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Solar geoengineering, delay, and addiction

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Abstract
It is increasingly common to hear solar geoengineering compared to opioids. I argue that probing this analogy can help us appreciate the following surprising point: Common arguments for solar geoengineering, if taken to their logical conclusion, imply that the technology should be used to slow the pace of emissions reductions. Indeed, Integrated Assessment Models (IAMs)—a widely used and influential climate policy tool—produce the same result. This conclusion is striking because, if there is one area of consensus across debates about solar geoengineering, it is that the technology should *not* be used as a 'substitute for' or to 'delay' the energy transition. I argue that we can make sense of this apparent tension by recognizing that different parties to the solar geoengineering debate have different conceptions of the kind of 'substitution' or 'delay' to be avoided. The surface-level consensus that solar geoengineering should not substitute for emissions reductions thus masks an important dispute: How does the prospect of solar geoengineering influence the speed of emissions cuts we should aim for? In the final pages of the paper, I'll return to the opioids analogy to briefly draw out the implications of answering this question in the way recommended by IAMs. In short, we risk adopting an approach to solar geoengineering policy that advances our own interests at the expense of locking those that follow us into a form of addiction.

Keywords solar geoengineering · ethics · mitigation deterrence · integrated assessment models · substitution · lock-in

It is increasingly common to hear solar geoengineering compared to opioids.[1] Typically, the analogy is employed to bolster the case *for* the technology. The underlying argument sug-

[1] This paper was inspired by a panel discussion I participated in during the 2024 Harvard Climate Action Week, where fellow panelist Frank Keutsch stated that "Geoengineering is like taking painkillers. When things are really bad, painkillers can help but they don't address the cause of a disease and they may cause

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gested by the analogy is this: The fact that opioids do not attend to the root cause of pain is no reason not to use them, and solar geoengineering is relevantly similar enough for us to transfer the moral inference from one case to the other.[2]

In the forthcoming reflections, I want to press on this analogy between solar geoengineering and opioids to see what we can learn from it. I'll suggest that the analogy can help us appreciate the following surprising point: Common arguments for solar geoengineering, if taken to their logical conclusion, imply that the technology should be used to slow the pace of emissions reductions. Indeed, Integrated Assessment Models (IAMs)—a widely used and influential climate policy tool—produce the same result. This conclusion is striking because, if there is one area of consensus across debates about solar geoengineering, it is that the technology should *not* be used as a 'substitute for' or to 'delay' the energy transition. I argue that we can make sense of this apparent tension by recognizing that different parties to the solar geoengineering debate have different conceptions of the kind of 'substitution' or 'delay' to be avoided. The surface-level consensus that solar geoengineering should not substitute for emissions reductions thus masks an important dispute: How does the prospect of solar geoengineering influence the speed of emissions cuts we should aim for? In the final pages of the paper, I'll return to the analogy I started with to briefly draw out the implications of answering this question in the way recommended by IAMs. In short, we risk adopting an approach to solar geoengineering policy that advances our own interests at the expense of locking those that follow us into a form of addiction.

Here's how the analogy, as I've encountered it, tends to go.[3] Climate change-fueled heat waves, storms, wildfires, and sea level rise are like the painful symptoms of an injury. On the most promising version of the analogy, the injury is the avoidable result of everyday activity. We can imagine, for instance, that the impacts of ongoing warming are like the symptoms of a chronic back injury from too much heavy lifting at work.

Like any injury, addressing the root cause will typically address the pain. The person with back pain should avoid lifting heavy things and go to physical therapy just as we globally should reduce emissions to net zero. However, addressing the root cause doesn't *immediately* eliminate the discomfort—anyone who has been to physical therapy will be familiar with this. In the meantime, if a relatively cheap solution can mask the pain, it makes perfect sense to use it. Why suffer—from back pain, or locked-in climate impacts—for no good reason?

more harm than good." For other instances of the geoengineering—opioid analogy, see Kaufman (2019); Keith (2024); Chen et al. (2024).

[2] 'Solar geoengineering' typically refers to a set of technologies that aim to decrease global average surface temperature by increasing the reflection of sunlight away from earth. The arguments in this paper won't turn on a particular definition of 'solar geoengineering' or type of technology.

