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Ethical and Technical Challenges in Compensating for Harm Due to Solar Radiation Management Geoengineering

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Abstract.

As a response to climate change, geoengineering with solar radiation management (SRM) has the potential to result in unjust harm. Potentially, this injustice could be ameliorated by providing compensation to victims of SRM. However, establishing a just SRM compensation system faces severe challenges. First, there is scientific uncertainty in detecting particular harmful impacts and causally attributing them to SRM. Second, there is ethical uncertainty regarding what principles should be used to determine responsibility and eligibility for compensation, as well as determining how much compensation ought to be paid. Significant challenges loom for crafting a just SRM compensation system.

Introduction.

As the effects of climate change become more apparent and efforts to reduce greenhouse gas emissions continue to make little progress, various climate scientists are calling for serious research into a radical solution: geoengineering via solar radiation management (SRM) (Crutzen, 2006; Keith *et al.*, 2010; Wigley, 2006). Geoengineering is defined as the intentional, large-scale manipulation of the Earth's environment via technological means (Keith, 2000). SRM geoengineering would reduce the amount of solar radiation that is absorbed by the Earth's

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surface and thus cool the planet, such as by brightening marine clouds or injecting reflective aerosols into the stratosphere. However, although SRM techniques could reduce or avert many of the harmful impacts of climate change, such as sea-level rise (Irvine *et al.*, 2009; Irvine *et al*., 2012), such techniques also may carry various risks, such as reducing regional precipitation considerably (Irvine *et al*., 2011; Robock *et al*., 2008). This raises concerns that SRM deployment could be unjust, such as by disproportionately harming some persons through droughts caused by reductions in precipitation (Svoboda *et al.*, 2011).[3] One possibility for ameliorating potential injustices of SRM would be to compensate those harmed by it (Bunzl, 2011). There are precedents for compensating victims of environmental harm, such as the United Nations Compensation Commission requiring Iraq to pay various parties harmed by environmental degradation in the wake of its 1990 invasion of Kuwait (Farber, 2007, pp. 1619-1620). Unfortunately, it is far from clear both how an SRM compensation system ought to be structured and whether it can be applied in a satisfactory manner.

In this paper, we examine the ethics of providing economic compensation to persons who would be harmed by SRM deployment, if any. After briefly discussing the science of both climate change and SRM, we examine the potential for SRM deployment to benefit some persons while harming others due to changes in the climate and in other biophysical systems. We argue that instituting a just and effective SRM compensation system faces daunting challenges, both technical and ethical. Given the chaotic and highly variable nature of the climate system, it could be very difficult to determine what harmful impacts are due to SRM rather than natural

[3] We focus on matters of justice because SRM has the potential to violate widely recognized norms of distributive and intergenerational justice (Goes *et al*., 2011; Svoboda *et al*., 2011), although we recognize that various other ethical approaches are available for considering SRM, such as consequentialist ones based on maximizing welfare. Deciding among competing normative approaches to ethical issues raised by climate change and SRM is a controversial matter that we cannot resolve here, of course. However, we note that concerns about justice are widely shared in the climate ethics literature (Caney, 2005; Page, 1999), thus making our choice of approach non-idiosyncratic.

occurrences in the climate system. Likewise, we argue that there is substantial ethical uncertainty regarding which principles ought to govern a just SRM compensation system, such as those determining who would be responsible for providing compensation, who would be eligible for receiving compensation, and how much compensation ought to be provided.[4] Although we focus on matters of justice while considering these questions, we also suggest that analogous issues might arise for alternative ethical approaches, such as welfarist approaches concerned with maximizing overall welfare (Crisp, 2008). Finally, we argue that economic compensation is unlikely to be able to redress all harm due to SRM deployment, given that some kinds of harm, such as death or the loss of one's culture, do not seem susceptible to economic remuneration.

We conclude that establishing a just SRM compensation system faces severe difficulties. This does not necessarily imply that SRM ought never to be deployed, as there might be satisfactory ways to resolve these difficulties. Further, even if these difficulties are not fully surmounted, it does not necessarily follow that SRM deployment would be impermissible. We recognize that, if an SRM compensation system is put in place in the future, it is likely to be the result of complex political processes and negotiations. Such a compensation system is unlikely to be perfect from an ethical standpoint. Nonetheless, prior to any deployment of SRM, it is important to identify and carefully consider the ethical and technical challenges of crafting an appropriate SRM compensation system, both because many members of the global public would have stakes in this issue and because negotiations among policy-makers might be at least partly guided by ethical considerations. In particular, one's evaluation of some SRM policy could depend crucially on whether it would include just compensation to those who are harmed.

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[4] As we note below, there would be similar ethical uncertainty for alternatives to our justice approach. For example, on a certain kind of consequentialist approach that seeks to maximize welfare, there would still be questions regarding who ought to provide and receive compensation. Presumably, on this approach, the payers and payees would be determined by whatever arrangement maximizes net welfare, but there may be substantial uncertainty regarding what arrangement would in fact do so.

The Science of Climate Change and Solar Radiation Management.

