PIVOT

Exploring the Ethics and Outcomes of Solar Geoengineering

PIVOT Think Tank

July, 2025

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Introduction

With the last few decades showing a steady increase in global temperatures, many have started to wake up and take action on climate change - an IPCC Special Report notes that global temperatures have risen by approximately 1.1°C since pre-industrial levels.[1] Methods have been developed in order to slow down this change, from the "Three R's" consisting of “Reduce, Reuse, Recycle” that can be traced back to the 1970s[2] to artificial processes such as Carbon Capture, Utilisation and Storage (CCUS), Solar Radiation Management (SRM) and other such technologies, which will be the main focus of this policy brief, along with offering alternative, more beneficial solutions.

Solar geoengineering can be described as "a group of large-scale approaches to reduce global warming by increasing the amount of sunlight that is reflected away from Earth and back to space".[3] It includes mimicking the aftermath of a volcanic eruption, when small, sunlight-reflecting particles are produced, resulting in a cooling effect. To achieve this, scientists have been investigating Stratospheric Aerosol Injection (SAI) in which aerosols are injected into the upper atmosphere, and Marine Cloud Brightening (MCB), where sea salt is used to simulate cloud formation over the ocean. [4] This alone has stirred huge controversy amongst the general public, being dubbed a "moral hazard" by some, and a lesser-of-two-evils by others. Stanford scientist Ken Caldeira likens it to "chemotherapy for the planet" - perhaps it is wiser to cope with poison than something worse.[5] The key distinction is that, unlike mitigation strategies such as reducing emissions and encouraging a greener lifestyle, geoengineering seeks to artificially manipulate and directly interfere with the climate system.

Before continuing further, it’s important to survey and explore these innovations in detail to gain a deeper understanding of the issues at hand. CCUS captures CO2 in concentrated form, usually from large industrial facilities. It can be divided into two distinct terms: Carbon Capture and Utilisation (CCU) or Carbon Capture and Storage (CCS). Unused or excess carbon is compressed and stored in deep geological formations, oil and gas reservoirs or in onshore and offshore storage sites underground in CCS after being transported by pipeline, ship, or truck, mainly. In CCU, the gas is put to use either in goods such as construction materials, for example, or be used in making synthetic fuels, undergoing chemical conversion. The UK is capable of safely storing up to 78 billion tonnes of the greenhouse gas, with the Labour Party promising to invest £1billion in the process to produce blue hydrogen (commonly used in the CCUS practice

[1] Chapter 1 — Global Warming of 1.5 °C
[2] https://pantheonchemical.com/reduce-reuse-recycle/
[3] https://en.wikipedia.org/wiki/S olar_radiation_modification
[4] https://www.ucs.org/resources/what-solar-geoengineering
[5] https://grist.org/climate-energy/geoengineering-research-never-or-now/

to trap the carbon[6]) and to capture carbon dioxide from new gas-fired power stations, despite scientists' concerns on the unproven technological advances involved with the process. Writing to Ed Miliband, the energy security and net zero secretary, 23 doctors, professors and researchers signed to say, "We strongly urge you to pause your government's policy for CCUS-based blue hydrogen and gas power, and delay any investment decision into the Track 1 programme until all the relevant evidence concerning the whole-life emissions and safety of these technologies has been properly evaluated."[7]

Stratospheric Aerosol injection (SAI) is another proposed method of climate intervention aiming to reduce global warming's effects via sunlight-reflecting particles (predominantly sulfur dioxide, SO2), a common trend in geoengineering technologies. A 2023 study found that injecting the chemical at higher latitudes, rather than in the tropics as originally sought out, could lessen some of the more negative and undesirable side effects of SAI. In the 2023 study published in the journal *Atmospheric Chemistry and Physics*, scientists from NOAA CSL and CIRES, working alongside Cornell and Indiana University, thoroughly reviewed a variety of potential injection approaches using a chemistry-climate model to simulate SAI while varying both the amount of SO2 injected into the stratosphere and the latitudes where it is injected. Complex, complicated data were ultimately found, with ranging results, with precipitation, weather patterns and the ozone layer impacted, though these impacts also further vary when season and land area are taken into consideration. However, one thing became clear; the drawbacks and harmful side-effects of SAI appear to be most prevalent at tropical latitudes and areas along the equator, becoming less notable out of this zone.[8]