[3] Health-related geoengineering metaphors/analogies have a long history, and have been used for different purposes. Nerlich and Jaspal (2012) find that, in a survey of literature from the 1980's to 2010, one key metaphor used by *proponents* of geoengineering involves seeing the planet as a 'patient/addict'. By contrast, Luokkanen et al. (2014) find that health metaphors are also used as part of arguments *against* geoengineering. Unlike these and other authors discussing metaphor and geoengineering (see also Scholte et al. (2013), Anshelm and Hansson (2014), and Sikka (2012), my central project here is not to provide an empirical assessment of the historical or present use of health-related geoengineering analogies or metaphors. Nor is my primary aim to explore the discursive role of these analogies in framing the geoengineering problem. Rather, I employ this analogy for explicitly normative ends: the analogy is as a tool to help us arrive at and assess the plausibility of a set of *arguments.* Along the way we'll also learn something about how the geoengineering-opioids analogy as I've encountered it may distort our thinking.

Of course, both opioids and solar geoengineering come with risks. Solar geoengineering might change local precipitation patterns (Bal et al. 2019), damage the ozone layer (Nowack et al. 2016), and impact plant photosynthesis (Cao 2018). If we deploy the technology over a long enough period, any cessation of solar geoengineering would cause temperatures to rise rapidly to the level they would have reached in the absence of the technology. This risk of 'termination shock' has been likened to withdrawals from opioid use. But, the analogy (often implicitly) urges us to think, the potential benefits of solar geoengineering outweigh these risks.

Often, this is where the analogy ends. Indeed, it often stops earlier, without any mention of the cause of the injury, side effects, or withdrawals. What does the analogy leave out?[4] As a first observation, it's surprising that this analogy is often wielded as part of an argument *for* solar geoengineering research and potential deployment. After all, in 2023, over 81,000 people died from opioid overdoses in the United States alone (National Institute on Drug Abuse 2024). Another two million Americans have opioid use disorder (Dydyk et al. 2024). Various rules and lack thereof have fueled this increase (Marks 2020). Donations from opioid manufacturers have routinely impacted policy decisions. It is common for employees to move quickly between positions at prescription drug companies and health departments. Drug companies have falsely marketed their opioids as being less addictive than the drugs in fact were, and pharmacists have regularly been incentivized to increase the strength of prescriptions.

An initial lesson we can learn from this is that the above version of the solar geoengineering-opioid analogy focuses our attention in the wrong place. The analogy as I've sketched it disposes us to think about an individual suffering from some pain, deciding whether to take opioids despite the potential risk for addiction. The question of whether to deploy geoengineering is framed by this analogy as a question of individual rationality: take the pill or don't, given your understanding of the risks and consequences. This framing obscures the different actors that could benefit from or be harmed by solar geoengineering, in the same way as thinking about the injured person's choice to accept an opioid prescription obscures the background story about why this individual is facing such a choice to begin with, who benefits from increased opioid use, and who stands to suffer.

So, who does stand to benefit from the potential deployment of solar geoengineering techniques? One (but certainly not the only) 'beneficiary' to look out for is presently living. Just as we might be skeptical when pharmaceutical companies argue for increasing prescription drug doses, so too should we be on the lookout for arguments for solar geoengineering that, often with a subtle sleight of hand, function to advance our own short-term interests.[5]

The solar geoengineering-opioid analogy can help illuminate one such argument. Consider drug manufacturers, who benefit from a population with high rates of substance use disorder. One way of growing and maintaining demand for opioids is to market these products not only for *temporary pain relief*, such as during a period of acute injury, but as a tool

[4] Are opioids the correct analogy to begin with? Joe Aldy has suggested to me that we should think of solar geoengineering as more akin to medication for high blood pressure. I think that given the risks and uncertainties associated with solar geoengineering, opioids are a more fitting comparison. But there are likely to be other disanalogies, especially given that opioids and opioid use disorder are understood and treated differently in different places and contexts. Luckily, the central claims of this paper can be defended independently of the descriptive accuracy of the analogy.

[5] For the original argument that background incentives and short-term self-interest can distort the way we frame the climate change problem, see Gardiner (2010, 2011, pp.144–183).

to manage *chronic pain*. Take the 1998 video 'I Got My Life Back' that Purdue Pharma sent to over 15,000 doctors. The video shows construction worker Johnny Sullivan in a hard hat and boots. "Physically, with my medication, I'm able to get out there and work and make my company grow," he says. "You can get right back to normal."[6]

The story Purdue Pharma pushed was that their product allows individuals to continue doing what they were doing before *without* taking as drastic steps to address the root cause of the pain. "They don't wear out. They go on working. They don't have serious medical side effects," says a Purdue Pharma doctor in that same video. From the perspective of pharmaceutical companies, this marketing strategy is brilliant: the longer a person goes without addressing the cause of pain, the worse the underlying condition becomes, and the more medication they need to mask it.

