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CLIMATE ANALYTICS

# SOLAR GEOENGINEERING: A NOTE TO INFORM DISCUSSIONS ON PHYSICAL CLIMATE IMPACTS, RISKS, AND GOVERNANCE ISSUES

With international efforts on climate action still not on track to limit warming to 1.5°C, technological fixes that aim to intentionally alter the Earth's climate, such as solar geoengineering, might seem like appealing options for tackling global warming. But they come with questions in terms of feasibility, impacts and risks, governance and geopolitics, and who may or may not benefit.

**Crucially, no mature solar geoengineering technology exists today**. And even if solar geoengineering was deployed, it would not reverse or halt climate change but **create a different, engineered climate future**.

Solar geoengineering would result in **new and additional impacts on and risks to human and natural systems**, mainly driven by changes in temperature, precipitation and extreme events. These would be **distributed unequally**, with regions already most vulnerable to climate impacts disproportionately affected.

And, as solar geoengineering does not cut emissions, **non-temperature related impacts associated with continuing emissions would also continue**, including ocean acidification. Also, it would put the world at risk of a sudden rise in global temperatures if solar geoengineering suddenly ends or fails – the **"termination shock"**.

Since solar geoengineering would not affect all regions of the world equally, it could **aggravate existing inequalities and regional conflicts**, exacerbating the existing divide between those countries contributing most to climate change and those forced to bear the highest physical, societal and economic costs. This also raises questions around how additional **adverse impacts from solar geoengineering could require new finance and support systems** for adaptation and loss & damage, especially for particularly vulnerable regions.

Motivations for developing and deploying solar geoengineering could meanwhile be driven by geopolitical considerations rather than the actual risks of the climate crisis. Even the hypothetical prospect of solar geoengineering could **"green light" the continued burning of fossil fuels**, posing a threat to net zero commitments and other mitigation ambitions. And only major world powers have the capacity and capability to deploy solar geoengineering at scale, posing the **risk of unilateral solar geoengineering deployment controlling regional and global temperatures and associated impacts and risks**.

Rather than promoting potentially dangerous real-world experiments, both **climate policy and action must follow the best available science**, which is clear on the need for **urgent and strong cuts to greenhouse gas emissions** if we are to meet the Paris Agreement objectives.

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Published 2024

## What is solar geoengineering?

The Earth's climate system is incredibly complex, and our understanding of the potential impacts and risks of ongoing anthropogenic climate change is still evolving. These impacts depend not only on future greenhouse gas emissions and the capacity of human and natural systems to respond, but also on any additional technical interventions introduced to the Earth system. Such interventions are often referred to as **geoengineering**.[1]

A variety of **solar geoengineering** techniques, also known as **Solar Radiation Modification (SRM)**, has been proposed over the years. These are increasingly being discussed in policy and science fora as well as in the media. The most frequently discussed technique is Stratospheric Aerosol Injection (SAI). SAI involves the injection of aerosols (small particles) into the upper atmosphere to counteract global warming by reflecting a portion of the Sun's rays back into space, thereby reducing the amount of solar radiation reaching and heating the Earth's surface.[2]

It sounds simple, but SAI is not a ready-made, easy-to-control tool. Injecting aerosols into the stratosphere poses technical challenges and the size of the aerosol particle plays an important role in how effectively it can scatter solar radiation back to space.[2]

**Importantly, no mature solar geoengineering technology exists today and there are still many uncertainties surrounding any future use and the associated impacts and risks, whether physical, societal or political.**[3]