These unfavourable outcomes could potentially be alleviated by switching out sulfates for materials such as alumina (Al2O3) or calcite (CaCO3) as these solid particles absorb less terrestrial infrared radiation, longwave radiation emitted by Earth's surface and atmosphere, disparate to shortwave radiation found in sunlight which SAI aims to reflect to reduce global warming's adversities.[9]

Although over 99% of scientific papers agree on the human cause of climate change[10], only a slight majority of climate change experts (52%) support large-scale deployment of geoengineering in the event of an approaching climate emergency, 30% do not support

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[6] Climate scientists call on Labour to pause £1bn plans for carbon capture | Carbon capture and storage (CCS) | The Guardian

[7] Ed Miliband letter print version

[8] NOAA CSL: 2023 News & Events: For Stratospheric Aerosol Injection, All Strategies are Not Created Equal

[9] Outgoing longwave radiation - Wikipedia Injecting solid particles into the stratosphere could mitigate global warming but currently entails great uncertainties | Communications Earth & Environment

[10] https://en.wikipedia.org/wiki/Scientific_consensus_on_climate_change

such a response, and 18% are unsure, according to a 2020 article written by Astrid Bannenberg and Sonja Zitzelsberger, both specialising in Economics.[11] Perhaps it would be wise to develop a more firm, solid understanding of the nature, adversities, and effects of such an important process which may shape our future for the better or worse, which will be taken into consideration in this brief via a multitude of methods - evaluating and comparing the risks and benefits of solar geoengineering, exploring its ethical implications, and proposing recommended policies to guide future research and regulations.

Issue Overview / Background

To evaluate potential solutions to global warming and climate change, we first need a clear understanding of the problem at hand.

Anyone who's stepped outside in recent years can sense the planet is getting warmer, and the data confirms it. Since the late 19th century, Earth's temperature has increased by about 2°F in total, with an average of 0.11°F, or 0.06°C, per decade. In the past decade of 2015 to 2024, the 10 warmest years recorded have all occurred within this time frame, 2024 in particular being the overall winning contender since global records began in 1850[12].

It's important that we also take a look at the lows as well as the highs. For example, the lowest recorded temperature in the UK of -15.0°F (-25.1°C) was observed on January 10th,1982 in Newport, Shropshire. On the flip side, England's hottest day was recorded in Coningsby, Lincolnshire, on July 19th, 2022 at an alarming 10.45°F (40.3°C).[13] Similarly, France's extreme climate data differs drastically, with the highest temperature of 114.8 °F (46.0 °C) recorded just 6 years ago now in Vérargues and the coldest recorded temperature of 41.8 °F (−41.0 °C) documented on 17 January 1985 in Doubs.[14]

A common thread we see connecting these countries, along with many more such as Canada and Russia for instance, is that the recorded temperatures laying on the higher end of the scale are more abundant in and around the past 2 decades, whereas the colder extremes are much more likely to be observed in the mid to late 20th century,

[11] https://pmc.ncbi.nlm.nih.gov/articles/PMC6774770/#:~:text=Finally%2C%2052%25%20support%20large%2D,know%20(N%20%3D%20705)
[12] https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature
[13] https://en.m.wikipedia.org/wiki/United_Kingdom_weather_records
[14] https://simple.m.wikipedia.org/wiki/Climate_of_France#:~:text=Temperature%20records%20The%20highest%20temperature%20ever%20recorded,%C2%B0F

with the coldest years on record all at least 90 years ago[15], before the mass release of greenhouse gases, burning of fossil fuels, and deforestation began to take place.

Some say the Industrial Revolution is partly to blame, when these aforementioned processes, essentially acting as a catalyst for climate change, began to be utilised more than ever, unleashing huge amounts of carbon dioxide into the atmosphere. Natural processes such as changes in the sun's energy and volcanic eruptions do not explain the level of global warming we have seen in the last hundred years[16], especially as the outcomes of the Industrial Revolution are in accordance with rising global temperatures; the US' coal output skyrocketed from <100,000 tons in 1800 to 17.5 million tons just 60 years later, the First Revolution being described as a "turning point".[17]

Global average temperatures in 2024 were around 1.6°C above pre-industrial levels, surpassing the target laid out in 2015's Paris Agreement. It is clear that pivotal climate events, or so-called "shifts" and "tipping points" are closer to happening than we think, likely in the next Century.[18] A collapse of the Atlantic Meridional Overturning Circulation could serve as one example - a number of scientists are concerned that the ocean currents that bring warm, salty water from the Tropics to regions around Greenland and Iceland could weaken, eventually resulting in "freezing winters".[19] This data serves to prove the need to carefully examine radical solutions and experiments such as geoengineering. It is also clear that this is not just an issue of preventing worryingly high temperatures unskewed by man-made processes, but maintaining stable levels whilst avoiding extremes on both ends of the spectrum.

