Solar Radiation Modification: A Risk-Risk Analysis

Summary

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Summary

Solar radiation modification as an additional climate risk reduction strategy

Climate change poses multiple, interacting risks to human society and the environment which are only expected to worsen with additional warming. Managing these risks going forward requires a portfolio of policy responses. Mitigation strategies (which include both the reduction of greenhouse gas (GHG) emissions and the removal of carbon dioxide from the atmosphere (CDR)) must remain the policy focus, as they are the only means for addressing the root cause of climate change. However, it may be extremely difficult to meet the global warming temperature goals of 1.5 or 2°C stipulated in the Paris Agreement on climate with mitigation alone. Further, as CO_2 (the primary driver of current climate change) has a long lifetime in the atmosphere, CO_2 and temperatures are likely to remain elevated for hundreds of years in the absence of net-negative emissions. Adaptation may help reduce risks associated with a particular level of warming but is limited in its effectiveness and sustainability. For these reasons, solar radiation modification has been proposed as a complementary approach for quickly reducing many of the near-term risks of global warming and possibly helping to avoid irreversible climate tipping points while increased efforts are made to bring down atmospheric GHG concentrations.

Solar radiation modification (SRM) is an umbrella term for a suite of approaches that propose to reduce or stop global warming by intentionally increasing the amount of incoming sunlight that is reflected by the atmosphere back to space. The most-studied SRM options to date are stratospheric aerosol injection (SAI), the intentional release of highly reflective fine particles or their precursors into the stratosphere, and marine cloud brightening (MCB), the purposeful enhancement of the reflectivity of marine clouds. While other SRM approaches have also been proposed, in this report we focus on SAI and MCB, as they appear to be the most effective options, when employed with emissions mitigation and CDR, with the potential to help meet the Paris temperature goals.

As a proposed climate risk reduction option, SRM is categorically different from mitigation. Rather than addressing climate change at its source (via reduction in GHG emissions) or attempting to reverse climate change (via CDR), SRM is intentional climate change of another form. While still highly uncertain, its proposed benefits would be that, once the necessary technology and infrastructure are developed, it could be a fast, effective, and financially inexpensive means of cooling the Earth at a global scale. However, SRM is also imperfect as it would not completely offset climate change in all regions and seasons. Further, both SAI and MCB would need to be deployed continuously, as their effects are only expected to be temporary. These new technologies may also be risky, both in their interactions with the climate, and in their potential for exacerbating existing risks and introducing new biophysical and societal risks, including novel governance challenges. These fundamental tradeoffs—between SRM's potential to reduce climate risks and its likelihood of introducing its own countervailing risks—are the focus of this report.

The risk-risk tradeoff framework

In this paper, a risk-risk tradeoff framework is used to compare a world with SRM and a world without SRM in addressing climate change. The risk-risk tradeoff framework considers the full portfolio or scope of important consequences that may arise from a decision. In this framework, *risk* is measured by both the *magnitude* of undesired consequences and the *likelihood* of the occurrence of these consequences. In the risk-risk *tradeoff framework*, the particular risk that an action or policy aims to address is referred to as the target risk, the additional risks that are produced in addressing the target risk are called *countervailing risks*, and ancillary reductions in non-target risks and other gains are termed *co-benefits*. The framework then identifies key attributes for comparing these risks, including the type, magnitude, likelihood, timing, and distribution of consequences associated with various actions or policies. The risk-risk tradeoff framework is intended to improve outcomes by helping analysts think beyond the direct costs and benefits associated with reducing the target risk alone. As with all public policies, SRM, as well as other climate policy options, might encounter "non-rational" public responses that could strongly influence decision-making; this report offers the risk-risk framework in order to help guide policies toward socially desirable outcomes informed by science.

Solar radiation modification within the risk vs. risk framework

Based on the latest research literature, the potential impacts of adding SRM to a hypothetical policy portfolio of mitigation and adaptation could include the following (in which most effects would come from a global deployment of SAI, except where noted that the effect is specific to MCB):

	Impacts of adding SRM to mitigation and adaptation	
	positive	**negative**
Impact of SRM on target risk: climate change impacts	**Climatic benefits** SRM would be expected to quickly reduce the significant future risks associated with temperature rise in most regions of the world. The most important such benefits include: • reduction in the frequency and intensity of extremes of temperature and precipitation • slowed melting of Arctic sea ice and mountain glaciers • reduced loss of the Greenland and Antarctic ice sheets slowed sea level rise • reduced weakening of the Atlantic meridional overturning circulation reduction in the intensity of tropical cyclones • reduced decline in soil moisture slight reduction in atmospheric carbon dioxide concentrations	**Climatic risks** SRM does not reverse climate change, but rather is a different and additional type of climate change with distinct impacts, some of the most important of which include: • unintended climate changes (unintended warming or excessive cooling due to uncertainty in our estimates of the amount of SAI needed) • regional precipitation changes

<table>
<tr><td rowspan="2">Ancillary impacts of SRM:
non-climate change impacts</td><td>Co-benefits
SRM could have the side benefits of reducing other risks or adding value, both biophysical and social. Examples include:
• reduced tropospheric ozone
• increase in water availability over land in the tropical regions (MCB)</td><td>Countervailing risks
Depending on the technology employed, SRM introduces some novel risks, both biophysical and social, including:
• increased acid deposition in pristine areas in the high latitudes
• effects on stratospheric ozone
• light diffusion and dimming
• potential for international conflict and other societal risks
• potential interactions with a major volcanic eruption
• shock of sudden termination
• increase in salt deposition over land (MCB)</td></tr>
<tr><td colspan="2">Positive or negative impacts
• influence on motivation for emissions abatement policy or behaviour
• light diffusion and dimming and its effects on human health, ecosystems, and agriculture
• effects on procedural and distributional justice, and other ethical concerns</td></tr>
</table>