At first glance, this kind of argument appears absent from discussions of solar geoengineering. After all, proponents of solar geoengineering go to great pains to ward off exactly the above reasoning. Solar geoengineering, it is often said, is a *complement to*, not a *substitute for*, mitigation. That's why the idea that solar geoengineering would postpone mitigation is often called a *moral* hazard: it would be wrong to use solar geoengineering as an excuse to slow the energy transition.[7] Indeed, it is the concern that solar geoengineering will deter emissions reductions that has prompted a cottage industry of research into whether learning about solar geoengineering reduces individuals' commitment to mitigation.[8] Solar geoengineering, it is often emphasized, is not a reason to put off addressing the root cause of climate change.

It seems as if anyone speaking about solar geoengineering feels responsible for driving this point home. For instance, the (2021) National Academy of Sciences, Engineering, and Medicine's 'Reflecting Sunlight' report repeatedly emphasizes that "the starting position of the committee is that [solar geoengineering] is not a substitute for mitigation, nor does it lessen the urgency for pursuing mitigation actions." More recently, the American Geophysical Union's (2024) report on ethical principles for solar geoengineering research states that "the pursuit of climate intervention research should not be presented as a replacement or alternative to emissions reductions." Jessie Reynolds sums it up, writing that "The prospect that solar geoengineering's evaluation, research, and development would lessen mitigation is the strongest, most widespread, and most influential associated concern" (Reynolds 2022, p. 286). You'll find this same point stressed in the first few pages of just about any policy document or public statement regarding solar geoengineering.

Yet, if one examines the arguments often used to justify solar geoengineering closely, one can see that these arguments also recommend using the technology for *precisely this purpose*—lessening the urgency of pursuing mitigation. Take, for instance, the following two premises:

[6] Video accessed via Mettler (2018). Sullivan was killed in a car crash 9 years later after falling asleep at the wheel, a common side effect of opioid use.

[7] The term 'moral hazard' is sometimes used, especially in the wider economics literature, in a purely descriptive sense—if a policy represents a moral hazard it incentivizes risky behavior, but this can be distinguished from a negative normative evaluation of that behavior (Hale 2012). My sense is that those using the term in the solar geoengineering discourse typically assume the negative normative conception of moral hazard. One message of this paper is that this assumption is too quick, for (as we'll see below) many arguments in favor of solar geoengineering *endorse* moral hazard or mitigation inhibition.

[8] See (Merk et al. 2016; Andrews et al. 2022; Schoenegger and Mintz-Woo 2024).

1) Policies that reduce costs ought to be put in place, barring important reasons to act otherwise.[9]
2) Solar geoengineering, if deployed safely, would reduce the costs of committed warming.

The conclusion of this commonsense argument, of course, is that steps should be taken to move in the direction of deployment. [10] After all, it is often added, solar geoengineering is the only tool we know of that could *quickly* reduce the impacts of previous emissions. Carbon dioxide removal is expensive and will take years to scale up (Vaughan et al. 2024; Chap. 3), and future mitigation does not ameliorate the impacts of our cumulative emissions to date.

However, notice that the following also appears plausible:

3) A slower energy transition will be less costly than a faster one, so long as the consequences of higher cumulative emissions can be avoided.

Think, for instance, of the trillions of dollars of functioning fossil fuel infrastructure that, absent solar geoengineering, will need to be shut down before the end of its anticipated economic lifetime—so-called 'stranded assets' (Semieniuk et al. 2022). With a slower energy transition, societies will have more time to develop the technologies required to mitigate emissions, more time to retrain those who will lose their jobs in the fossil fuel industry, more time to create new opportunities for communities whose prosperity depends on coal fired-power plants, and more time to figure out the logistics of large-scale renewable energy production.