Atmospheric concentrations of carbon dioxide (CO_2) have been rising rapidly since the dawn of the industrial age, increasing from approximately 280 parts per million in 1850 to 390 parts per million in 2010 (Arndt *et al.*, 2011). CO_2 is a long-lived greenhouse gas that absorbs thermal radiation in the atmosphere, and so as concentrations increase the planet is warmed. The anthropogenic changes in the composition of the atmosphere are thought to be largely responsible for the estimated ~0.8° Celsius rise in global average temperature that has been observed in the same period (IPCC, 2007). The effects of these human-made changes to the planet's atmosphere are already being seen today, and in the future changes will occur which will profoundly affect populations and species across the world. Temperatures have risen around the world (IPCC, 2007); glaciers are retreating world-wide (Radic and Hock, 2011); sea-levels are rising at approximately 3 millimeters per year (IPCC, 2007); and global average precipitation is rising and becoming more extreme, with more frequent flooding and droughts (Trenberth, 2011). The changes to the Earth system so far are relatively small compared to those predicted by the end of the century if CO_2 emissions continue in a business-as-usual scenario. Additionally, ocean acidification, which is caused by rising levels of dissolved CO_2 that lowers the pH of the oceans, could harm some calcifying marine organisms and damage coral reefs (Doney *et al.*, 2009).These changes to the physical world are affecting plants and animals already: species are adapting by shifting to cooler climates at higher latitudes and altitudes (IPCC, 2007), and organisms are making phenological changes to adapt (Sutherland *et al.*, 2010). These physical and biological changes are affecting human populations as well. For example, dangerous events, like the

European heat wave in 2003 (Stott *et al.*, 2004), and flooding, like that which struck England in Autumn 2000, are more likely to occur today than they were in the past (Pall *et al.*, 2011).

SRM geoengineering techniques could offer a means to address some of the problems of anthropogenic greenhouse warming. If it works as planned, SRM would cool the planet by reflecting incoming sunlight before it is absorbed, thus compensating for the warming caused by atmospheric greenhouse gases. SRM could thus avert some of the impacts of climate change, such as by lowering global temperatures and reducing sea-level rise due to melting ice sheets (Irvine *et al.*, 2009; Lunt *et al.*, 2008). Various SRM techniques have been suggested, such as increasing the reflectivity of the land surface (e.g., roofs, crops, or deserts) (Akbari *et al.*, 2009; Ridgwell *et al.*, 2009), brightening marine clouds in order to make them more reflective (Latham, 1990), installing mirrors in space (Angel, 2006), and replicating volcanic eruptions by injecting reflective sulfate aerosols into the stratosphere (Crutzen, 2006; Wigley, 2006). One argument for researching SRM techniques is that, although geoengineering would be an “imperfect” response to climate change, it might be preferable to other available responses in certain scenarios, such as a pending climate emergency (Keith *et al.*, 2010). This is because some SRM techniques offer potentially fast and effective influence over some aspects of the climate (Lenton and Vaughan, 2009), although timescales for deployment would be constrained by availability of the infrastructure and technologies needed for delivery and upkeep. This contrasts with mitigation of CO_2 emissions or techniques to remove CO_2 from the atmosphere, both of which would operate over long timescales and thus would not be fast enough to counter imminent climate emergencies or tipping points, such as the collapse of major polar ice sheets (Lenton *et al.*, 2008).

Stratospheric aerosol injections, for example, offer the potential for a substantial cooling effect (Lenton and Vaughan, 2009) that could be delivered rapidly, perhaps allowing significant control over both the rate of global warming or cooling and the temperature of the planet. Thus, SRM *could* be a feasible strategy prior to some forms of climate emergency, such as rapid warming caused by methane release from clathrates or permafrost, assuming such an emergency could be identified before it occurs (Archer, 2007). Since SRM could facilitate a large change in the Earth's radiation balance over a short timescale, it could halt or reverse warming within months or years rather than decades or centuries (Schneider, 2009; Wigley, 2006). This is not to deny that SRM would be an "imperfect" strategy (Keith *et al.*, 2010). For example, most studies of SRM geoengineering have shown that there would be a reduction in the intensity of the hydrological cycle (Bala *et al.*, 2010; Lunt *et al.*, 2008), decreasing average annual precipitation in some regions. Further, SRM would do nothing to reverse the effects of ocean acidification, which could become a major problem in the future (Matthews *et al.*, 2009). Finally, once deployed, some techniques require constant application to maintain their cooling effect. If that application was abruptly discontinued, the result would be rapid global warming at a rate much higher than if geoengineering had not been initiated (Goes *et al.*, 2011; Irvine *et al.*, 2012; Ross and Matthews, 2009). This risk of discontinuation raises serious ethical concerns, as those harmed by the discontinuation of geoengineering might not belong to the same generation as those that initiated it (Svoboda *et al.*, 2011).

<u>Beneficiaries and Victims of Solar Radiation Management</u>.

If deployed, SRM geoengineering likely would result in harm to some persons and benefit to others, thus creating both "winners" and "losers." For example, some persons might benefit from a reduced global temperature that lowers the risk of substantial sea-level rise or intense heat waves (IPCC, 2007). Others might be harmed in various ways: reduced precipitation could lead to droughts or decreased agricultural productivity (Irvine *et al.*, 2011; Robock *et al.*, 2008), and the depletion of ozone caused by stratospheric aerosol particles could negatively impact the health of some individuals (Tilmes *et al.*, 2008). SRM geoengineering would also not address all the harms caused by anthropogenic greenhouse gas emissions, such as ocean acidification and the regional reductions in evapotranspiration caused by elevated CO_2 concentrations (Boucher, 2009; Matthews, 2009). While the extent of such harm is deeply uncertain and would depend on both the variety and intensity of the SRM technique that was deployed, there is a risk that SRM geoengineering could result in substantial harm that is unequally distributed among persons around the world. This risk raises the concern that SRM deployment could violate principles of distributive justice (Svoboda *et al.*, 2011).

