Ethical and Technical Challenges in Compensating for Harm Due to Solar Radiation Management Geoengineering[1]

(Pre-Print Version)

Toby Svoboda[2] and Peter J. Irvine[3]

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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 work remains in 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

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[2] Assistant Professor of Philosophy, Fairfield University, 1073 North Benson Road, Fairfield, Connnecticut, USA, tsvoboda@fairfield.edu

[3] Research Fellow, Institute for Advanced Sustainability Sciences, 130 Berliner Strasse, 14467, Potsdam, Germany, peter.irvine@iass-potsdam.de

geoengineering would reduce the amount of solar radiation that is absorbed by the Earth's surface and thus cool the planet, such as by brightening marine clouds or injecting reflective aerosols into the stratosphere. However, SRM techniques may carry various risks. If deployed, some SRM technique could result in substantial harm that would be distributed unequally among persons. This raises concerns that SRM deployment could be unjust (Svoboda *et al.*, 2011). One possibility for ameliorating such potential injustice would be to compensate victims of SRM (Bunzl, 2011), but 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. 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 some natural occurrence 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. 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. Nonetheless, we argue that it is important to identify these challenges and consider them carefully prior to any deployment of SRM, since whether or not some SRM policy is ethically permissible could depend crucially on whether it would include just compensation to those who are harmed.

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 profound changes will occur which will profoundly affect populations and species across the world.

Anthropogenic greenhouse gas emissions are having an effect on the climate and on other aspects of the earth system. Temperatures have risen around the world (IPCC, 2007), with the high latitudes warming faster than the rest of the planet (Serreze *et al.*, 2000); 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). These changes to the physical world are affecting plants and animals: 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 today. For example, dangerous events, like the deadly 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).

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. Temperatures are expected to rise world-wide, with heat waves becoming both more common and more intense (Meehl and Tebaldi, 2004). The hydrological cycle is expected to intensify, with most wet regions getting wetter and most dry regions getting drier (IPCC, 2007). Sea-level rise is also expected to accelerate, both due to a warming and expanding ocean and to a highly uncertain contribution from melting glaciers and ice sheets (Domingues *et al.*, 2008; Radic and Hock, 2011; Rignot *et al.*, 2011). 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).

It is difficult to know how much warmer the planet will become in response to rising CO_2 levels, due to an incomplete understanding of the Earth's climate and uncertainties in model representations of that climate (IPCC, 2007). A standard metric in climate modeling is climate sensitivity, which describes the equilibrium rise in temperature for a doubling of CO_2 levels (IPCC, 2007). The latest intergovernmental panel on climate change report estimated the value of climate sensitivity to be in the range 2.0 – 4.5 °C with a most likely value of 3.0 °C, although higher values could not be ruled out (IPCC, 2007). There is also considerable uncertainty in the response of the Earth's carbon cycle to anthropogenic climate change, which may change in such a way to amplify or dampen the effects of global warming by absorbing more or less of the emitted CO_2. It is very difficult to estimate the response of the whole carbon cycle to anthropogenic CO_2, and it has been estimated that uncertainties in the carbon cycle may be as important as uncertainties in the climate system (Gregory *et al.*, 2009).

SRM geoengineering techniques may offer a human-made means to address some of the problems of anthropogenic greenhouse warming. SRM geoengineering 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 aerosols into the stratosphere (Crutzen, 2006; Wigley, 2006). The amount of cooling possible varies among these techniques. Some, such as increasing the reflectivity of roofs, have only a minor, local effect on climate, whereas others, such as the injection of stratospheric aerosols, have the potential to cool the entire globe for the indefinite future (Lenton and Vaughan, 2009).

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). 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 an effectively unlimited cooling effect that could be delivered rapidly, perhaps allowing significant control over both the rate of global warming or cooling and the long-term temperature of the planet.[4] Thus, SRM could be a viable response prior to a climate emergency (assuming such an emergency could be identified before it occurs), since a large change in the Earth's radiation balance would be possible over a short timescale, thus halting or reversing warming within years rather than decades or centuries (Wigley, 2006). Once deployed, however, some techniques, such as marine cloud brightening or stratospheric aerosol injections, would need to be applied continuously, as their abrupt discontinuation would result in 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 failure of geoengineering might not belong to the same generation as those that initiated it (Svoboda *et al.*, 2011).