If it is true that a slower energy transition will be less costly than a faster one, and if it is true that policies that reduce overall costs ought to be put in place, then mitigating slower and deploying solar geoengineering is, all else equal, preferable to solar geoengineering alone. In other words, if this argument is correct, solar geoengineering should be used not only to ameliorate the consequences of previous emissions, but also as a strategy to reduce the costs of a rapid energy transition by *proceeding more slowly.*

This implication is not a mere philosopher's thought experiment. We see the same conclusion in the results of one commonly used and widely influential climate policy tool, Integrated Assessment Models (IAMs). There's variation across these models: Some look to calculate the most cost-effective pathway to reaching a given climate target, such as 2

[9] Many theorists have attempted to flesh out what might count as an 'important reason.' For instance, some think that deployment, and possibly even research, exhibits a kind of environmental hubris that should be avoided (Gardiner 2010). Other critics worry about the authoritarian implications of the technology and its potential for militarization (Stephens and Surprise 2020; Surprise 2020a, b) And still others think that there is no democratically legitimate way to deploy solar geoengineering (Szerszynski et al. 2013). One can understand my argument concerning addiction at the end of this paper as a contribution to this list. My argument, however, is more modest than the above contributions. I don't argue for a general prohibition on the eventual deployment of solar geoengineering; rather, I argue that solar geoengineering should not be used alongside a slower energy transition, and explain more precisely the baseline from which 'slower' should be understood.

[10] To streamline presentation, I have formulated this argument (as well as the argument on pg. 7) in terms of the *deployment* of solar geoengineering. This is preemptive—after all, we are arguably not yet in an epistemic position to contemplate deployment. However, we could easily extend this argument so that it pertains to research—for instance by noting that determining what 'safe' deployment would look like, and whether it is even possible, requires further research.

degrees C or 1.5 degrees C. Other models will allow global temperature to be one variable up for manipulation and ask about the emission reduction trajectory that maximizes aggregate benefits over the long term. Regardless, the results of these models echo the conclusion from the simple reasoning above. If your goal is to minimize costs of reaching a given target, or maximize aggregate benefits, then the presence of solar geoengineering in the model *slows the pace of emissions reductions* relative to a scenario without solar geoengineering.

Modelers are not oblivious to this result. One study finds that "in our model, the introduction of solar geoengineering unambiguously results in higher emissions and, thus, higher concentrations, yet also lower temperatures" (Moreno-Cruz et al. 2018, p. 26). A second study states that "by postponing costly abatement to future periods, [solar geoengineering] also helps to reduce the aggregate costs of climate change" (Heutel et al. 2018, p. 33). Similarly, Keith (2021) writes that "if the pace of emissions cuts is determined by balancing the cost of faster cuts against future climate risks, then a benevolent policy-maker who expects [solar geoengineering] to reduce some risks will delay emissions cuts relative to the rate of mitigation without [solar geoengineering]" (p. 813). The idea that solar geoengineering, if it is used, *should* delay emissions reductions is not a new one. In one of the first presentations of the widely-used 'DICE' Integrated Assessment Model, William Nordhaus writes that geoengineering could "cut the costs of both climate damage and of mitigation," because it would reduce the need for costly emissions cuts (Nordhaus 1993, p. 47). Thus, despite the dogma that solar geoengineering is no reason to delay emissions cuts, the results of widely used economic models have long delivered quite the opposite result.[11]

Are researchers who oppose the use of solar geoengineering as a substitute for emissions cuts yet produce or endorse such modeling efforts speaking out of both sides of their mouth? If they are not, it is because of a certain equivocation concerning what it means to say that solar geoengineering should not 'substitute for' or 'delay' emissions reductions.

Let me explain. It is rare to encounter academic work endorsing the idea that the prospect of solar geoengineering should allow a complete abandonment of the energy transition.[12] Minimally, most fair-minded people will agree that solar geoengineering should not *fully* substitute for emissions reductions—the option to use solar geoengineering does not imply that we should not be working towards a carbon-neutral society. It is perfectly consistent to endorse the results of the above IAMs and maintain that 'solar geoengineering should not substitute for emissions cuts,' if 'substituting for emissions cuts' just means 'abandoning the energy transition entirely.'[13]

Surely, however, when concerns are raised about the impact of solar geoengineering on emissions cuts, these concerns extend beyond the flat-footed consensus that solar geoengineering should not entirely supplant an energy transition. And it is here that clarity is needed. For beyond this superficial consensus, there is deep disagreement about the rela-

[11] For one clear-eyed discussion of this phenomenon, see McLaren (2016).

