that the fast-start focus is sufficient to raise suspicions about GPG, and so to put us on our guard and encourage counter-measures. Fortunately, some of these are relatively straight-forward. For instance, at a minimum, we would suggest that a sensible research program into protecting future generations should aim to model and prepare for other salient possibilities than near-term deployment (e.g., 2035 for 1.5°C), including medium-term deployment (e.g., 2050-2060 for 1.7°C), long-term deployment (e.g., 2070-2080 for 2.0°C) and perhaps very long-term deployment (e.g., post 2100 deployment for 2.3°C). Such an expanded mindset would likely increase the prospects of intergenerationally ethical geoengineering.

Sign 3: Neglect of Maintenance and Exit Strategies

A third early warning sign of potential GPG and possible moral corruption concerns long-term maintenance and the need for an exit strategy. Many current geoengineering advocates argue for SSI on the grounds that it will "buy time" for emissions reductions by "shaving the peak" of climate impacts (e.g., Keith and MacMartin 2015). This rationale implicitly assumes that the climate intervention will be maintained for at least several decades, and perhaps centuries, but then ultimately be wound down. Given this, it is striking that little work has yet been done on what these pathways might look like. Instead, while most appear to presume a phaseout, they do not actually model it (e.g., a prominent research group reports that "*only one [paper*] simulates a deliberate gradual phaseout to a warmer world" (MacMartin et al. 2022, 1–2 of 9; emphasis added).) This creates a situation where, in effect if not in intent, the models typically assume that SSI will be ongoing, continuing indefinitely into the future.

Again, this situation would be surprising under ethical geoengineering, but becomes deeply worrying considering the threat of GPG. A current generation

intent on protecting itself and indifferent to the longer-term future would not be motivated to explore how to phase out SSI, if it assumed drawdown would only occur long after it had departed the scene.[27]

As well as the general issue of phaseout, there are some more specific concerns about the focal modelling scenarios and the issues of actively managing SSI, especially for the long-term. A prominent research group tells us: "few papers … have considered a temperature target lower than that at the start date", while "none explore the dependence on the assumed start date" (MacMartin et al. 2022, 1). Both points are concerning, given the risk of GPG. The first does not seem to take seriously enough the idea that global temperature may substantially overshoot mainstream targets, for instance while the testing, impact-assessment and institution-building necessary for responsible SSI is being developed.[28] The second *assumes away* the issue that perhaps the best start date for SSI aimed at the overall intergenerational good of humanity differs from that which would be best for the current generation.

Perhaps the most important concerns, however, are around the potential for serious risks associated with the maintenance of, and ultimate exit from, SSI. The essential role of SSI is to *mask* warming by preventing the accumulation of greenhouse gases from having its full effect. This implies that if SSI is masking a substantial temperature rise, it cannot be safely stopped until the excess greenhouse gases are removed. Thus, substantial SSI must be maintained over a considerable period of time. The reason is simple: if the SSI "mask" is taken away, the planet's temperature will swiftly "bounce back" to the level it would have been absent the intervention. This threat is known as "termination shock" (e.g., Parker and Irvine 2018; Rabitz 2018).

The term 'shock' is employed for a reason. The change would be relatively quick. Current wisdom suggests that the particles injected in the stratosphere (the "mask") would wash out in 6–18 months. Thus, exposure to normal levels of solar radiation would resume within a couple of years, and exposure to the full effects of the rebound within 10–15 years. This kind of rapid warming would likely have *much worse* impacts even than the gradual climate change that the SSI is attempting to block. Moreover, if the masking effect is large, the magnitude of the shock resulting from withdrawing SSI will also be high. For example, if the SSI were holding off a

[27] MacMartin et al. 2022 consider very short deployments of only a few decades, with SSI to be wound up late in this century. This is laudable from the point of view of prompting modelers to think about exit strategies. Nevertheless, it is not clear why it should be the only scenario to be considered, or among the most likely. For discussion, see Gardiner & McKinnon, in preparation.