Of course, SRM deployment would not occur in isolation, so its benefits and risks would depend on a number of other factors, including the particular goals of the SRM deployment, the background emissions pathway and adaptation plans being followed, sustainable development goals pursued, and the governance framework in place. Conceptually, the emissions pathway and anticipated adaptive capacity would determine the level of residual climate risk that might be addressed by SRM. SRM deployment and its governance would then seek to simultaneously minimize these climate risks, maximize additional gains, and limit its own added climate and countervailing risks.
To make these tradeoffs explicit, in the full report we consider three specific climate risk management scenarios with different relative contributions of mitigation and SRM.

Key insights

1) Employing a risk-risk framework in policy analysis and decision-making concerning SRM would enable a more comprehensive assessment, comparison, and management of risks associated with climate change, emissions reductions, CDR, adaptation, and SRM. This risk-risk framework would include identifying and weighing impacts on the target risk, countervailing risks, and co-benefits, recognizing that they may interrelate in complex ways. The public and policymakers may encounter heuristics and biases that influence decision making, and a risk-risk framework can help strengthen deliberation addressing the full portfolio of important impacts. Attempts to identify measures that minimize overall risk can help reduce the single target risk but also limit or reduce multiple countervailing risks in concert.

(2) The target risk that SRM seeks to address is the risk of climate change, taking into account the emission scenario and the effects of emissions reduction, CDR, and adaptation. Depending on the policy pathway, these risks may be large.

(3) As a target risk reduction strategy (along with emissions reductions, CDR, and adaptation), SRM deployment may have the potential to reduce climate risks, yielding large direct benefits to humans and natural ecosystems. By reducing the global mean temperature increase (or by stabilizing temperature at a given target) SRM could potentially lessen the near-term damages of climate change and lower the chances of crossing irreversible climate tipping points.

(4) SRM could pose countervailing risks to biophysical systems. These could include (depending on the SRM approach) changes in stratospheric ozone and surface UV radiation, acid rain, and unintended climate changes such as altered temperature and precipitation patterns or excessive cooling. The level of many of these risks would be partially affected by the design and governance of an SRM deployment.

(5) SRM could also pose countervailing risks to societal systems. These could include (depending on the approach) the risk of international conflict over deployment (especially in cases of ungoverned and unilateral deployment, the prospect or threat of deployment, or perceived harms between deployment and local/regional unexpected impacts), the risk of rapid climate change resulting from sudden termination (which is also a biophysical risk), and the risk that SRM could displace GHG emissions mitigation, among other concerns. Again, the level of many of these risks would be partially affected by the design and governance of an SRM deployment.

(6) SRM could present some co-benefits. The co-benefits of some SRM approaches may include an increase in diffuse solar radiation (sunlight), which may be beneficial to some ecosystems and crops, and slightly reduced tropospheric ozone in the mid and high latitudes. However, these uncertain effects are likely to be small and are not expected to play a significant role in weighing risk-risk tradeoffs.

(7) Policymaking regarding SRM should compare its effects on multiple risks (including target risk reductions, co-benefits, and countervailing harms), as part of a policy portfolio that also takes into account emissions reductions, CDR, and adaptation. These interconnected effects should be assessed in terms of their likelihood, impact, timing, uncertainty, distribution, and related factors.

(8) Different levels of SRM may pose different implications for overall risk depending on the technology, its deployment, and governance. Higher levels of SRM may be expected to yield greater decreases in temperature-associated climate target risks, but also increases in SRM's own countervailing risks. The particular levels and response patterns of target and countervailing risks to varying levels of SRM would depend on the SRM technology, deployment strategy, and governance mechanisms employed. It is possible that the level of SRM that minimizes total risk may be a low-to-intermediate level of deployment designed to avoid the worst near-term climate impacts by shaving the peak warming while GHG emissions mitigation and CDR efforts take effect.

(9) As larger GHG emissions reductions, CDR, and adaptation reduce overall risks, the less need there may be for SRM with its countervailing risks, thereby reducing overall risk exposure (subject to any countervailing risks of emissions mitigation options). Further attention must be given to the interdependence among multiple risks that can be created by shared causes or policy interactions.

(10) Risk-risk analysis can help focus climate change risk management on broader societal objectives, rather than on temperature goals alone. While temperature goals may be an important objective, there are many climate impacts that do not scale directly with temperature, and many other ancillary risks beyond climate. The indicators used to evaluate the United Nations' Sustainable Development Goals (SDGs) offer measures of well-being that may be used to evaluate the multiple risks of SRM. This report presents a preliminary evaluation of how three hypothetical risk management portfolios supplementing GHG emissions mitigation, CDR, and adaptation with SRM might be expected to impact attainment of the SDGs relative to not using SRM.

(11) New governance institutions or mechanisms may be needed to restrain harmful or unjust use of SRM, ensure that any deployment is beneficial and just, and assess and minimize any countervailing harms. Existing international governance aimed at addressing climate change and its impacts may offer some useful mechanisms, but currently appears to be inadequately designed for addressing SRM and its distinctive characteristics. As an attempt to restrain the imposition of global risks through hasty or unwise action, governance of SRM may be more analogous to arms control agreements than environmental treaties.