Current Policy Landscape

When considering the laws and policies which govern our day-to-day lives, we must not only look at the written legislation itself, but the observable action taken by government bodies to carry out and go through with their promised proposals. This is particularly evident in real-life scenarios, and it is vital we pressure these systems and lawmakers to inform us of updates, alterations or the dismissal of certain policies.

In 2013, the UK government published a statement addressing its position on Greenhouse Gas Removal (GGR) and Solar Radiation Management (SRM). The statement claimed that the priority is "to tackle the root cause of climate change by reducing

[15] https://site.extension.uga.edu/climate/2019/02/earths-coldest-years-on-record-were-all-at-least-90-years-ago/#:~:text=Recent%20news%20stories%20have%20shown,90%2Dyears%2Dago/
[16] https://www.epa.gov/climatechange-science/causes-climate-change#:~:text=Since%20the%20Industrial%20Revolution%2C%20human,observed%20over%20the%20last%20century
[17] https://www.sciencedirect.com/science/article/pii/S2325426221001194
[18] https://www.bbc.co.uk/weather/articles/c5ygydeqq08o
[19] https://www.bbc.co.uk/news/articles/cn938ze4yyeo

emissions of greenhouse gases from human activities, and adapting to those impacts that are unavoidable." However, the government also referenced an £8.6 million GGR research programme and investments in CCUS[20], directly contradicting the notion of tackling the "root cause" of climate change. The UK is also planning to launch experiments into geoengineering, making them one of the biggest funders of the practice at over £50million.[21]

The UK is shown to be actively contributing to the expansion of geoengineering, allowing many CCUS, SRM and other research projects to take place around the country.[22]Some argue that investment in geoengineering research may normalize these technologies as acceptable solutions, potentially distracting from emissions reduction efforts. In reality, we should be focusing on stopping the damage being done to our planet.

The current party in the UK government, the Labour Party, wants to make Britain a "clean energy superpower". Labour has publicly laid out their plans to invest in carbon capture and storage, hydrogen and marine energy, and a new Energy Independence Act which will essentially outline all of Labour's environmental and energy policies.[23]

However, instead of providing governments and systems with the options of undoing their climate damage such as carbon credits and storing carbon, we should aim to eradicate excessive carbon emissions to begin with.

Problem Analysis

Aside from SRM doing nothing to address the root cause of climate change, it detracts from finding ways to decrease greenhouse gas output and can endanger biodiversity and our natural resources. SRM allows governments to avoid accountability, delay meaningful emissions reduction, or rely on technological fixes instead of policy reform. It discourages governments and world leaders to invest in effective, real solutions to the climate crisis, instead offering a "quick fix". In some projects which require vast amounts of land, animals and people will likely be forced to relocate whilst environmental systems and our natural world are exploited.[24]

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[20] https://www.gov.uk/government/publications/geo-engineering-research-the-government-s-view
[21]https://www.theguardian.com/environment/2025/apr/22/uk-scientists-outdoor-geoengineering-experiments

[22] https://www.geoengineeringmonitor.org/geoengineering-map-explainer
[23] https://labour.org.uk/change/make-britain-a-clean-energy-superpower/
[24] https://www.geoengineeringmonitor.org/reasons-to-oppose

Speaking of the potentially catastrophic environmental aspects of geoengineering, a 2023 report from the United Nations Environment Programme explores the risky side effects of SRM, including the response of Earth's climate and our ecosystems. It takes note of the lack of research and uncertainty of the changes in human health, not just the health of our plants and natural resources.[25]