[28] A reviewer reminds us that researchers are clearly concerned about the risk of overshoot more generally, and often say that it motivates their work. Our observation is more specific: given the risk of overshoot, it is surprising that lower temperature targets are not prominent. This observation encourages worries about GPG.

global rise of 2–3 degrees, then withdrawing it suddenly would see that materialize very quickly by climate standards and human standards.

Most commentators recognize that termination shock is one of the most serious risks associated with SSI, and some believe that it poses such a large threat that we should not seriously consider this kind of geoengineering. Some of the reasons are scientific or technical. People doubt that we can develop or fine-tune SSI sufficiently quickly to a reasonable level, and so fear that the threat to the future of proceeding is too high. Other reasons are political: many are highly skeptical that humanity would develop the kind of governance for SSI that would be resilient enough to provide a decent level of protection against the kinds of failure (whether accidental or intentional) that would result in termination shock (McKinnon 2020). Even if one has faith that *eventually* humanity could achieve this, to assume that we could do so quickly – within the next few decades – is worrying.

Termination shock is explored to some extent in the scientific literature. Still, how to address it, and how to ramp down more gradually remains underexplored. Similarly, "no papers include scenarios that explore the effects of a temporary interruption or other deployment inconsistencies ..." (MacMartin et al. 2022, 1-2). While all of this is worrying, it would be sadly predictable under GPG. Again, it is highly plausible that an older generation focused on protecting itself would not be too concerned about the need for long-term maintenance or an exit strategy. Evidence that SSI is a better bet than climate change over a couple of decades would probably be enough.

A further, more general worry also underlies concern about maintenance and exit. The "buying time" strategy assumes that SSI will be deployed only for a limited period while rapid decarbonization is occurring. However, this may be a bold assumption, and the relevant time-period is uncertain. One issue is, of course, ongoing political inertia around addressing the underlying causes of climate change, and particularly the global economy's heavy reliance on fossil fuels. SSI that is even moderately successful may encourage further procrastination and delay (e.g., the "moral hazard" worry and its cousins)[29]. Moreover, it may do so even as continued intervention becomes more and more risky as it masks ever larger temperature increases.

Another issue is that most proponents of the "buying time" strategy assume that the main way humanity will wean itself from SSI is through directly removing greenhouse gases from the atmosphere, especially through carbon dioxide removal on a massive scale. Yet, as mentioned above, that technology is also highly speculative,

[29] Early references include: Gardiner 2007, 2010, 2011a; Hale 2012; Hamilton 2013. For a more extensive list, see Pamplany et al. 2020, 3093-4.

and may not develop as hoped. Notably, this worry is serious enough to have prompted some prominent climate scientists, such as Ray Pierrehumbert, Professor of Physics at Oxford, to reject SSI completely (e.g., Pierrehumbert 2019).

We conclude that a generation focused on GPG would probably neglect long-term maintenance, exit strategies, the potential failure of CDR, and the threat of termination shock. We therefore suggest that, if we are to forestall GPG, questions surrounding these matters should be much more central to geoengineering research and policy.

4.2. Governance

A second area of concern surrounding generational parochialism and possibly moral corruption involves governance and how it is conceptualized.

Sign 4: Status Quo Bias

Our fourth early warning sign is that current policy analysis often involves what later generations may come to see as a *status quo* bias. For example, the collection cited earlier assumes:

> "[T]he general state of world development and geopolitics is described as *broadly similar to that of today*. Present trends of broad world development and relative decline of dominant powers have continued, but there have been no world wars, regime changes in major powers, or fundamental re-alignments of the international system ... There has still been *no significant progress* at developing relevant international governance capacity ..." (Parson and Reynolds 2021, 7–8, emphasis added).

In short, this is modelling for political and institutional business-as-usual.

Unfortunately, in our view some level of transformation of the global system is probably required to govern geoengineering, and perhaps to deal with climate change itself (Gardiner 2014a; 2019; Maltais and McKinnon 2015; Kashwan et al. 2020; McLaren and Corry 2021b). The status quo, then, while of understandable concern to the current generation, may not be of much use to future generations, and indeed may constitute a core part of the problem they face. Given this, a status quo bias is likely to facilitate and encourage GPG.