It is not known in detail what the effects of SRM geoengineering would be, but from computer modeling studies it is possible to predict a number of changes that likely would occur. It is clear from simple calculations of the Earth's energy balance that reflecting more sunlight will lower the global average temperature (Lenton and Vaughan, 2009). In addition, most studies

[4] Other SRM techniques, or combinations of them, could have different spatial extents, and perhaps significant influence over regional climates would be possible. Due to the complexity of the Earth's climate system and challenges to modeling such a system, this influence over regional climate could be hard to transform into detailed control.

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. The regional effects of SRM would differ among techniques, and studies show that large shifts in climate patterns are possible, such as desert geoengineering causing a large reduction in the intensity of the Indian monsoon (Irvine *et al.*, 2011) and cloud albedo geoengineering potentially causing a large reduction in Amazon rainfall (Jones *et al.*, 2009). Finally, SRM would do nothing to reverse the effects of ocean acidification, which could become a major problem in the future (Matthews *et al.*, 2009).

<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 reduced global temperatures 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); by damaging coral reefs, unaddressed ocean acidification could result in a loss of coastal protection or economic income for some persons (Crabbe, 2009); and the depletion of ozone caused by stratospheric aerosol particles could negatively impact the health of some individuals (Tilmes *et al.*, 2008). 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 justice (Svoboda *et al.*, 2011).

There are several factors that would determine whether certain climate change outcomes are beneficial or harmful for various individuals in different regions. These factors include the initial climatic conditions, the nature of the climate change, the rate of the climate change, and the activities being pursued in the region. 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 geoengineering would differ greatly between regions (Irvine *et al.*, 2010; Jones *et al.*, 2011). 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. The nature of the climate change and the rate at which it occurs will impact animals, plants and human populations, as a change in behavior or migration may be required to adapt to the changed conditions (IPCC, 2007). 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 causing 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 deeply 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 thus 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 can 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 would 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 challenging and it remains an active area of research (Stone *et al.*, 2009). Confirming that the Earth's temperature is increasing required decades of observational data from around the world (IPCC, 2007), and confirmation of independent warming signals for each continent was not made until recently (Gillett *et al.*, 2008). When analyzing the response of the Earth's climate to a change in forcing, it is not possible to follow standard scientific procedures for isolated systems, such as repeated experimentation. Instead, only observations and modeling are available. Climate variables have been recorded for centuries in certain regions, and a substantial historical database has been built. However, some regions are still under sampled, and it is difficult to know what the current climate condition is, much less how it has changed (Stone *et al.*, 2009). Moreover, detecting a change in climate becomes even more difficult the smaller the region of interest is, as fewer observational data points are available, and the highly variable nature of local weather becomes more significant (Gillett *et al.*, 2008; Stone *et al.*, 2009). Some of the impacts of climate change occur indirectly through non-climate systems, such as ecosystems and disease vectors. In such cases, it is even more challenging to detect a change, as these systems can be under-observed, studied with techniques that vary significantly, and subject to a host of other non-climate influences (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 detection, because it 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. Further confidence is gained by the models simulating additional changes that are consistent with rising anthropogenic greenhouse gas concentrations, e.g. stratospheric cooling that would not arise if an increase in solar activity was the cause of the warming (IPCC, 2007).

The uncertainty involved in attributing particular changes in climate to specific causes could make it very difficult to determine whether some harmful impact, such as a prolonged drought, is due to a deployed SRM technique or not. 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 epistemically. Thus, it would not be easy to determine whether those harmed by a drought deserve SRM compensation, because it could be unclear whether they are victims of SRM deployment rather than victims of a natural weather event. The matter is likewise with other potentially harmful impacts of SRM, such as ozone depletion due to stratospheric aerosols (Tilmes *et al.*, 2008). It would be virtually impossible to link a specific case of skin cancer to SRM-induced ozone depletion, for example. However, it may be possible to determine if SRM has made a particular climate impact more likely to occur or more severe. For example, although an individual drought event may not be attributed to SRM geoengineering per se, if simulations of SRM geoengineering predicted an increased tendency for droughts in a region, and if that prediction was borne out by observations, then it seems reasonable to suggest that SRM geoengineering is to some extent responsible for the drought.