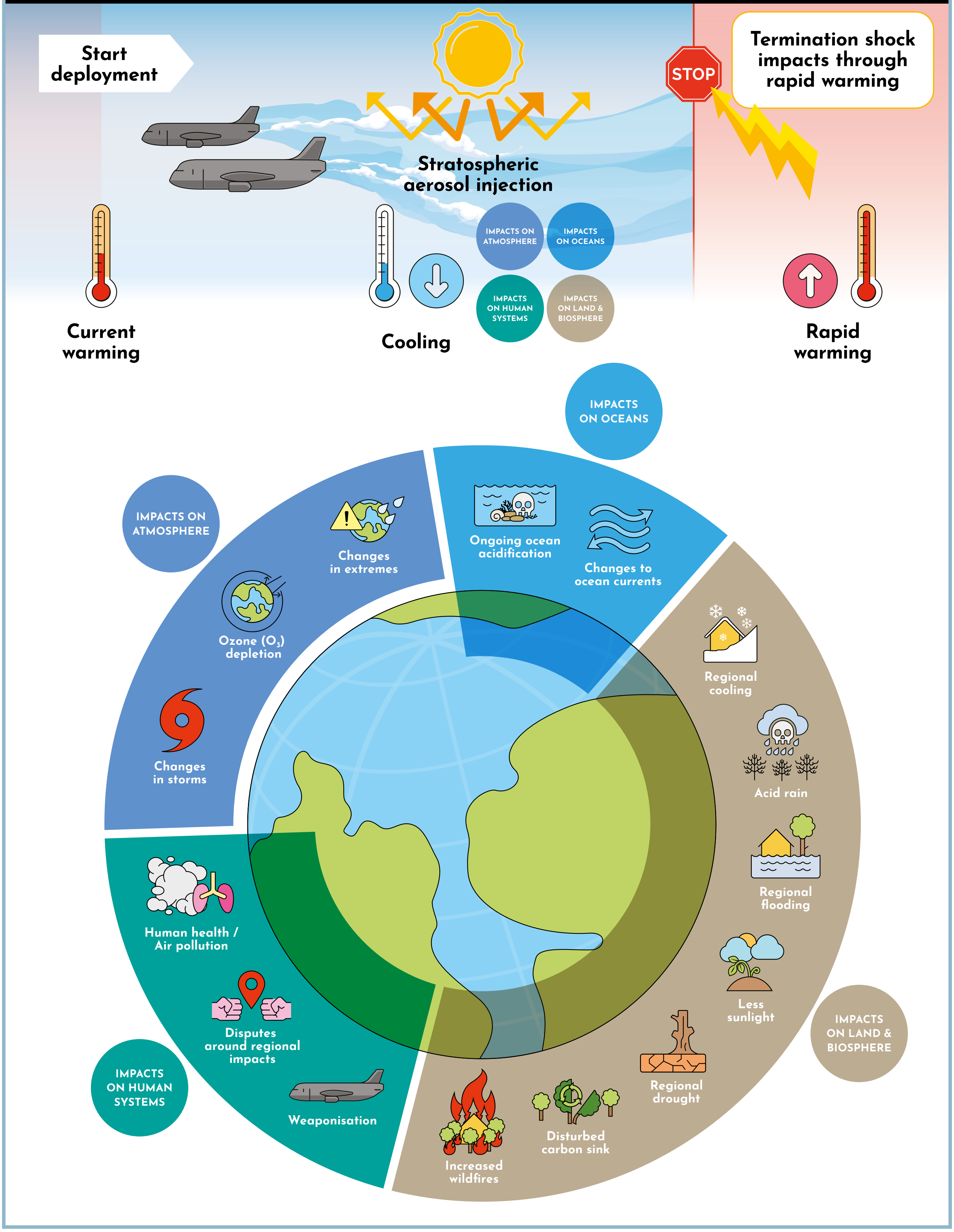
[1] Patt et al., 2022: **International Cooperation**. In *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (eds. Shukla, P. R. et al.).

[2] Haywood et al., 2022: **Assessing the consequences of including aerosol absorption in potential stratospheric aerosol injection climate intervention strategies**.

[3] Lee et al., 2021: **Future Global Climate: Scenario-Based Projections and Near-Term Information**. In Climate Change 2021: *The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (eds. Masson-Delmotte et al.).

# Impacts and risks from solar geoengineering

Deploying solar geoengineering would lead to widespread, additional impacts and risks on top of climate change. Not captured below are the impacts and risks from ongoing climate change that would be present, as solar geoengineering would likely be deployed in a world with continued emissions.



## Impacts and risks

Solar geoengineering would do more than just reflect sunlight back into space.

As well as the desired effect of reducing global temperatures, and their climate impacts and risks, solar geoengineering has the potential to create **new and additional impacts on and risks to human and natural systems**. Many of these are not well understood or are even deeply uncertain: our knowledge of solar geoengineering is primarily based on theory combined with climate model simulations, and different ways of deploying solar geoengineering would likely lead to different climate outcomes regionally.[1]

Still, the best available science, as set out in the 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR6), highlights how solar geoengineering would introduce a wide range of risks to people and ecosystems.[4]

It could, for example, affect temperatures beyond the target area, or cool them more than planned. It could also **change fundamental aspects of the Earth system**, including through reducing the amount of light reaching the Earth's surface[5], altering the intensity and patterns of precipitation[6] and storms[7], or affecting the recovery of the ozone hole.[8] Other areas that could be impacted include ocean currents[9], wildfires[10], biodiversity[11], ecosystem services[12], air pollution[13], and acid rain.[14]

At the same time, solar geoengineering will do nothing to address the non-temperature impacts of continued greenhouse gas emissions such as **ocean acidification**. Continued ocean acidification means continued negative impacts on many species, including the destruction of corals.[15]