Sign 5: Underestimating the Task

The fifth early warning sign is that of underestimating the governance task. Notably, some ways of framing SSI seem highly complacent, even to the point that they

"encourage a kind of *hyper-optimism* about SSI that amounts to utopianism" (Fragniere and Gardiner 2016; Gardiner, 2013b); indeed, some governance proposals appear "Panglossian" (McKinnon 2020). To illustrate this, let us identify three forms of complacency that are common in the literature.

The first is *political complacency*. For example, Catriona McKinnon cautions us that we should not promote governing deployment with policies that *simply assume* a background infrastructure that ensures sustained trust, transparency and cooperation between states with histories of conflict, enmity, and espionage. This makes future people hostages of best-case scenarios coming to pass (McKinnon 2020). Similarly, we should beware of proposals that suggest that nation states and other key actors will easily converge on key ethical aims, such as protecting the global poor (Horton and Keith 2016). After all, progress on similar objectives has not usually been impressive (e.g., the "war on drugs"; the UN sustainable development goals).

The second form of complacency is *institutional complacency*. One aspect of this is procedural. Advocates for SSI tend to focus their efforts on pushing for improving geoengineering science. They do not prioritize, and in general pay much less attention to, the need for effective institutions to govern eventual deployment (including maintenance and exit). This is so even though some of the biggest worries about SSI deployment are its likely lack of political legitimacy (e.g., Gardiner 2011b; Morrow, Kopp, and Oppenheimer 2013; Callies 2019; Gardiner et al. 2021), and that it may be "ungovernable" given the current shape of international politics (e.g., Hulme 2012; Hamilton 2013; Biermann et al. 2022). Tellingly, there seems very little political momentum towards serious institutional change thus far. For instance, we do not see an urgent push to prepare robust new global institutions to govern geoengineering, even as support for scientific research picks up. This may suggest that the current generation of decision-makers are not truly serious about ethical forms of geoengineering, but are instead mostly drawn to unethical forms, including GPG.

Another aspect of institutional complacency is more substantive. Often, the kinds of existing mechanisms and venues recommended for governance appear modest at best. Consider, for example, proposals to refer SSI to the United Nations' Commission on Sustainable Development (Royal Society, 2009) or place it under the UNFCCC. Such approaches seem woefully inadequate given the high stakes and fundamental issues involved in SSI. Other suggestions are somewhat more promising, such as referring geoengineering to an *ad hoc* committee of the United Nations' General Assembly (e.g., NASEM 2021, 190), or to the UN Security Council. Nevertheless, there seems little interest in the idea that fundamental political reform may be required.

By contrast, in our view, existing political institutions and legal systems offer little to no protection to future people against GPG; hence, taking the threat

seriously requires a strong focus on governance, and one that likely requires fundamental reform. We need to think seriously about how to reconfigure institutions and systems in ways that prevent or mitigate GPG, compensate future people who suffer as a result of GPG, and hold to account relevant agents who pursue GPG.

To illustrate, in previous work, each of us has offered proposals for the kinds of changes that should be considered. One is a global constitutional convention focused on protecting future generations (Gardiner 2014a, 2019). Another is global legal reform that includes making existential threats against the future ('postericide') subject to serious sanctions (McKinnon 2017, 2021). We would also advise taking seriously the idea of an Intergenerational Geoengineering Compensation Fund, such that if geoengineering is pursued by the present generation then those responsible for that pursuit are required to pay into the fund, and future people can make compensation claims if they are damaged by the geoengineering initiated by generations before them. In addition, thought should be given to how to protect nonhuman nature (e.g., by developing international laws against 'ecocide').

Our main point here, however, is not to push specific proposals. It is that conventional proposals often implicitly overestimate – sometimes radically – the capabilities of current institutions for dealing with the challenges associated with SSI, especially for governance across generations. Thus, worries about GPG seem more than reasonable.