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. Stott et al. (2004) analyzed the likelihood of occurrence of a summer as anomalously warm as 2003 in Europe, the year of a sever European heat wave (Robine *et al.*, 2008), in climate simulations with and without anthropogenic greenhouse gas contributions. 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 for the summer 2003 heat wave of 50%. This method 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 an event requires that simulations of the observed climate be compared to an unobserved climate in which the forcing of interest (anthropogenic greenhouse gases in the case above) is excluded. To find the likelihood of rare climatic events, such as extreme heat waves, 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.

<u>Ethical Issues Regarding Compensation for Solar Radiation Management</u>.

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 each of these questions, noting certain disadvantages and problems for all of them. We also argue that even if these questions are answered adequately, it likely remains the case that not all harm due to SRM can be redressed by economic compensation. 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 for 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. Our goal is to show that there is significant uncertainty about 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.

Who Ought to Pay?

Principle	**Compensator**
Polluter Pays	Agents of SRM
Ability to Pay	Rich persons/states

Beneficiary Pays	Beneficiaries of SRM
Hybrids	Variable

According to the polluter pays principle, the agents of harmful pollution are responsible for compensating the 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. 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 to raise revenue for a compensation fund? May they tax citizens who initially opposed SRM deployment? 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 a 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, this state 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 give the wrong verdict 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 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. 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 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. This raises a serious question about whether it would be correct to consider future persons as either beneficiaries or victims of SRM. Since future persons affected by SRM might 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. Among such persons, no one would be responsible for providing compensation for SRM. 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 distant future (Goes *et al.*, 2011).

The non-identity 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.

Like the previous two principles, the ability to pay principle seems to yield some unfair requirements. Suppose that some developed state refuses to join a 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. Arguably, the ability to pay principle gives the wrong verdict in this case.

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? 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?[5] Proponents of hybrid principles must meet this difficult challenge of explaining why one particular hybrid should be adopted over others.

Although we lack space to endorse or reject any of these principles (hybrid or otherwise), 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 would make it difficult to construct a just SRM compensation system.

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.[6] 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.

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[5] Of course, many other permutations of this and other hybrids are possible, but space limits us to discussion of these particular versions.

[6] 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 emissions. Perhaps the most important example of this is ocean acidification, which is caused by increasing concentrations of atmospheric CO_2 (Doney *et al.*,

2009) and 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, and it has little effect on the chemistry of ocean acidification (Ross and Matthews, 2009). In addition to at least some victims of the impacts of SRM itself, would those harmed by ocean acidification deserve compensation as well? The answer is negative if one accepts the principle that only victims of SRM impacts deserve compensation, since ocean acidification is not caused by SRM but rather by CO_2 emissions.

One might argue, however, that since SRM is intended to be a response to problems caused by anthropogenic emissions, and since SRM does not address one of these major problems, those who are harmed by ocean acidification ought to be eligible for compensation under a just SRM compensation system.[7] A possible reply is that the responsibility to compensate for harm caused by CO_2 emissions is distinct from the responsibility to compensate for harm caused by SRM. Hence, it might be the case that victims of ocean acidification deserve compensation, but not within the framework of an SRM compensation system. We do not have a solution to this problem, but one would need to be worked out in order to craft a working SRM compensation system.

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

[7] Where one falls on this issue might depend on whether one accepts or rejects that there is a moral distinction between doing and allowing. 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.

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 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, the non-identity problem arises again. Should compensation 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 different answers can make significant differences for determining who ought to be paid SRM compensation. 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. In comparison to what should recipients be compensated? 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. 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 more 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, for 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 climates resulting from varying degrees of anthropogenic emissions and various SRM geoengineering interventions. 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 these 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.

<u>Ethical Caveats Regarding Compensation</u>.

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 compensation can recompense that cultural loss. Cases like these would limit the effectiveness of a compensation system meant to ameliorate the 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 (Gardiner, 2010; Jamieson, 1996; Svoboda *et al.*, 2011; 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 optimal. 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.

Conclusion.

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. These difficulties must be addressed in order to craft a just SRM compensation system. Otherwise, if SRM was deployed, there is a risk of substantial injustice, with some persons suffering disproportionate harm that is not properly remunerated.

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