Geoengineering Report

Policy, Research, Technology and the Future

CSIGG
Centre for Sustainability, Innovation & Good Governance

Foreword

Geoengineering is a subject of profound fascination and intense debate. As we confront the complex issues of climate change, environmental degradation, and societal well-being, the need for innovative solutions becomes ever more pressing. Geoengineering, the deliberate manipulation the earth's climate systems, offers a potential, albeit controversial, avenue to address these challenges on a large scale.

Geoengineering holds promise as a tool to mitigate the effects of climate change, offering innovative methods to capture carbon dioxide, modulate solar radiation, or manipulate atmospheric chemistry. Yet, understandably, the prospect of intentionally altering the Earth's climate raises complex questions about unintended consequences, ethical considerations, and impact on vulnerable ecosystems and communities.

Given these contrasting perspectives, ***The Centre for Sustainability, Innovation & Good Governance (CSIGG)*** explored the role of geoengineering in supplementing climate mitigation and adaptation efforts. We conducted in depth interviews with some of the world's leading experts as well as policy makers to better understand the risks and rewards. To encourage further dialogue, we hosted a roundtable discussion to take steps towards an objective assessment of the suitability of geoengineering in tackling climate change. A summary of key findings from this meeting, along with contributions from various stakeholders, forms the basis of this report. Furthermore, it represents an exploration of the science, ethics, and implications of geoengineering. It is a collaborative effort of experts from diverse disciplines, united by a shared commitment to understanding the possibilities and risks inherent in geoengineering approaches.

I hope the insights presented within this report will contribute to informed discussions and decision-making processes as we collectively grapple with the complexities of geoengineering.

I would like to thank all our contributors for their time and effort in sharing their views on the subject and I hope you enjoy the read.

Arvind Venkataramana
Executive Director
Centre for Sustainability, Innovation & Good Governance (CSIGG)

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Geoengineering – Policy, Technology, Research and the Future

Sharmishta Reddy Tupalle & Victoria Cronin, Research Associates, Centre for Sustainability, Innovation and Good Governance (CSIGG)

The Centre for Sustainability, Innovation & Good Governance (CSIGG) has been exploring the role of geoengineering in tackling climate change over the last twelve months. Given the lack of consensus among various stakeholders about the benefits and risks of various climate intervention strategies, CSIGG's research team organised a one-day roundtable discussion to try and bring some clarity around the subject. Held in May 2023, the roundtable was attended by over 30 experts from around the world which included policy makers, academics, representatives from technology companies and interest groups.

Here is a summary of some of the key points that were discussed over the course of the meeting.

Nomenclature of Geoengineering

The definition of geoengineering is still vague and encompasses a wide range of techniques, theories and interpretations. Geoengineering divides all deliberate attempts to change climate science into two specialised concepts: Solar Radiation Management (SRM), and Carbon Dioxide Removal (CDR). While SRM and CDR are the most prominent, other forms such as marine/ocean geoengineering and passive daytime radiative cooling were briefly discussed.

Most participants expressed their concerns about the use of the term "geoengineering." Although the term is now accepted by the community, there is still a strong feeling to revisit it and create a globally accepted word/phrase to replace it. The scientific community of experts claimed that the term is ambiguous, and it is not useful to lump the ideas of CDR and SRM. They reiterate how crucial it is to be technology-specific while carrying out model experiments and conducting research. To quote a participant, *"Geoengineering doesn't capture the natural elements of climate intervention; it doesn't communicate a relationship to climate, in particular"*.

Despite diverse opinions, there is agreement that the terminology has become rooted, and public perception established. Even if it produces ambiguity it, nevertheless, attempts to provide comprehensive knowledge for the general public, which can be as a positive consequence. Alternative terms like climate intervention, solar climate intervention, climate remediation, climate management, solar radiation modification, and solar geoengineering are also being explored.

All in all, the social science world provides evidence that relabelling a concept does not change the underlying attitudes that come with it. It, therefore, becomes important to focus on the risks and benefits while continuing to find better nomenclature, as the term geoengineering has already taken the spotlight.