According to model simulations, the response to SRM would be an average global cooling and a reduction in the intensity of the hydrological cycle (i.e., less precipitation and evaporation). However, the response of temperature and, in particular, precipitation to SRM would differ greatly among regions (Irvine *et al.*, 2010; Jones *et al.*, 2011). In some cases, to determine whether a change in the climate of a specific region is harmful or beneficial, the existing climatic conditions must be considered. For example, an increase in precipitation might be beneficial to inhabitants of a dry region, but the same increase might be harmful to inhabitants of a region prone to flooding. In other cases, however, some climate states might be beneficial to some individual or set of individuals irrespective of the initial climatic conditions. For example, a farmer wishing to grow a certain valuable crop might benefit overall from the conditions most suited to growing that crop, regardless of the initial climatic conditions of the region. More broadly, the predicted impacts of anthropogenic climate change might be beneficial to some set of persons, even if those impacts would be harmful to the vast majority of persons on Earth. An example of this is offered by Arctic warming, which is creating problems in permafrost areas, such as subsidence of the land surface and increased erosion resulting in infrastructure damage (Hinzman *et al.*, 2005). While this warming results in harm for some individuals, it also opens shipping routes and access to resources due to retreating sea ice, thus benefiting others (Liu and Kronbak, 2010).

The potential for SRM deployment to result in an unequal distribution of harm and benefit among persons raises a serious ethical challenge. It seems unfair to adopt a climate change strategy that benefits some at the expense of harming others. This is especially the case if those harmed bear little or no responsibility for the problem of anthropogenic climate change. For example, given the potential for stratospheric aerosol injections to reduce precipitation in South America, Africa, and southeast Asia (Robock *et al.*, 2008), this form of SRM could harm persons in countries with some of the lowest per capita CO_2 emissions in the world (UN, 2009). Presumably, it is unjust to burden individuals with the heavy costs of addressing a problem to which those individuals did not contribute. One way to address this potential injustice is to institute a compensation system for those who are harmed as a result of SRM deployment (Bunzl, 2011). Perhaps economic remuneration could redress the harm suffered by some persons, thus ameliorating the injustice that otherwise could result from SRM deployment. Indeed, instituting a *just* SRM compensation system might be a necessary condition for SRM to be ethically permissible. However, due to substantial scientific and ethical uncertainty, it is far from clear what such a system would be. First, there would be severe challenges to establishing that particular impacts were in fact caused by the deployment of SRM. Second, it is controversial what ethical principles should govern just compensation for SRM. We will now consider both these sets of challenges in turn.

Technical Difficulties of Detection and Attribution.

The Earth's climate is a chaotic, highly variable, non-linear system, and as such a determinate prediction of its evolution is not possible (IPCC, 2007). This makes detecting changes in the climate system a challenging and active area of research (Stone *et al.*, 2009). The observational record of climate variables is long but incomplete. Some regions have records going back hundreds of years, while other regions are still under-sampled, making it difficult to know what the current climate condition is, much less how it has changed (Stone *et al.*, 2009). To detect a climate-driven change in non-climate systems, such as ecosystems and disease vectors, there are even greater problems, as observations are even more sparse and techniques vary across regions and time (Stone *et al.*, 2009). Despite these difficulties, a number of changes in the climate have been detected: warming, globally and on each continent (Gillett *et al.*, 2008; IPCC, 2007); an increase in the frequency of extreme precipitation events (Trenberth, 2011); and a reduction in Arctic sea-ice extent (Min *et al.*, 2008).

The problem of attributing climate change to some cause is even more challenging than that of detecting it, because doing so requires one to compare observations of the climate to the predictions of climate models under a number of different scenarios. For example, in order to attribute global warming to anthropogenic greenhouse gas emissions, two scenarios are simulated: the first includes all relevant factors, while the second includes all these factors except anthropogenic emissions of greenhouse gases. To attribute most of the observed warming to anthropogenic greenhouse gas emissions, it needs to be shown that a better fit to the observed changes in climate is found by including anthropogenic emissions than not including them. It must also be shown that the climate models produce a reasonable physical representation of the climate (IPCC, 2007). The uncertainty involved in attributing particular changes in climate to specific causes could make it very difficult to determine whether or not some harmful impact, such as a prolonged drought, is due to a deployed SRM technique. If SRM is deployed, droughts and other weather events will continue to occur, causing harm to various persons. Determining whether SRM is causally responsible for each of these events would be extremely difficult. Thus, it would not be easy to determine whether those harmed by a drought or some other impact deserve SRM compensation, because it could be unclear whether they are victims of SRM deployment rather than victims of a natural event.