Solar geoengineering would also **not affect all regions of the world equally**, potentially aggravating existing inequalities and regional conflicts. Some of the regions already most vulnerable to climate change could be disproportionately affected. For example, Africa and equatorial Asia are likely to be highly sensitive to changes induced by solar geoengineering, including through a weakening of the Asian and African monsoons.[16,17,18]

Solar geoengineering could also exacerbate water shortages in Asia[19], or amplify the effects of extreme weather events such as increased flood risk.[20] In the tropical regions, solar geoengineering could reduce evaporation from land and plant transpiration in forests, eventually impacting the distribution and abundance of species and ecosystems.[21]

The **impacts and risks will vary with different forms, levels and strategies of intervention**, with the potential for complex feedbacks within the climate system. And if the use of solar geoengineering increased, so would the associated impacts and risks.[22]

[4] IPCC, 2023: **Sections**. In *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (eds. Core Writing Team, H. Lee and J. Romero).*

[5] Bao et al., 2018: **Potential effects of ultraviolet radiation reduction on tundra nitrous oxide and methane fluxes in maritime Antarctica.**

[6] Ricke et al., 2023: **Hydrological Consequences of Solar Geoengineering.**

[7] Pausata and Camargo, 2019: **Tropical cyclone activity affected by volcanically induced ITCZ shifts.**

[8] Tilmes et al., 2022: **Stratospheric ozone response to sulfate aerosol and solar dimming climate interventions based on the G6 Geoengineering Model Intercomparison Project (GeoMIP) simulations.**

[9] Partanen et al., 2016: **Impacts of sea spray geoengineering on ocean biogeochemistry.**

[10] Tang et al., 2023: **Impact of Solar Geoengineering on Wildfires in the 21st Century in CESM2/WACCM6.**

[11] Trisos et al., 2018: **Potentially dangerous consequences for biodiversity of solar geoengineering implementation and termination.**

[12] Zarnestske et al., 2021: **Potential ecological impacts of climate intervention by reflecting sunlight to cool Earth.**

[13] Effiong and Neitzel, 2016: **Assessing the direct occupational and public health impacts of solar radiation management with stratospheric aerosols.**

[14] Visioni et al., 2020: **What Goes up Must Come down: Impacts of Deposition in a Sulfate Geoengineering Scenario.**

[15] Williamson and Turley, 2012: **Ocean acidification in a geoengineering context.**

[16] Tilmes et al., 2013: **The hydrological impact of geoengineering in the Geoengineering Model Intercomparison Project (GeoMIP).**

[17] Da-allada et al., 2020: **Changes in West African Summer Monsoon Precipitation Under Stratospheric Aerosol Geoengineering.**

[18] Robock et al., 2008: **Regional climate responses to geoengineering with tropical and Arctic $SO_2$ injections.**

[19] Tan et al., 2023: **Impacts of Solar Radiation Management on Hydro-Climatic Extremes in Southeast Asia.**

[20] Wei et al., 2018. **Global streamflow and flood response to stratospheric aerosol geoengineering.**

[21] Eliseev, 2012: **Climate change mitigation via sulfate injection to the stratosphere: impact on the global carbon cycle and terrestrial biosphere.**

[22] Tang and Kemp, 2021: **A Fate Worse Than Warming? Stratospheric Aerosol Injection and Global Catastrophic Risk.**

### An engineered climate future?

Although it would lower temperatures, solar geoengineering would not reverse or halt climate change. Instead it would **create a different, engineered climate future**, depending on exactly how it is deployed, how the climate responds, and how this impacts other natural and human systems.[1]

Even with lowered temperatures, if emissions continued there would still be **impacts from increasing atmospheric greenhouse gas concentrations**, including on biodiversity and ecosystem function. This could include **ocean acidification** and its harmful effects on coral reefs and other marine life and, on land, varying and complex implications for plant growth.[11]

Meanwhile, the **cooling effects of solar geoengineering would only last for as long as it is deployed**. Rather than being a one-off, aerosols would need to be repeatedly injected into the atmosphere to hold down global temperatures and phased out gradually over several decades. A sudden end to solar geoengineering would result in a rapid and potentially catastrophic **"termination shock"**, unmasking the effects of greenhouse gases that had continued to build up in the atmosphere, and causing a sudden rise in global temperatures, with unprecedented impacts and risks.[23]

In fact, research suggests that without strong and simultaneous emissions cuts aimed at meeting the Paris Agreement, **solar geoengineering would have to be maintained for more than 100 years** to avoid any sudden impacts.[24]

### Risks to efforts on mitigation, adaptation, and climate finance

In contrast to greenhouse gas mitigation and adaptation, the impacts of solar geoengineering remain unclear.[4]

Expert interviews suggest that there would be **more negative than positive side effects** from solar geoengineering, while mitigation and adaptation have more synergies than trade-offs with sustainable development.[25] Moreover, adapting to new regional climatic changes, such as shifts in precipitation patterns, could involve **large transition costs**, particularly for less developed countries or economic sectors that are already climate-dependent, such as agriculture or forestry.[26]

There is also a danger that solar geoengineering could **“green light” the continued burning of fossil fuels**, posing a threat to net zero commitments and other mitigation ambitions. Investments in solar geoengineering could divert resources from mitigation ambition as well as climate finance.