Risks and Benefits

It is still too early to be quantitative of the risks and benefits of geoengineering without making assumptions. The urgency of the climate crisis poses a great threat in itself, as one participant explained, *"We cannot use our uncertainty about the exact degree of efficacy of geoengineering as an excuse not to research it further"*. On the other hand, the magnitude of effects must be taken into account, considering the intention to potentially change the composition of the natural environment. This can have an effect on multiple variables that may include agriculture, migration, weather patterns and the risk lies in how this could affect the wider ecosystem. The "learn-as-we-go" approach, while not the preferred route to improving our understanding of geoengineering, seems to be the most predominant. It is important to keep in mind the rights of all stakeholders before acting on the urgency posed by the climate crisis.

From private companies executing small scale projects to some governments issuing a complete ban on any acts relating to geoengineering, the absence of consensus and coordination among nations is quite evident. As a subject that transcends international boundaries, the notion that the atmosphere is considered a platform on which ‘risky’ experiments take place, may result in negative propaganda and pushback which may hinder further research. Considering the potential benefits that geoengineering may possess, it is important to continue our research in this space in complete transparency and by regularly including multi-stakeholder views and consultations to ensure this does not result in a blanket ban on exploring it. It would also be short sighted to promote geoengineering as a solution or substitute to climate change mitigation and adaptation, rather as a supplement to it.

Policy and Regulatory Gaps

Despite differing viewpoints, there was consensus on two issues; (1) there is a surprising lack of policies and regulatory frameworks around the research and implementation of various aspect of geoengineering and (2) there needs to be international cooperation and sharing of knowhow between developing and developed nations to help formulate a universally accepted set of rules. A participant commented, *"There's certain hesitation or worry around the activities of rogue developers developing geoengineering solutions without the appropriate attention to risks and so on, as it may not affect them as much as their neighbours"*.

Cam Calder's analysis of the hypothetical circumstance of fossil fuels being more economical than renewable energy was used as an example during the discussion. The options would undoubtedly be examined for the risks they might pose if the world were considering fossil fuels as a solution to the challenges faced by the renewable energy sector. Although geoengineering is commonly referred to as a new concept, it isn’t and there is enough research to put together a reasonable level of regulatory frameworks for further research and development at a larger scale than is currently being done.

As the risks are not quantifiable, it is important to continue research activities with a certain level of caution. According to one of the experts, *“In order to improve existing research models, the next step would be to explore systems to look at analogues to naturally existing phenomena and then test some of these models. Getting more “actual” observations or field experiments that are done in a smart way in the administration of the climate system is critical, but there's not enough of that taking place. They pose much larger challenges in some aspects than running models; they have their own challenges, but there is enough proof to do it, keeping the precautionary principle in mind, which will pave the way for policymakers.”* Even though research and the need for field experiments are growing in the field of geoengineering, the lack of a comprehensive regulatory framework is obvious.

The Case for Further Investment

A climate expert who has worked in securing funding and financing for research projects remarked, *“Investments made in the field of geoengineering for research or small-scale field experiments should have clearly set out objectives to enable a pathway to successful deployment. Key questions around what specifically needs/gets funding, who undertakes what aspects of research and, critically, who governs it, in terms of results and progress. These parameters are crucial to ensuring the investments are made in the right areas and we don’t end up reinventing the wheel”.*

One aspect that was highly debated was the role of the private sector in geoengineering projects. While it was acknowledged that it is important to have effective public-private engagement, most participants felt it was counterproductive for certain private initiatives to start implementing SRM projects independently, without completely understanding its risks. *"So, keeping in mind that the profit of their own company will be put above the interest of the environment we will end up at a point of no return. Those are the real dangers. That is why, to protect the common good, a collective approach is needed, an approach based on stakeholder engagement. And only once there is sufficient agreement, once there is a global policy framework, is it safer to move ahead with real-world initiatives"* – argued one climate expert.

Another participant added, *"On the other hand, governments, the research community and private sector cannot have their hands tied while waiting for global consensus. Active private companies claim to be open to new research and are welcoming experts onto their teams to make their efforts more legitimate. It is also noted, without the private sector's involvement, researchers will keep discussing and continue model experiments in the lab rather than experiment with real-world complications."*

It is believed that around 130 to 140 start-ups in Europe are focussing on geoengineering at a moment and they have raised maybe 1.5 - 1.6 billion Euros in funding from private investments. This shows there is investor appetite to furthering technologies and initiatives to counter climate change via the SRM and CDR routes.