[12] Rare, but not entirely absent. For instance, Alan Carlin, who worked as an economist at the EPA for over 30 years, has stated that "superior alternatives exist involving radiative forcing and that these alternatives would be technically sound; would allow continued growth of fossil fuel use; would very dramatically lower control costs; are economically efficient; would avoid the need for individual actions to reduce GHG emissions; and would permit relatively precise, rapid, and flexible adjustment of global temperatures" (Carlin 2007, p. 1487). He recommends research be conducted to look for technological solutions for avoiding what he sees as the main downfall of this approach, ocean acidification.

[13] Thanks to an anonymous reviewer for helping clarify the ideas in this section.

tionship between solar geoengineering and emissions reductions; disagreement that the language of ‘substitution’ and ‘delay’ tends to obscure.

The disagreement, at its heart, is about whether solar geoengineering should be used to postpone addressing the root cause of climate change. More specifically, it is about whether solar geoengineering is a good reason to emit more CO_2 than we otherwise should aim to emit. As we’ve seen, IAMs that incorporate solar geoengineering recommend higher levels of cumulative CO_2 emissions in the scenario with solar geoengineering than they recommend in the scenario without it. So, if modelers who affirm the view that solar geoengineering is no substitute for emissions reductions mean anything *beyond* the above flat-footed consensus, they must mean something very specific:

> *No Delay/Substitution (Cost Baseline)*[14] The prospect of solar geoengineering does not justify increasing CO_2 emissions beyond the level that would be cost-effective, or optimal.[15]

The thought, in other words, is that the kind of substitution or delay we should collectively aim to *avoid* is substitution *beyond* some baseline of cost-effectiveness or optimality. However, this understanding of the baseline from which ‘delay’ or ‘substitute’ should be understood is not the only, nor to my mind the most natural one. Indeed, the following understanding strikes me as more intuitive:

> *No Delay/Substitution (Normative Counterfactual Baseline)* The prospect of solar geoengineering does not justify increasing CO_2 emissions beyond the level that would be recommended in a scenario without solar geoengineering.[16]

In a word, this principle says: Solar geoengineering is not a good reason to move the mitigation goalposts. I suspect that those not steeped in the economic approach to address-

[14] I say ‘optimal or cost effective’ to account for two different types of models mentioned above. In models where the temperature target is exogenously constrained, solar geoengineering alongside a slower energy transition will be the most cost-effective way to reach that target. On models where the temperature target is one variable up for manipulation, solar geoengineering alongside a slower energy transition will maximize benefits or welfare. See Belaia et al. (2021, p. 18) for a brief endorsement of a similar idea. This principle would presumably condemn a scenario in which the energy transition is abandoned entirely (so long, of course, as such a scenario would be sub-optimal).

[15] For the purposes of this paper, I’m assuming that a delay in emissions reductions results in higher cumulative emissions—thus ‘delaying emissions reductions’ and ‘substituting for emissions reductions’ are equivalent. It is possible, of course, that these two dimensions could come apart: A delay in emissions reductions with steep emissions cuts could result in the same cumulative emissions as an energy transition that begins sooner and proceeds more slowly. Further work clarifying these ideas would pull apart these two dimensions, but I treat them together for now, in part because the IAMs that integrate solar geoengineering, postponed emissions cuts come with higher cumulative emissions.

[16] I say ‘*normative* counterfactual’ to emphasize that the relevant counterfactual is the rate of emissions reductions that *should* proceed absent solar geoengineering. On another reading, solar geoengineering should not delay emissions reductions relative to the rate at which we predict we will reduce emissions (a predictive counterfactual). Perhaps when some commentators state that solar geoengineering should not delay the energy transition, they mean that it should not delay the energy transition relative to what *would* happen absent solar geoengineering. This approach relies, however, on a background understanding of the normative counterfactual: In order to claim that solar geoengineering should not delay emissions reductions relative to what *would* happen without solar geoengineering, we will need to first determine the impact of solar geoengineering on what the speed of emissions reductions *should* be.

ing climate change are more likely to conceptualize delay and substitution in terms of the Normative Counterfactual Baseline. Intuitively, at least, the idea that solar geoengineering should not delay or substitute for emissions reductions (or lessen the urgency of mitigation), suggests that solar geoengineering should not shift the rate at which societies aim to reduce emissions.[17]

Regardless of whether the above (ultimately empirical) suspicion is correct, absent shared understanding of what is meant by the claim that solar geoengineering should not 'delay' or 'substitute for' emissions reductions, debates about solar geoengineering will proceed at cross-purposes. It can appear as if all parties to the debate agree about how to understand the relationship between solar geoengineering and emissions reductions, but in fact there is disagreement over the baseline from which *problematic* delay or substitution should be understood.