A potential solution to this problem would be to adopt an approach based on fractions of attributable risk (Allen, 2003; Stott *et al.*, 2004), which does not causally attribute an event to some single cause but rather calculates the increase in the likelihood of an event due to a change in a certain forcing. Using climate simulations both with and without anthropogenic greenhouse gas contributions, Stott et al. (2004) analyze the likelihood of the occurrence of a summer as anomalously warm as 2003 in Europe, the year of a severe heat wave (Robine *et al.*, 2008). They found that greenhouse gas increases had made such extremely warm summers twice as likely to occur, and thus had a fraction of attributable risk of 50% for the summer 2003 heat wave. However, this method still involves uncertainty, given that it requires a climate model (or an ensemble of several climate models) to predict the chances of an event occurring both with and without a forcing agent. Thus, to calculate the fraction of attributable risk of some event requires that simulations of the observed climate be compared to an unobserved climate in which the forcing of interest (e.g., anthropogenic greenhouse gases) is excluded. To find the likelihood of extreme climatic events, which are rare, hundreds or thousands of years of observations would be needed. Since such extensive observations are not available, many simulations of the observed climate are needed to estimate the likelihood of these events. Accordingly, attributing certain impacts to SRM via this approach still requires reliance on imperfect computer simulations of the climate.

Ethical Issues Regarding Compensation for Solar Radiation Management.

In addition to the technical challenges of detecting certain impacts and attributing them to certain causes, there are difficult ethical questions regarding what would constitute a just compensation system for harm caused by SRM. We identify three sets of such ethical questions: (1) who ought to provide compensation, (2) who ought to receive compensation, and (3) how much compensation ought to be provided. We consider familiar principles in the climate ethics literature that might be relied upon to answer these questions, noting certain disadvantages and problems for all of them. While these three sets of questions do not address all the ethical issues that are raised by the prospect of SRM compensation, they are important questions that should be addressed and considered carefully before an SRM policy is implemented.

Who Ought to Provide Compensation?

First, it is not obvious who ought to pay compensation to persons harmed by SRM. We discuss three principles often considered in the climate ethics literature (Singer, 2004, pp. 14-50), which could be used to determine responsibility for SRM compensation: the polluter pays, the beneficiary pays, and the ability to pay principles. We also consider possible hybrids of these principles. While we neither endorse nor reject any one of these, we do highlight various advantages and disadvantages of each. We argue that it is uncertain what ethical principles should be used to determine who is responsible for providing compensation to victims of SRM. Like scientific uncertainty about the impacts of climate change and SRM, this ethical uncertainty is a major challenge to developing a just compensation system for SRM. We also note that this is an important issue for ethical approaches that, unlike our own, do not adopt a justice framework. For example, on an approach based on maximizing welfare, it might be the case that some amount of SRM compensation would, compared to other possible policies, increase overall welfare to the greatest degree. However, even if we determine that some amount of payment to victims of SRM would best increase overall welfare, we still would need to know who ought to make those payments, given that welfare-maximizing payment would require payers.

Who Ought to Pay?

Principle	**Compensator**
Polluter Pays	Agents of SRM
Beneficiary Pays	Beneficiaries of SRM
Ability to Pay	Rich Persons/States
Hybrids	Variable

According to the polluter pays principle, the agents of harmful pollution are responsible for compensating victims of that pollution. Simon Caney distinguishes between a micro-version and a macro-version of this principle. On the former, “if an individual actor, X, performs an action that causes pollution, then that actor should pay for the ill effects of that action.” On the latter, “if actors X, Y, and Z perform actions that together cause pollution, then they should pay for the cost of the ensuing pollution in proportion to the amount of pollution that they have caused" (Caney, 2005, p. 753). In the context of SRM deployment that causes harmful pollution, such as aerosols that deplete ozone (Tilmes *et al.*, 2008), those who deployed SRM would be responsible for compensating those who are harmed as a result of that deployment.[5] If one was to apply Caney's macro-version of the polluter pays principle, each agent of SRM would be responsible for providing a quantity of compensation that is in proportion to the quantity of pollution that agent caused.

Initially, it seems reasonable to hold with the polluter pays principle that agents are responsible both for the actions they perform and for ameliorating any harm their actions cause. However, it is not obvious what kind of entity counts as a polluter (Caney, 2005, p. 754), and hence it is unclear what kind of entity should be held accountable for providing compensation. In the context of compensation for harm caused by SRM deployment, should the compensators be individuals, collectives (e.g., states or corporations involved in SRM deployment), or perhaps some combination of these? If states are held responsible, how should they raise revenue for a compensation fund? May they tax citizens who initially opposed SRM deployment? Moreover, should individual or collective emitters of greenhouse gases also be deemed "polluters" who are responsible for compensating those harmed by SRM? After all, such emitters would be causally responsible for the climate change to which SRM would be a response. However, unless all greenhouse gas emitters were also agents of SRM, the former would not be causally responsible for harms due to SRM itself. Are emitters nonetheless ethically required to provide SRM

[5] One might ask why it is reasonable to frame SRM as a pollution issue. First, many SRM techniques arguably involve pollutants, insofar as they introduce into the environment materials (e.g., sulfate precursor aerosols) that have harmful impacts. Second, even if some SRM technique does not technically count as a form of pollution (e.g., space mirrors), the polluter pays principle nonetheless captures an applicable ethical commitment in the context of SRM compensation, namely that those who cause environmental problems via SRM are responsible for addressing those problems through compensation.

compensation? The answer to such questions could make an important difference for determining who is to provide compensation.

Further, applying the polluter pays principle in the case of SRM compensation could lead to implausible and unfair requirements. Suppose that a developing island state with widespread poverty, whose survival is threatened by sea-level rise, decides to join an international coalition of states that deploys SRM. Since this developing state (and/or individuals within it) would be an agent of SRM, it would be responsible for providing compensation to victims. Yet it is arguably unfair to require this state to pay compensation. Since it suffers from widespread poverty, it presumably would lack the resources to provide compensation for others without substantially harming its own citizens. Further, since this state would itself have been a victim of sea-level rise if SRM had not been deployed, it arguably had little choice but to support deployment. Unless it is ethically appropriate to require a poor state to compensate victims of a policy that was necessary for that state's survival, the polluter pays principle seems to levy an implausible requirement in this case.