Technologies in Geoengineering

SRM and CDR show growing prospects in the field of geoengineering; nevertheless, there are numerous other practical solutions that are being explored. Carbon Capture and Storage was seen as a viable solution to reducing carbon emissions from industrial processes in steel and cement production. Atmospheric methane removal was also discussed as a, potentially, more effective method of reducing global temperatures than CDR. Although within the wider SRM/CDR remit, marine cloud brightening, space-based reflectors, BECCS, ocean fertilisation and enhanced weathering are also possible solutions that are being explored further. While not the most popular option, a climate expert remarked, *"There are also approaches to manipulating the sea ice in the Arctic, whether that's ice volcanoes or breaking it up in the early stages of the winter to try to expose more water to the Arctic winter, that are being looked into but will probably have an adverse on climate change and weather systems than a favourable one."*

Governance, Policy Development and the Future

Considering the limitless possibilities geoengineering opens up, it is challenging to build a one-size-fits-all policy or regulatory structure. Creating jurisdiction is a challenge as various geoengineering approaches require multi-national and global agreements and accords**.** Despite the absence of agreements or successful international partnerships, noted developments like the Artic Treaty, Convention on Biological Diversity, London Protocol and Convention, UNFCCC and IPCC discussions form the broad basis of governance in this area.

To quote one of the participants, *"Hence, an important aspect of building an acceptable intervention is to try to do it hand in hand and to make sure that it has local as well as global benefits. Sovereignty persists over the landscape, and some regions feel free to pursue pretty widespread weather modification strategies because they are purely domestic considerations. Speaking from an anthropological perspective, it is important to bear in mind that there's technology or science, and then there's technology or science in use in different cultural contexts and regional settings. It is important to remember that the cultures of technology and science affect how these different solutions will be carried out and perceived."*

Finally, another climate expert summarised the current state of play, *"The world has unanimously agreed on the need to act on the climate crisis and on the need to make large changes before it's too late. This global society must be or wants to be involved and consulted, and obviously this consensus must happen at some point, but is there such a thing? Not just a bunch of a few billion individuals, there are institutions, it's structures, there are various jurisdictions, and there are political regimes with very contrasted processes of decision-making. The scientific community is also divided and has a hard time building consensus, making it even more difficult to move in the same direction with others in the same field."*

At the end of the meeting, CSIGG asked all the participants to put forward recommendations for policy makers as well as climate experts. Here is a summary:

1. The term "Geoengineering" needs to be re-examined and there needs to be a unilateral agreement about whether it is to be used as the term to represent any form of climate intervention. In fact, the term, "Climate Intervention", was suggested as an alternative to geoengineering.

2. Governments should take an active interest in funding research and development. They should also develop strong public private partnerships to improve access to funding. Governments should continue to work towards climate mitigation and adaptation and only look to geoengineering to supplement its efforts, not as a substitute.

3. Given the nature of geoengineering, policy development, treaties and agreements should be multi-national and global in nature to ensure all parties concerned understand and agree with any large-scale implementation.

4. There is still significant uncertainty in understanding stratosphere aerosol, particularly in the context of SAI processes. Further research is required to understand the various effects of stratospheric aerosols.

5. While there is urgency to address climate change, it is equally important to focus significant efforts on adequate due diligence in geoengineering before any form of deployment.

6. Governments, international organisations and experts should allocate resources in educating and improving the understanding of geoengineering among the general public. False narratives, fake news and propaganda will find its way in social media and other channels and, eventually, into the minds of people if policy makers do not make a conscious effort to bridge the knowledge gap.

7. Another area of interest is conducting a lifecycle analysis of all technologies in this sector to ensure they are sustainable.

8. Establishing clear guidelines for experimentation and deployment. This is a crucial conversation to have, as concerns are already being raised about the potential for a strong boundary between prototyping and deployment.

9. Policy makers should continue to look at other forms of climate intervention such as nature-based solutions. While geoengineering is often cited as a means to respond to climate change, other forms of climate action are also evolving.