This disagreement has stakes: At issue is the question of whether solar geoengineering provides a good reason to extend the life of the fossil fuel industry. The results of a widely used climate policy tool—IAMs—suggest that it does. Indeed, the recommended level of additional emissions is not trivial. Heutel et al. (2018) find, for instance, that allowing solar geoengineering lowers the optimal level of emissions reductions, letting humanity emit roughly 600 Gt CO_2 more in total—about 15 years of today's emissions—before atmospheric carbon reaches its peak.[18]

Thus far, I've tried to show that if you take lowering the costs of meeting a given climate target or pursuing the 'optimal' (welfare-maximizing) climate policy as your central goal, you'll be hard-pressed to avoid the conclusion that solar geoengineering should be used to emit *more* than would be recommended in a scenario without the technology. One way to avoid this conclusion may be to emphasize the uncertainties and 'unknown unknowns' involved in the use of solar geoengineering. Indeed, as researchers often rightly acknowledge, Integrated Assessment Models often struggle to incorporate such dimensions.[19] Perhaps, once scientific uncertainties concerning solar geoengineering are factored in, we will see that solar geoengineering does not provide a good reason to delay emissions reductions. But if this approach is pursued, it should be made clear that the present prohibition on using solar geoengineering to delay emissions reductions is *epistemic*. According to this approach, the reason that solar geoengineering should not be used to delay emissions reductions has to do with our lack of knowledge of its effects. If some uncertainties can be reduced and solar geoengineering is shown to be safe, the substitution effect will likely once again kick into gear.

[17] This way of explaining the distinction keeps the meaning of 'delay' and 'substitution' constant, and points out that different parties to the debate have different views regarding when delay would be problematic. Of course, it could also be the case that different parties to the debate are using the terms *themselves* differently (by, say, understanding 'delay' as 'delay relative to some optimum). In what follows, when I use the term 'delay' or 'substitute' for, I mean it in the former sense.

[18] Heutel et al. (2018) find that introducing solar geoengineering into an optimizing model raises the peak atmospheric stock from ≈1,780 Gt C to ≈1,850 Gt C (a 70 Gt C≈257 Gt CO_2 increase). Assuming 45% of each tonne emitted stays aloft, that implies ~600 Gt CO_2 of extra cumulative emissions.

[19] For instance, Belaia et al. (2021) acknowledge that "our modeling approach comes with the usual limitations attached to IAMs in general and DICE in particular. Our centralized, benevolent decision-maker is a fiction, and we ignore large uncertainties associated with climate interventions. Some of climate damages may be irreversible, which would make an early action in every policy dimension even more important, while rendering long-term CDR less relevant" (p. 18).

You might think that another strategy for resisting the conclusion that solar geoengineering should delay emissions reductions is to move away from the idea that what matters when it comes to the potential future use of solar geoengineering is maximizing benefits, or minimizing the costs of reaching a given climate target. After all, these approaches notoriously struggle to attend to distributional and other justice-related considerations. However, at least one justice-oriented argument for solar geoengineering can also be extended to yield the conclusion that solar geoengineering should substitute for emissions reductions. This argument for solar geoengineering relies on the following two premises:

1. Policies that benefit the worst off among us ought to be put in place, barring important reasons to act otherwise.
2. Solar geoengineering would *benefit the worst off among us.*

Like before, the conclusion to this simple argument is that we should take steps towards the deployment of solar geoengineering. This argument is commonly evoked in both academic and popular discussions of the technology.[20] Regardless of the *aggregate* impacts of solar geoengineering, the worst off among us stand (the argument goes) uniquely poised to benefit from solar geoengineering, and this amounts to a prima facie argument in favor of eventual deployment. Notice, however, that the following proposition appears plausible:

3. A slower energy transition would *further* benefit the worst off, so long as the consequences of higher cumulative emissions can be avoided.