The third kind of complacency runs even deeper: some analyses seem to manifest *theoretical complacency*. For instance, some early work suggested that SSI interventions will "benefit everyone"; similarly, some have analyzed SSI as a "global public good". Moreover, both accounts have been used to suggest that SSI escapes many of the usual problems facing international climate policy. Yet such characterizations are usually optimistic at best, and deeply misleading at worst (Gardiner 2013b, 2014; Hourdequin 2018).[30]

Sadly, all three kinds of complacency (political, institutional and theoretical) suggest the lurking presence of moral corruption, and often in ways that raise worries about GPG. For instance, it is predictable that a generational elite tempted by using GPG to protect itself would promote the idea that SSI would be "good for everyone" and easy to govern. Yet a quick reality-check reveals that it is almost certain that SSI (like most other large-scale policies) will have winners and losers, that decisions over it carry with them a tremendous amount of power, and that this is likely to generate conflict. Such issues may not matter much if you are the ones with your hands on the levers of power; still, to ignore or downplay them is to

[30] Fortunately, such claims now seem much less fashionable. For example, most modelers are very clear that they expect winners and losers (e.g., MacMartin et al. 2022).

obscure some of the most fundamental ethical issues at stake in geoengineering. Given all this, another step toward protecting against GPG would be to demand that proposals for developing SSI become much more serious about governance and institutional reform.

5. Objections

5.1. Uncertainty

One scientific objection (to our suggestion that current SSI research encourages GPG) rejects our criticism of the short time-horizons of SSI models, saying that these are unavoidable given the uncertainties involved in climate projections.[31] Specifically, at some point beyond 50-100 years, other uncertainties – such as the evolution of the global economic system or the nature of scientific progress – start to overwhelm the ability of models to project the effects of SSI.[32] Since, it is said, the point of having models is to increase our knowledge of the probability of various outcomes, if they do not do this, there is no good reason to have them.

We understand the basic concern, but remain unconvinced. First, we question whether it is ethically reasonable to proceed with SSI if reasonable long-term projections are not possible. Flying blind in this way seems, on the face of it, to pose huge risks to future generations. It is difficult to imagine that they would approve of the experiment without some level of reassurance as to the longer-term consequences. Surely this, if anything, is a warning sign that GPG is a live threat.

Second, few have tried to model SSI over the much longer term. It may well be very difficult, but a real commitment to avoiding GPG requires at least making a serious attempt. Moreover, some climate models have this temporal reach, and the uncertainties navigated by these models are arguably as great, if not greater, than those facing long term SSI modellers. If climate modellers are at least trying to do this, why not SSI modellers? In addition, as we noted above, the few who have tried have come up with interesting conclusions.

Third, we question the more specific claim that the only point of models is to enable better informed *probability* judgements of various possible outcomes. For one thing, it is already the case that the scenarios used by the IPCC for different

[31] MacMartin et al. 2022 explicitly defend the limited temporal scope of much of the modelling. We address their specific claims in work in progress (Gardiner & McKinnon, in preparation). In order not to overwhelm what is already a long paper, here we consider the issues at a more general level.

[32] Scientists often report that scenario uncertainty becomes the biggest source of uncertainty after 40-50 years or so (e.g., Hawkins 2009, Figure 4). We thank Tom Ackerman and Cecilia Bitz for discussion on this point.

emissions trajectories are informed by models, but do not deliver robust probability assessments and are not designed to do so. For another thing, we think that establishing the extent and range of uncertainty through the use of longer-term models could be extremely useful: it would bring future SSI deployment scenarios within the purview of precautionary approaches, which help to avoid GPG (e.g., Hartzell-Nichols 2012; McKinnon 2019).

5.2. Urgency

A second objection to our account concerns urgency. For instance, some imply that the fast-start focus is appropriate because humanity is so close to breaching the 1.5 and 2.0°C thresholds. Since such breaches threaten climate catastrophe, they suggest, early intervention is necessary even if it comes with extra risks.