10. Whilst this may not be exclusive to geoengineering, there needs to be a better system in place to share knowledge and research across various geographies and disciplines. The active involvement of organisation such as the UN, IPCC and global meetings such as COP should facilitate smooth exchange of information.

11. It is not sustainable for developed nations to work independently from developing ones in finding a solution for climate change though geoengineering. Poorer nations are the most affected by climate change and are also likely to be affected by large scale geoengineering deployments so it is crucial to involve them at all stages.

12. Although some governments, the IPCC and the UN have made it clear that given the current trajectory, the goals set out in the Paris Agreement will not be met, there is still a large majority who do not believe that to be the case. Unanimously or collectively acknowledging the failure to meet climate targets could be the first step towards finding supplementary solutions such as geoengineering.

13. Some experts suggested the UN and IPCC create a policy making it mandatory for equal participation among developed and developing nations in geoengineering negotiations.

14. Bioenergy and carbon storage are essential for mitigating climate change, but there is limited research on low-scale experimentation or trials. Increasing funding for research in this space could be beneficial.

15. Further research is needed in aquatic and marine biology and how it could be affected by geoengineering. Currently, there is very little information available to base policy decisions on.

16. There is a need for more scientifically rigorous field experiments to test the boundaries of geoengineering and learn from their results.

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The World Needs to Explore Solar Geoengineering as a Tool to Fight Climate Change

David Keith, Professor and Founding Faculty Director, Climate Systems Engineering Initiative, University of Chicago

As with other technologies, the risks of solar geoengineering cannot be sensibly evaluated without a scenario for goals and governance. Solar geoengineering, also called solar climate intervention, is the idea that humans could make the planet a bit more reflective to reduce temperatures and other climate changes caused by accumulating carbon emissions. But at what cost?

A casual observer will read that geoengineering causes droughts, makes weather less predictable, dims the blue sky, and threatens the food supply of billions who depend on monsoon rains. And that's the short list. But is it fair?

NASA/Globe Photo Illustration

A technology's risks depend on how it's used. Antibiotics save lives, but if overused to make cheap beef in feedlots they breed deadly antibiotic-resistant bacteria. As with other technologies, the risks of geoengineering cannot be evaluated without a scenario for goals and governance. Like antibiotics, geoengineering could be deadly if overused. A technology's risks depend on how it's used. Antibiotics save lives, but if overused to make cheap beef in feedlots they breed deadly antibiotic-resistant bacteria

As with other technologies, the risks of geoengineering cannot be evaluated without a scenario for goals and governance. Like antibiotics, geoengineering could be deadly if overused.

A worthy goal for solar geoengineering is to slow climate change without making any region worse off. Plausible methods include spraying sea salt into the air to brighten marine clouds or injecting sulpur into the stratosphere to reflect some sunlight back to space. A fairly uniform application of geoengineering across the globe is less prone to make some regions worse off because atmospheric teleconnections mean that a strong localized application may cause unwanted climate changes elsewhere. While there will certainly be harmful impacts of geoengineering under such a scenario, evidence suggests that it would reduce heat waves, extreme storms, and rising seas, and the benefits would greatly outweigh direct physical risks, such as added air pollution. Studies suggest that such geoengineering would increase crop yields, and it would not perceptibly dim the blue sky. And because the benefits of reduced climate change are felt most strongly in the hottest and poorest parts of the world, it would reduce global income inequality.

An Internet search for "geoengineering and drought" turns up thousands of hits, most prominently a Guardian article titled "Geoengineering could bring severe drought to the tropics, research shows." But despite widespread reporting, not a single scientific article demonstrates that geoengineering increases droughts. This disconnect is not confined to the popular press. The only article on geoengineering to make the cover of Nature, the world's most prestigious scientific journal, did so under the headline "Veiled threat."

Yet the research article simply showed that geoengineering might not have an effect on crop yields, in contrast to previous research that suggested geoengineering would increase yields.

Why the sharp divergence between media and science? It's driven, in part, by a well-intentioned sense of caution that solar geoengineering will weaken efforts to cut carbon emissions. This is geoengineering's addiction problem, often called its moral hazard. If it encourages more fossil emissions by masking the climate pain they cause, then it is addictive because every ton of extra fossil carbon emissions increases climate risks, thereby increasing the demand for geoengineering to mask the pain.