After all, economic activity still requires steel, aluminum, concrete, aviation, and shipping, among other things. These activities are carbon-intensive, yet they are undoubtedly linked to positive outcomes for the worst off.[21] Once again, on pain of inconsistency, it seems the supporter of this 'pro-poor' argument is committed to using solar geoengineering as a tool to emit more, "get back out there," and get "back to work." Turning back to our guiding analogy: In a society where Johnny Sullivan must earn a paycheck to survive, surely it benefits Johnny more, at least in the short term, to continue working while taking the opioids than it does to simply take the opioids and focus on recovering from his injury.

It takes some work to see it, then, but two of the arguments commonly leveraged to support solar geoengineering, if extended, recommend using solar geoengineering to slow the speed of the energy transition relative to a scenario without the technology. In the remainder of this paper, I want to revisit the analogy we started with to explain how I believe we should respond to these observations. Recall that so far I have used the opioid–solar geoengineering analogy to help us *see* something. Just as it is sensible, in the case of opioids, to be on the lookout for forms of reasoning that advance the interests of Purdue Pharma at the expense of individuals in pain, so too should we stay attuned to arguments for solar geoengineering that play a similar ideological role. And, as it turns out, just as Purdue Pharma marketed their product as a way to put off addressing the root cause of an injury, it appears that (at least) two arguments for solar geoengineering can be extended to justify increased emissions.

[20] David Keith and Josh Horton (2016) make this point in an early influential paper on the topic. For a separate important critique of the 'pro-poor' argument of solar geoengineering, see Hourdequin (2018).

[21] Of course, if it turns out that a *faster* energy transition would benefit the worst off more than a *slower* one, then the argument would not imply that solar geoengineering should substitute for emissions reductions.

We can react to this implication in a few ways. Some might treat the implications of the above arguments as a *reductio*, and reject the above two arguments in favor of solar geoengineering. In other words, if an argument in favor of solar geoengineering implies that the technology should be used to emit more than otherwise would be recommended, then that is sufficient reason to reject those specific arguments in favor of solar geoengineering. Others might reply by more publicly endorsing the idea that solar geoengineering provides a good reason to emit more than they would recommend in a situation without the technology.

I want to suggest another way to proceed. What we'll end up with is the very beginnings of an argument that does not impugn solar geoengineering research or potential deployment itself, but *does* condemn using solar geoengineering to delay emissions in the sense endorsed by the reasoning and economic models investigated above. To begin, notice that the fact that the arguments I have canvassed imply that solar geoengineering should be used to delay emissions reductions should not be understood as a decisive mark against those arguments. A slower energy transition can bring enormous benefits; we should not reject out of hand any argument that endorses a slower energy transition.[22] We'll need more than simply an environmentalist's conviction to show that solar geoengineering should not delay emissions reductions—we'll need an *argument.*[23]

We can begin to develop the contours of such an argument by returning to our guiding metaphor and the concept of addiction. Importantly, opioid use disorder is not merely harmful because of the withdrawal symptoms when one stops using. It is harmful because of, among other things, the way in which one structures one's life to keep using. Addiction involves a lack of attention to key priorities—friends, family, health, and so on.

There is an analog to this in the solar geoengineering case. Imagine that solar geoengineering is used to manage *chronic* pain and delay attention to the underlying cause: Governments use solar geoengineering as a tool to emit more, as the above arguments and the economic models that mimic them suggest they should. Doing so commits those governments to invest resources and labor power in the continual deployment of aerosols over hundred-year timescales (Baur et al. 2023). On one popular scenario, day in and day out retrofitted military jets must fly around the Earth releasing some reflective substance into the upper atmosphere (Smith 2020; Horton et al. 2025).

More importantly for my argument, however, is that if governments use solar geoengineering alongside delayed emissions reductions, they engage in a kind of procrastination.[24] They commit future generations to the enormous task of removing *additional* years' worth of human emissions from the atmosphere via carbon dioxide removal. Already, carbon dioxide removal plays a role in modeled mitigation scenarios that many have deemed unjustifiably large (Anderson and Peters 2016; Lenzi 2018). The addition of solar geoengineering to the policy mix makes matters worse, in at least two interlocking respects. First, if solar geoengineering is used as a tool to emit more than in the non-solar geoengineering scenario, then more carbon removal will be necessary if societies hope to correct for the eventual

[22] As Gardiner (2011) has argued, it is false that we should reduce emissions as fast as possible. After all, there are plenty of effective ways of reducing emissions that we would consider reprehensible.