An alternative is offered by the beneficiary pays principle, according to which those who benefit from some action are responsible for compensating those who are harmed by that action. In the context of SRM deployment, those who are made better off by SRM would be responsible for compensating those who are harmed by SRM. As Caney notes, the beneficiary pays principle is not a revision of the polluter pays principle but rather an "abandonment" of it (Caney, 2005, p. 756). This is because the set of beneficiaries of some action might not be identical to the set of agents of that action, so adopting a beneficiary pays principle over a polluter pays principle could make a difference for determining who owes compensation to victims of SRM.

Yet this principle is also subject to certain difficulties. Like the polluter pays principle, the beneficiary pays principle could impose implausible and unfair requirements. Suppose that SRM is deployed over the strong objection of some state and the vast majority of its citizens, but that this state and its citizens happen to benefit from the impacts of SRM. According to the beneficiary pays principle, this state and its citizens would be responsible for compensating those who are harmed by SRM, despite their opposition to its deployment. Many may share the intuition that this would place an unfair burden on this state and its citizens. Conversely, suppose that some developed state unilaterally deploys SRM in accordance with its perceived self-interest and with the consent of the vast majority of its citizens, but that in doing so its own citizens are made slightly worse off and those of other states are made substantially worse off. According to the beneficiary pays principle, those individuals within the deploying state who are made slightly worse off by SRM would not be responsible for providing compensation to others.[6] But this seems implausible, because it implies that one can sidestep responsibility for ameliorating the harm one's action causes, provided that the action also harms oneself only slightly.

The beneficiary pays principle faces various other challenges as well, such as uncertainty in identifying beneficiaries of SRM. Given the above-discussed difficulties of detecting particular climatic impacts and attributing them to SRM, it likewise could be very challenging to determine whether some individuals or collectives have been made better off by SRM deployment. This seems especially daunting in the case of future persons who are affected by a previous generation's decision to deploy SRM, since the task of determining whether such

[6] It could be argued that those who are slightly worse off are beneficiaries relative to those who are substantially worse off, thus making the former responsible for compensating the latter. Whether this is so would depend on the controversial and uncertain issue of what baseline should be used for determining what counts as being made worse off or better off by SRM (see below).

persons are beneficiaries of SRM is posed with the problem of comparing their current well-being to what it would have been in a non-SRM world.

This principle also faces the so-called non-identity problem (Parfit, 1982). If SRM was deployed, it could alter what individual persons are born in the future. This is because an SRM policy, especially one that involves global-scale deployment, could affect the circumstances and timing of human reproduction, such that different persons are born in an SRM scenario than in a non-SRM scenario. Since some future persons affected by SRM would not have existed in a non-SRM world, it is arguably the case that SRM could not make them either better or worse off. If so, then the beneficiary pays principle would have no applicability among future persons who owe their existence to the past deployment of SRM, since such persons could be neither beneficiaries nor victims of that deployment. If this is so, then the beneficiary pays principle would have no purchase beyond the present generation, even though SRM could have substantial impacts into the future (Goes *et al.*, 2011). This problem has led some to argue that the beneficiaries of some environmental impact are not individual persons but rather collectives, such as states or communities (Caney, 2005, pp. 758-760; Page, 1999). If this strategy were used in the context of SRM compensation, one could contend that at least some collectives existing in the future would not owe their existence to SRM deployment, in which case such collectives that benefited from that deployment would be responsible for compensating collectives harmed by it. However, this raises the challenge of determining what kinds of collective should be treated as beneficiaries and victims of SRM. Should it be states, corporations, social groups, or some combination of these?

Finally, according to the ability to pay principle, those who have the capacity to provide compensation for victims of harm are responsible for doing so in proportion to their capacity to pay. As Henry Shue puts it, "the parties who have the most resources normally should contribute the most…" (Shue, 1999, p. 537). In the context of harm caused by SRM deployment, those who can afford to compensate victims of SRM would be responsible for doing so, regardless of whether they are either agents or beneficiaries of SRM. As Shue notes, this is a "no-fault principle," whereas the polluter pays principle is "fault-based" (Shue, 1993, pp. 53-54). According to the ability to pay principle, the alleged guilt of various parties is irrelevant to determining who ought to compensate victims of harm. While those who are able to pay in some situation might happen to be agents (or beneficiaries) of SRM, their responsibility to compensate those harmed by SRM rests on the fact that they have the capacity to provide compensation. This principle might be especially appealing to welfarists, given that relatively small payments from rich compensators could go quite a distance in improving the well-being of those who are much less well-off.

Yet like the previous two principles, the ability to pay principle seems to yield some unfair requirements. Suppose that some developed state refuses to join an international coalition of states deploying SRM, arguing against such deployment. According to the ability to pay principle, this state would be responsible for compensating victims of SRM since it has the resources to do so, despite the fact that it opposed deployment. Yet it seems unfair to require a state to provide compensation for harm caused by the actions of others, especially when that state warned against those actions. Of course, one could simply hold that, since the ability to pay principle is a no-fault principle, it is ethically irrelevant whether or not some state was part of the deploying coalition. However, to require a non-deploying state to pay for the damages of SRM deployment will seem counter-intuitive to some. While welfarists simply could maintain that questions of fairness are not morally relevant here, the ability to pay principle would seem to have controversial implications.