We have two basic responses. First, there is a worry about begging the question. The time-constraints associated with responsible development of SSI (e.g., around testing, institutions, etc.) are *already aimed at* determining what kinds of SSI might reasonably be tried and reducing the risks of trying them. Thus, while it is true that humanity may face a "risk-risk" tradeoff (e.g., Parson 2021) or "lesser evil" choice (e.g., Jamieson 1996, Gardiner 2010), it would be a mistake simply to assume that this tradeoff is strongly in favor of a very fast deployment of SSI, especially at this early stage of research and within a governance vacuum. Serious work would need to be done to make that view plausible, which is one reason why a research program is needed.

Our second response is that comparisons with catastrophe can be treacherous. For instance, at first glance it may appear automatically true that SSI would be better than very severe climate change, since the latter is, by definition, genuinely catastrophic. However, such arguments can mislead (e.g., Gardiner 2013b, 2022b). First, if by 'catastrophe', we mean extreme outcomes such as the suffering and death of billions of people or the extinction of humanity, then it is worth emphasizing that SSI is actually only being asked to meet a very low bar of justification: for it can seem that *almost anything* is better than these extremes. Second, being "slightly better than complete catastrophe" is not very impressive or comforting. For instance, meeting the low bar may be easy to achieve, and a characteristic that might be shared with some very unattractive and unethical proposals (e.g., installing a global dictator intent on drastically reducing the human population through genocide). Third, we should not simply *assume* that fast-start SSI passes the low bar, that it is the only policy that would pass it, or that passing it is the threshold we are interested in. Fourth, most strikingly, making the relevant criterion merely the *bare possibility* that fast-start SSI might be better than catastrophic climate change is a clear

mistake. Plausibly, before rushing into SSI on such a thin basis, we should at least consider other strategies within the climate portfolio, including slower-start SSI as well as other radical solutions (e.g., Fragniere and Gardiner 2016). To be clear, our point is *not* that urgency is not an important issue, but that it requires deeper analysis. One should not be too quick to assume that urgency obviously and decisively favors fast-start SSI.

6. Conclusion

Our aim in this paper has been to motivate the idea that the threat of generationally-parochial geoengineering ought to be a core concern of both the ethics of geoengineering and any serious scientific, political or policy discussion. To do this, we explored the concept of GPG, suggested some salient scenarios, and identified early warning signs in the current scientific and policy literature. Within science and policy, the early warning signs include short-time horizons, fast-start focus, and neglect of exit scenarios. When it comes to governance, there is evidence of a status quo bias and of forms of political, institutional, and theoretical complacency that amount to underestimating the task at hand.

Ideally, our discussion will inform development of SSI in ways that help to moderate or even pre-empt GPG. At a minimum, we hope to have done enough to establish that the threat of GPG is sufficiently serious that SSI researchers in all areas should raise the level of alert in their communities, and be on their guard for blind spots, implicit biases, and unnoticed lapses.[33] Moreover, it is encouraging that some first steps for combatting GPG appear straight-forward (e.g., dropping the fast-start focus, exploring a range of scenarios with different start dates).

Nevertheless, in our view the good intentions of researchers are unlikely to be sufficient to protect against GPG. For one thing, often the early warning signs are at the level of norms, assumptions, practices, and shared standards. Good intentions alone do not necessarily control these drivers. Thus, a more robust, and distinctively ethical approach will ultimately be needed.

For another thing, focusing on research alone is inadequate. GPG threatens to impose unjustified risks on future people that involve severe injustices and major violations of legitimacy. Unfortunately, existing institutional architectures are ill-equipped to cope with intergenerational threats. Thus, our identification of GPG and early warning signals will not in itself deliver a shield against intergenerational injustice. Instead, addressing the challenge of GPG is likely to involve serious - and

[33] As we have emphasized, our purpose is not to accuse geoengineering researchers of bad intergenerational behaviour. Indeed, our hope is to make conversations about blame redundant.

perhaps radical – institutional reform. It may also prompt conceptual reform within moral and political philosophy itself. Ensuring that GPG is a core concern in the geoengineering discourse is therefore only an early step on a much longer journey.

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