[23] David Morrow (2014), in one of the few treatments I have found addressing the normative question of why mitigation deterrence might be bad or wrong, lays out three scenarios in which solar geoengineering alongside slower emissions reductions would be worse than not researching or deploying solar geoengineering at all. My suggestion can be understood as adding to his list.

[24] For a more detailed analyses of intergenerational injustice as 'kicking the can down the road' or 'buck passing', see Stanczyk (2021), Gardiner (2006).

overshoot. Second, societies will be constrained to continue solar geoengineering until they have accomplished this (now greater) carbon removal challenge. For ceasing aerosol injection without removing the CO_2 those aerosols are masking will result in a rapid rise in temperatures known as 'termination shock.'

A carbon dioxide removal project of this scale imagined in this scenario shares many characteristics with addiction. Opioid use disorder diverts the sufferer's attention away from critical social priorities. We can tell a parallel story about carbon removal. Consider, for instance, the projected energy use requirements of Direct Air Capture. According to a recent analysis, removing 30 gigatons of CO_2 per year—an upper-end estimate in some models—would require approximately 300 exajoules of energy each year (Realmonte et al. 2019). This is more than *half of overall global energy use today* from all sources. And even with the projected rising energy supply, 300 exajoules still amounts to a quarter of the expected demand in 2100. This energy could go towards purposes other than removing the emissions from past economic activity—these renewable energy sources could power schools, hospitals, businesses, and so on. [25] We see a similar dynamic when it comes to other carbon removal techniques. Bioenergy with carbon capture and storage and afforestation, for instance, have enormous land use requirements, and it has become increasingly well-recognized that a large-scale deployment of the technology could threaten food security (Fuhrman et al. 2020; Chiquier et al. 2025; Naef et al. 2025).

If solar geoengineering is used to slow the pace of emissions reductions, as common arguments for the technology imply, we should fear intergenerational addiction. Societies in the future will be trapped by the looming threat of withdrawal symptoms, manifesting as termination shock, and their resources and labor power will be diverted from other key priorities towards the massive challenge of removing the emissions of their predecessors. None of this is to deny that a carbon dioxide removal industry fit to this challenge could also bring significant benefits—providing employment, innovation, and so on. However, these benefits are nevertheless ones that future societies will be *constrained* to enjoy, on pain of either continued and increasingly risky solar geoengineering or termination shock. Perhaps somewhat counterintuitively, then, on this picture a central part of why solar geoengineering should not delay emissions reductions comes down to the way in which solar geoengineering alongside increased emissions locks those that follow us into an even more extensive project of carbon dioxide removal.

Nothing I've said thus far yields an answer to the question of whether to research, or eventually deploy solar geoengineering. Rather, I've tried to show *some* arguments for solar geoengineering imply that the technology *should* be used to delay emissions reductions, and provide one initial suggestion for resisting that conclusion. One important implication of these observations is that researchers should be more explicit that the results of their modeling suggest that if solar geoengineering is used, its use justifies a slower energy transition. Moreover, if my suggestion about geoengineering and addiction is on to something, I'm inclined to think that modelers should refrain from integrating solar geoengineering into economic analyses that look to calculate the lowest cost pathway to some temperature target or to calculate the optimal policy trajectory. Of course, modelers could attempt to incor-

[25] Many ethical concerns about carbon removal focus on what Anderson and Peters (2016) call the 'high stakes gamble' of betting on a technology that is not yet available at scale. The point I am raising is independent of these concerns. Even *if* we are optimistic that carbon dioxide removal can be scaled up quickly, the technology is still energy, labor, and often land intensive.

porate solar geoengineering into IAMs in a way that avoids the normative concern I have raised. Doing so would require further reflection on the nature of the normative concern itself, a project I have only begun here. Moreover, the project of incorporating solar geoengineering into IAMs—tools meant to guide toward some ‘ideal’ climate policy—involves thinking about solar geoengineering not fundamentally as a response to projected future *failure* to reduce emissions, but rather as an ordinary component of climate policy. If solar geoengineering is to be included in IAMs, modelers must further defend the view that solar geoengineering is not merely a response to projected future emergency, but a policy option to positively pursue, to be built in from the start. Failure to do so will support an approach to solar geoengineering policy that risks indulging short-term interests at the expense of facilitating future addiction.

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