The apparent imperfections of each of these three principles might lead one to search for a hybrid principle. One possibility is a combination of the polluter pays and ability to pay principles, as suggested by Dellink *et al.* (2009) for determining who ought to finance adaptation to climate change. Perhaps a similar hybrid principle should be used to determine who ought to compensate those harmed by SRM. In that case, both agents of SRM and those able to pay would be candidates for providing compensation to victims of SRM. The challenge for this and other hybrid principles, however, is situating the component principles in a non-arbitrary way. For example, if one adopts a polluter pays and ability to pay hybrid, how exactly should responsibility to compensate be apportioned among agents of SRM and those able to pay?[7] One possible permutation of this hybrid principle would require that all and only those that are both agents of SRM and able to pay are responsible for compensating victims of SRM. But why adopt this permutation rather than another, such as one that requires both agents of SRM (regardless of their ability to pay) and those able to pay (regardless of whether they are agents of SRM) to provide compensation to victims? Other hybrid principles are possible as well, such as various permutations of two (or even all three) of the principles discussed above. Although we lack space to consider any of these in detail, we note that proponents of some hybrid principle must meet the difficult challenge of justifying why one particular hybrid (or one particular permutation

[7] It would be fortunate if the set of agents of SRM was identical to the set of those able to pay, since this would allow us to sidestep the difficult issue of apportioning responsibility among different members of both sets. Unfortunately, this is unlikely to be the case. For example, while it might be reasonable to expect that all deploying states would also be states sufficiently wealthy to be able to provide compensation, it seems less likely that *all* states able to provide compensation would also be deploying states.

thereof) should be adopted over others. This seems to be a very acute challenge, although we do not suggest that meeting it is impossible.[8]

While we do not here endorse or reject any of these principles, our purpose has been to show both that there are a variety of available principles for determining who ought to provide compensation and that it is uncertain which of these ought to govern SRM compensation. We conclude that, at least at present, who ought to compensate victims of SRM is a matter of ethical uncertainty. This uncertainty could make it difficult to construct a just SRM compensation system, although this uncertainty could be reduced through future research on the matter.

Who Ought to Receive Compensation?

Second, it is not obvious who should count as a victim of SRM and hence be eligible to receive compensation. We identify three potential kinds of victim of SRM: those who are on balance harmed by the impacts of SRM itself, those who are on balance harmed by the impacts of anthropogenic emissions (e.g., ocean acidification), and those who are on balance harmed by missing out on benefits they would have enjoyed had anthropogenic climate change not been altered by SRM.[9] Should compensation be extended to some or all of these classes of individuals? The answer to this question could make a significant difference for determining who would receive compensation. Unfortunately, as we show below, there is substantial ethical uncertainty regarding the answer, thus making it difficult to know who would be paid under a just compensation system.

[8] It has been suggested to us that some hybrid principles might have the virtue of gaining political traction in the course of negotiating an SRM compensation regime, the ethical deficiencies of such hybrids notwithstanding. While this might be true, our purpose in this section is to examine questions pertaining to the justice (or lack thereof) of certain principles regarding who ought to provide compensation. In the course of actual negotiations, one could be justified in advocating an ethically imperfect but politically tractable compensation regime, but it seems useful first to clarify what the ethical issues and challenges of SRM compensation are.

[9] There is also the important question of what counts as harm, but limitations of space prevent us from exploring this here. See Sondøe (1999).

It might seem obvious that at least those persons harmed by the impacts of SRM itself ought to be compensated. For example, if persons in a developing state are on balance harmed by drought or famine attributable to SRM-caused precipitation change, then presumably such persons ought to be compensated. However, this becomes less clear in cases in which those harmed are also agents of SRM. For example, if citizens of a developed state unintentionally makes themselves on balance worse off by deploying SRM, do they deserve compensation from others? To take another example, if citizens of a developed state are made on balance only slightly worse off by SRM deployment but still enjoy a high standard of living, do they deserve compensation from others? If all those who are on balance harmed by SRM deserve compensation, then the citizens of the states in both these examples deserve compensation. Yet this seems implausible. It is clear neither that compensation is deserved by those responsible for harming themselves nor that it is deserved by those who are initially well off and harmed only slightly.

In order to avoid these implausible results, one might accept a principle according to which compensation is deserved by those who are on balance harmed by SRM past a certain threshold, provided that the potential recipients are not themselves agents of SRM. One challenge for such a principle, of course, would be specifying in a non-arbitrary way what that threshold should be. Further difficulties are raised by the proviso that recipients of compensation must not be agents of SRM. Would this exclude compensation for citizens in non-democratic states who have little or no say as to whether their governments deploy SRM?