Solar geoengineering would also have **long-term cost commitments** due to the length of deployment needed to limit long-term warming, potentially diverting resources away from the transition to a sustainable and low-carbon future.[27]

Also, it seems plausible that leading on **solar geoengineering** deployment **could be used as reasoning by big emitters to evade their responsibilities** to provide substantial means of implementation and support for vulnerable countries.[28,29]

In addition, solar geoengineering and continued emissions could well exist simultaneously, so the **risks resulting from both processes cannot be entirely separated**. Proposed “risk-risk frameworks”[30] that compare a world with only one or the other are therefore overly simplistic.[26]

[23] Parker and Irvine, 2018: **The Risk of Termination Shock From Solar Geoengineering.**

[24] Baur et al., 2023: **The deployment length of solar radiation modification: an interplay of mitigation, net-negative emissions and climate uncertainty.**

[25] Aaheim et al., 2015: **An economic evaluation of solar radiation management.**

[26] O’Neill et al., 2022: **Key Risks Across Sectors and Regions.** In *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (eds. Pörtner et al.).*

[27] Lanson et al., 2022: **Uncertainty in near-term temperature evolution must not obscure assessments of climate mitigation benefits.**

[28] Ott, 2018: **On the Political Economy of Solar Radiation Management.**

[29] Meredith, 2023: **Billionaires are fascinated by solar geoengineering — but climate scientists are far from convinced.**

[30] NASEM, 2021: **Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Governance.**

## Governance and geopolitical issues

There are considerable issues around the governance of any solar geoengineering schemes. These would lead to geopolitical tensions and potentially fundamental national security concerns, especially if solar geoengineering was deployed unilaterally.[31,32,33] There are further geopolitical risks that would arise from the "termination shock" if solar geoengineering deployment was suddenly stopped.[23]

**Current international instability** presents a difficult context in which to develop and implement any new governance regime, let alone one involving technological interventions with global implications. Any calls for the development of a robust, inclusive and **global governance regime of solar geoengineering** also need to consider the possibility of such efforts **being unsuccessful**, or not reaching the desired outcome. However these calls already contribute to **normalising** the possibility of **solar geoengineering deployment**.[34]

Realistically, only major world powers have the capacity and capability to deploy solar geoengineering at scale. Interest, research, funding and development are currently **centred in the Global North**, primarily the United States, highlighting the power imbalance.[31]

The potential for **broad and unequally distributed impacts** could exacerbate the existing divide between those countries contributing most to climate change and those forced to bear the highest physical, societal and economic costs. This also raises questions around how **additional adverse impacts from solar geoengineering** could **require new finance and support systems for adaptation and loss & damage**, especially for particularly vulnerable regions.[35,36]

Finally, solar geoengineering could appeal to political actors as a seemingly quick response to climate change, as a power move, or even as an ambitious attempt to gain first-mover advantage, **without scientific knowledge and effective governance**. There are also risks that solar geoengineering patterns could be altered in response to major geopolitical events or changing power dynamics. Also, justifying a unilateral deployment on the basis of tackling a critical collective issue would provide an opportunity for one state to control temperatures and associated impacts and risks across the globe.[22] This means that the **motivations for developing and deploying solar geoengineering** could be **driven by neither the actual risks of the climate crisis, nor the latest science**.[33]

[31] Smith, 2022: **Pandora's Toolbox: The Hopes and Hazards of Climate Intervention.**

[32] McKibben, 2022: **Dimming the Sun to Cool the Planet Is a Desperate Idea, Yet We're Inching Toward It.**

[33] Young, 2023: **Considering Stratospheric Aerosol Injections beyond an Environmental Frame: The Intelligible 'Emergency' Techno-Fix and Preemptive Security.**

[34] Biermann et al., 2022: **Solar geoengineering: The case for an international non-use agreement.**

[35] Jinnah and Nicholson, 2019: **Introduction to the Symposium on 'Geoengineering: Governing Solar Radiation Management.**

[36] Whyte, 2019: **Indigeneity in Geoengineering Discourses: Some Considerations.**