To successfully carry out SRM, particles and nanoparticles, particularly sulfates, are to be released into the stratosphere. Chemicals currently favoured in the realm of solar geoengineering consist of sulfur dioxide, hydrogen sulfide, carbonyl sulfide, and black carbon, just to name a few. Although sulfur dioxide has associations in causing acid rain and other health concerns, these nanoparticles are said to remain suspended longer than sulfate particles, and would therefore not disrupt stratospheric chemistry, not producing acid rain.[26] In spite of this, many have spoken out on the controversy of the use of these substances. For example, the University of California Press talks of risks ranging from changes in air quality to decreases in rainfall in certain regions around the globe. The injection of sulfur compounds could result in changes in "atmospheric concentrations of tropospheric ozone and particulate matter". Tropospheric ozone is an air pollutant, known to be associated with respiratory-related illnesses.[27]

In the UK, SRM and related experiments are "one step closer" to being carried out on a larger scale thanks to the government-backed Advanced Research and Innovation Agency (ARIA). ARIA's programme director Mark Symes said "there is a critical missing gap in our knowledge on the feasibility and impacts of SRM and to fill that gap requires real-world outdoor experiments". And in response to this, they declared in May that they will fund five projects. These projects, which include research into thickening Arctic sea ice, could take place as early as this winter. Although any outdoor experimentation "will only occur after robust oversight measures which won't include the release of any toxic materials"[28], many seem to be rightfully skeptical considering ARIA's uncertainty on the effects of SRM, some of which will remain unknown until real-world, large-scale deployment.

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25 https://www.unep.org/news-and-stories/story/new-report-explores-issues-around-solar-radiation-modification

26 https://pmc.ncbi.nlm.nih.gov/articles/PMC4717532/

27 https://online.ucpress.edu/elementa/article/10/1/00047/195026/Stratospheric-aerosol-injection-may-impact-global

28 https://www.bbc.co.uk/weather/articles/c5ygydegq08o

Policy Recommendations

Along with critiquing SRM, MCB, SAI and other technologies intervening with the climate crisis, this section proposes alternative policy strategies that prioritize prevention over technological intervention. Policymakers, governors and lawmakers should take inspiration and follow the “Oxford Principles”, a set of principles encouraging thorough regulation and governance of solar geoengineering, originally set out by the Oxford Geoengineering Programme. The Programme aims to alert society about the reality and risks of the practice. Their 5 main principles are as follows[29]:

1. Geoengineering to be regulated as a public good: although this does not mean complete disregard for private sector involvement, the public interest should be prioritised and acknowledged internationally.
2. Public participation in geoengineering decision-making: similarly to the previous point, consultation of the general public is key. Those who will be affected by the geoengineering are to have sufficient knowledge over the decisions in their planet.
3. Disclosure of geoengineering research and open publication of results: effectiveness, or lack thereof of research and experiments to be conducted, is to be at the hands of the public and published with accessibility.
4. Independent assessment of impacts: this speaks to overall freedom to critique and make opinions based on scientific review and evaluation. Individuals are to make informed decisions and observations on the effects of geoengineering.
5. Governance before deployment: deployment of geoengineering technologies must not proceed without established, transparent government oversight.

Thinking back to the role of the current UK Labour government in geoengineering, perhaps we should move towards uprooting the cause of the problem, not covering it up or repairing damage already done by fossil fuels and pollutants via artificial means. We should look to the policy of the Green Party who aims to do this. Some policies include:

- Wind to provide around 70% of the UK’s electricity by 2030.
- Delivery of 80GW of offshore wind, 53 GW of onshore wind, and 100 GW of solar by 2035.
- Investment in energy storage capacity and more efficient electricity distribution.
- Communities to own their own energy sources, ensuring they can use any profit from selling excess energy to reduce their bills or benefit their communities.

[29] https://www.oxfordmartin.ox.ac.uk/geoengineering

- Cancel recent fossil fuel licences such as for Rosebank and stop all new fossil fuel extraction projects in the UK.
- Remove all oil and gas subsidies.
- Introduce a carbon tax on all fossil fuel imports and domestic extraction, based on greenhouse gas emissions produced when fuel is burned.[30]

The Green Party's environmental policy values lie in bringing a firm halt to excessive greenhouse gas emissions, while also focusing on lowering energy costs. Reducing the effects of climate change whilst we still can will help avoid severe climate problems arising in the future, and therefore will leave little, or preferably no need for solar geoengineering, ice thickening, cloud brightening, etc. The party prioritises renewability and being environmentally friendly over artificial methods.