Another difficulty is raised by the fact that SRM techniques would not avert all impacts associated with anthropogenic greenhouse gas emissions. Perhaps the most important example of this is ocean acidification, which is caused by increasing concentrations of CO_2 dissolving in the oceans (Doney *et al.*, 2009), which could have harmful impacts on persons who rely on marine ecosystems for coastal protection and for economic purposes (Hoegh-Guldberg *et al.*, 2007). Ocean acidification would remain a problem, since SRM neither removes atmospheric CO_2 nor reduces CO_2 emissions (Ross and Matthews, 2009). It is unclear whether those harmed by ocean acidification would merit SRM compensation, given that ocean acidification is not caused by SRM but rather by CO_2 emissions.[10] This issue would need to be addressed in order to craft a working SRM compensation regime. One path toward doing so could involve structuring an SRM compensation system in tandem with a compensation system for harms due to greenhouse gas emissions.[11] This might amount to relying on a hybrid principle, according to which both those harmed by SRM and those harmed by emissions (e.g., via ocean acidification) are eligible for compensation, although how such a hybrid system would function remains to be specified.

There is also a difficult ethical question regarding whether persons ought to be compensated if SRM causes them to miss out on benefits they might otherwise have enjoyed in some non-SRM climate. For example, some persons in high latitudes might benefit from a warmer climate that could increase agricultural productivity and open more ports to year-round shipping (Liu and Kronbak, 2010). Even assuming that SRM on balance would be beneficial for persons as a whole, it might make some subset of persons worse off than they otherwise would have been, namely if anthropogenic climate change had been allowed to occur without

[10] Where one falls on this issue might depend on whether one accepts or rejects that there is an ethical distinction between doing and allowing (Scheffler, 2004). If this distinction is morally irrelevant, then perhaps those harmed by ocean acidification ought to be receive compensation, given that an SRM policy that does not include compensation for such persons would thereby allow them to suffer harm.

[11] Some might wonder whether the challenges of constructing a just SRM compensation system are any different from those of constructing a just compensation system for the impacts of greenhouse gas emissions (Farber, 2007; Anthoff and Tol, 2010). While we recognize that each raises some similar general concerns (e.g., who ought to pay), SRM compensation arguably involves some unique issues. For example, unlike greenhouse gas emissions, SRM has yet to be enacted, and thus considerations about the adequacy of potential compensation systems could influence decisions regarding whether to deploy SRM in the first place. This suggests that SRM compensation is worth investigating in its own right.

interruption. Ought such persons to be compensated for these missed benefits of climate change? The answer to this question is not obvious, but how one answers it could make a significant difference for determining who would be eligible for SRM compensation.

Finally, since SRM likely would have impacts for future generations, various difficulties arise regarding compensation for future persons. For example, there is uncertainty regarding the activities, values, and preferences of future generations, thus making it difficult to know which SRM impacts would be harmful to them, as well as to what degree such impacts would be harmful (Tuana *et al*., 2012). Further, the non-identity problem makes it unclear whether compensation should be paid to future persons who owe their existence to SRM. Even if such persons have a low standard of living, they are no worse off than they would have been in a non-SRM world, since they would not have existed in a non-SRM climate.

All these questions regarding who ought to receive compensation pose challenges for the establishment of a just SRM compensation system. We have attempted to show both that the answers to these questions are not obvious and that diverse answers can make significant differences for determining who ought to be paid SRM compensation. Again, similar concerns arise for a welfarist approach. For example, given uncertainty regarding future preferences and values, it would be difficult to know how a particular compensation system would affect future welfare. We conclude that, at least at present, who ought to be compensated for SRM is a matter of ethical uncertainty.

How Much Compensation Ought to Be Provided?

Third, it is not obvious how much SRM compensation ought to be paid to those who deserve it, given that it is unclear what baseline should be used to measure harm associated with

SRM. We consider two potential baselines, one historical and one counter-factual. First, perhaps victims should receive as much compensation as is necessary to make them as well off as they were just prior to the deployment of SRM. In that case, the baseline for determining compensation would be one's well-being before deployment, which is a historical matter of fact even if it is often difficult to determine. Second, perhaps victims of SRM should receive as much compensation as is necessary to make them as well off as they would have been if SRM had not been deployed, such as in a scenario of anthropogenic climate change without SRM. In that case, the baseline for determining compensation would be one's well-being in a counter-factual scenario, namely one in which SRM had not been deployed. The historical approach has the advantage of simplicity, as it only refers to past and present climate, which can be observed and simulated. The counter-factual approach faces greater technical challenges due to the fact that it compares the observed climate to one that never existed and thus is subject to greater uncertainty.

Adopting one of these baselines over the other could make a crucial difference for how much compensation ought to be paid to victims of SRM. For example, suppose that SRM-caused precipitation change leads to drought in a developing state that, if SRM had not been deployed, would have been subject to drastic sea-level rise. First, imagine that compensation is paid in accordance with the historical baseline. This could mean that persons within this state receive substantial compensation, since some (e.g., farmers who rely on ample precipitation) might be substantially worse off compared to their pre-deployment well-being. Now imagine instead that compensation is paid in accordance with the counter-factual baseline. This could mean that persons within this state receive little or no compensation, given that sea-level rise in a non-SRM climate could have caused even greater harm than that caused by SRM. Even if some set of persons is much worse off after SRM deployment than prior to it, they might still be better off in an SRM climate than they would have been in a non-SRM climate, e.g. one in which anthropogenic emissions are not mitigated.

A potential objection to this historical approach is that it could lead to unfair requirements, because it does not take into account future outcomes if SRM is not deployed. For example, suppose persons in developed states owe their ample well-being to a high-emissions lifestyle. Further, suppose that SRM deployment makes some persons in these developed states slightly worse off than they were prior to deployment, but also that they would have been even worse off without SRM due to the impacts caused by their own high-emissions lifestyle. Assuming these individuals merit SRM compensation in the first place, the historical approach entails that such persons ought to be compensated to the degree necessary to return their well-being to the level they enjoyed pre-deployment. Yet this arguably places an unfair burden on compensators. Although SRM deployment makes persons in developed states worse off than they were pre-deployment, it actually makes them better off than they would have been without deployment.