Impact Assessment / Benefits

Despite its significant risks and ongoing debates, it is important to assess the potential existing benefits of SRM. This section delves deeper into the aforementioned effects of the cooling sulfate aerosols favoured in solar geoengineering. The largest risks to health are thought to be mortality from temperature, air pollution and ozone loss. Sulfate air pollution is already responsible for deaths and damages to ecosystems worldwide, and known to be a leading cause of environmental mortality globally. Due to the potential damage of these aerosols to the ozone layer, UV radiation may also be tampered with, causing an increase in skin cancers.

The University of Chicago acknowledges these health risks, however, they present a different point of view. Researchers at the university believe we cannot ignore the danger severe global warming poses, which has been the main problem all environmental activists have been trying to avoid: increased mortality due to extreme heat and weather patterns. Their research has claimed that the reduction in mortality from the cooling effect brought by SRM is "roughly ten times larger" than the risk of increased mortality due to air pollution and ozone damage.[31]

On the other hand, Alan Robock, a leading professor, outlined the key advantages and disadvantages to geoengineering in a document with Rutgers University, with points ranging from "beautiful sunsets" to the question of "Whose hand on the thermostat?" when implementing laws pragmatically, described below.

[30] https://greenparty.org.uk/about/our-manifesto/powering-up-fairer-greener-energy/

[31] https://climate.uchicago.edu/insights/comparing-the-benefits-and-risks-of-solar-geoengineering/

Benefits include:

1. Reduce surface air temperatures, which could reduce or reverse impacts of global warming, including floods, droughts, stronger storms, sea ice melting, and sea level rise
2. Increase plant productivity
3. Increase terrestrial CO2 sink
4. Beautiful red and yellow sunsets
5. Unexpected benefits
6. Prospect of implementation could increase drive for mitigation

Risks or Concerns include:

1. Drought in Africa and Asia
2. Perturb ecology with more diffuse radiation
3. Ozone depletion
4. Continued ocean acidification
5. Additional acid rain and snow
6. May not stop ice sheets from melting
7. Impacts on tropospheric chemistry
8. Rapid warming if stopped (Physical and biological climate system)
9. Less solar electricity generation
10. Degrade passive solar heating
11. Effects on airplanes flying in stratosphere
12. Effects on electrical properties of atmosphere
13. Affect satellite remote sensing
14. Degrade terrestrial optical astronomy
15. More sunburn
16. Environmental impacts of injection technology (e.g. local pollution, noise, CO2 emissions; human impacts)
17. Whiter skies
18. Make stargazing more difficult (aesthetics)
19. Human error during implementation
20. Unexpected consequences (unknowns)
21. Cannot stop effects quickly
22. Commercial control
23. Whose hand on the thermostat?
24. Societal disruption, conflict between countries
25. Conflicts with current treaties

26. Moral hazard: the prospect of its effectiveness could reduce drive for low mitigation (governance)
27. Military use of technology
28. Moral authority: do humans have the right to do this?[32]

It is clear that the “risks and concerns” column heavily outweighs the few “benefits” at a hefty 28:6 points. The complexity of the SRM debate goes beyond simply weighing risks against benefits; it requires evaluating long-term global impacts, ethical concerns, and governance challenges against our own moral compasses.

Conclusion

Despite ARIA’s stresses and reassurances that any geoengineering will be safe, highly-regulated and carried out with great caution, Professor of Planetary Physics at Oxford University, Raymond Pierrehumbert, is "extremely worried" about the issue, saying, “People want a Plan B if we don't reduce global emissions. But there really is no Plan B, it just kicks the can down the road because [solar geo-engineering] doesn't take away the carbon dioxide in the atmosphere".

Perhaps more extensive and thorough research should be done on these programmes in conjunction with greater public involvement via education schemes for an equal say in what happens to our own planet. Instead of relying on solutions to fix damage done to our planet which will soon become irreversible, our governments should aim to crack down on the causes of these problems altogether.

Governments around the world need to stop damage being done at the source, rather than treating the symptoms or after-effects, which will not, and indeed cannot prevent catastrophic environmental and geological harms.

[32] https://climate.envsci.rutgers.edu/pdf/RobockBridge.pdf

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