Given this difficulty, one might adopt the counter-factual approach instead. However, a major difficulty arises in deciding which counter-factual climate to treat as a baseline. Unfortunately, it is far from clear which should be chosen. Possibilities include an indefinite number of anthropogenic emission scenarios and various SRM geoengineering interventions.[12] For example, one might treat the baseline as the result of aggressive emissions mitigation, or one might treat it as the result of dramatically increasing emissions. In the latter case, the impacts of climate change probably would be much more harmful than in the former case. Hence, which of

[12] It may be that SRM geoengineering would be deployed as a partial substitute for more stringent mitigation measures, such that, if it had not been applied, then stronger mitigation measures would have been taken.

these examples one treats as a baseline for compensation could alter significantly how much compensation is paid to recipients. Yet it is difficult to see what should guide one's choice of a baseline, since any prediction of what emissions path would have been followed by humans in a non-SRM scenario seems conjectural.

Finally, the amount of SRM compensation paid to future persons could be greatly affected by what discount rate is used on future well-being (Stern, 2007), since how one measures the magnitude of harms to future persons would depend in part on how much their well-being is discounted, with geophysically identical impacts being evaluated as more or less harmful depending on their temporal occurrence. Adopting a high discount rate may result in low payments to future generations, whereas adopting a low discount rate (or none at all) could result in high payments. However, it is a controversial matter what discount rate (if any) should be employed for future well-being (Broome, 1994; Cowen and Parfit, 1992), thus making it unclear what discount rate (if any) should be used for SRM compensation to future persons. This is a challenge for justice-based approaches, given that an inappropriate discount rate could impose unfair burdens on compensators, or it could result in underpaying future victims of SRM. This is also a challenge for welfarist approaches, because the discount rate that is used affects how much weight is given to future well-being, which in turn could alter how much compensation needs to be paid to future persons in order to maximize overall welfare. In order to assuage the potential problems discussed in this section, one might urge a policy of "playing it safe," whereby compensators err on the side of over-compensating rather than under-compensating, such as by utilizing a low discount rate or none at all. This might reduce the risk of future persons receiving less compensation than they deserve. However, one concern with this approach is that it threatens to impose unfair burdens on compensators by potentially requiring them to over-pay, perhaps substantially. Thus, erring on the side of over-compensation would seem to be controversial.

Ethical Caveats Regarding Compensation.

There are a number of outstanding ethical issues with SRM compensation that we shall mention briefly. First, it is presumably the case that some harms are economically irreparable, such that compensation is unable to redress them. For example, someone who dies as a result of SRM deployment obviously cannot be compensated for his or her own death. To take another example, the effects of SRM might require a particular community to abandon cultural practices that are central to its way of life, such as by being forced to relocate geographically. It might be the case that no amount of payment can compensate for that cultural loss. This would be a major limitation of a compensation system meant to ameliorate harm caused by SRM.

A second outstanding ethical issue is that the ability to compensate does not necessarily license one to inflict harm on others. For example, a real estate developer is not morally permitted to demolish someone's home without the homeowner's consent, even if the developer should offer the homeowner ample compensation afterward. Rather, compensation seems to be an ethically imperfect way of alleviating harm that caused. Analogously, compensation to victims would not justify the harm caused by SRM, although presumably it would be preferable to offering no compensation at all.

Both these outstanding ethical issues suggest that SRM compensation would be an imperfect, limited response to the harms caused by SRM. Even if one could appropriately identify who ought to pay SRM compensation, who ought to receive it, and how much compensation ought to be paid, it does not immediately follow that it is morally permissible to deploy SRM. In order to determine this, one would need to investigate other ethical issues associated with SRM, such as whether deploying SRM would be morally wrong even in climate emergencies (Gardiner, 2010), whether SRM research would create pressure to deploy it regardless of the risks (Jamieson, 1996), the conditions under which a decision to deploy SRM would be procedurally just (Svoboda *et al.*, 2011), and the conditions under which field tests of SRM would be permissible (Tuana *et al.*, 2011). Further, one also would need to compare SRM strategies with other available climate change strategies, assessing their relative ethical merits and deficiencies. It might be the case that, even from an ethical perspective, some strategy involving SRM would be preferable to other available strategies. If so, we contend that every attempt should be made to install a just compensation system. Unfortunately, this would seem to be a very difficult task, not least because of ethical uncertainty concerning what principles ought to govern such compensation.

<u>Conclusion</u>.

In this paper, we have identified various challenges to constructing a just compensation system for SRM. There are various ethical principles available for determining who ought to provide compensation, who ought to receive it, and how much ought to be provided. Choosing among these principles is controversial, as all have disadvantages. Yet even if this ethical uncertainty was significantly reduced, it could be extremely difficult to establish causal links between certain impacts and SRM, thus making it very challenging to determine whether some case of harm merits SRM compensation. Addressing these difficulties seems important for crafting a just SRM compensation system. If SRM is deployed without these issues being addressed, there is a risk of substantial injustice, given the possibility that some persons could suffer unjust harm that is not properly remunerated.

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