It's a reasonable fear. Heat waves, storms, and other climate changes grow in proportion to cumulative emissions of carbon. That is to the cumulative amount of coal, gas, and oil that humanity has used since the Industrial Revolution. Solar geoengineering acts quickly and temporarily, but it can only partially reduce climate risk, and it brings risks of its own. Suppose geoengineering were used to stop the rise in global temperatures while fossil fuel burning continued unabated. One would then need to keep increasing the geoengineering dose just to hold temperatures constant against the rising tide of carbon. This path leads to disaster.

Addiction is an apt analogy. Used wisely, morphine is a wonder drug, but using morphine to mask the pain while avoiding the exercise needed to cure it puts one on a path to disaster.

My guess is that many environmental scientists highlight the risks of geoengineering and downplay its benefits out of a well-founded concern of the potential for addiction. Many journalists share these instincts and further amplify this tendency, thus explaining the sharp divergence between media and geoengineering science.

The intentions are good, but the consequences are not. Decision-makers and the public they serve need balanced information about the effectiveness and risks of geoengineering. They are ill-served if the geoengineering's real physical risks are conflated with the equally real political threat that geoengineering will be exploited by fossil fuel interest groups to block the transformation of our energy infrastructure away from carbon.

How to address the political risk of geoengineering addiction? First, the research community working on geoengineering must speak unequivocally about the dangers of the continued reliance on fossil fuels and confront attempts by fossil fuel interests to exploit geoengineering research by falsely arguing that it justifies inaction. More important, policy makers can build governance that links decisions about the implementation of geoengineering to accelerated efforts to cut emissions.

Climate advocates, including the big environmental groups, have generally avoided talk of geoengineering out of concern that it will divert attention from the urgent goal of cutting emissions. With a few exceptions, their strategy has generally been to wish the geoengineering issue away. There are three things wrong with this.

First, it's not likely to go away. Some crude methods of geoengineering could be implemented cheaply with technologies accessible to all but the smallest countries. The likelihood that a coalition of countries facing extreme climate damages will move toward ill-considered deployment of geoengineering grows with the increase in climate risks and the gradual accumulation of knowledge and technological capability. Second, the wish-it-away strategy blocks development of a serious research effort that could reduce uncertainty. Less than 1 percent of climate science funds are focused on geoengineering. Finally, there is the prospect that geoengineering could substantially reduce climate risks for most humans and reduce the net human impact on the natural world.

We must be wary of errors of both commission and omission. The obvious nightmare is that the future possibility of geoengineering slows efforts to stop emissions but that the technology turns out to be infeasible.

People are right to fear over-reliance on technofixes. But there's another nightmare: It's that after bringing emissions to zero, we realize in hindsight that early use of geoengineering could have saved millions of lives lost in heat waves and helped preserve some of the natural world. The rise of the antivax movement sadly demonstrates the dangers of prejudice against life-saving technologies.

There are no easy answers. Both errors are possible. But societies have the best chance to make good decisions if they distinguish the very real political risks of geoengineering addiction from the equally real physical risks and benefits of solar geoengineering. It would be crazy to start deploying solar geoengineering today. It's perhaps equally crazy to keep ignoring it. Our children will be better served by a serious international open-access research effort coupled with stronger action to end the world's reliance on fossil fuels.

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Questions That Count When Navigating the Pitfalls of Geoengineering

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Geoengineering presumes that planetary scale processes are so disordered that they call for hasty and desperate measures while, at the same time, it promises the possibility of taking control of climate change and producing knowledge, action, and governance adequate to the task. This makes for a challenging political topic. Indeed, can geoengineering be anything else than intimidating if not terrifying? Research is gathering pace yet heated debates are far from settled. For instance, does geoengineering compete with, complement or absorb other modes of climate action such as mitigation, adaptation or systemic change?

Regardless, unregulated experiments are already conducted on land, at sea and in the air. Yet, all actors involved call for urgent regulation or, at the very least, that national governments and supranational institutions take geoengineering seriously. If this suite of techniques is not simply banned, as some non-governmental organizations demand, decision makers face a cascade of dilemmas. Is doing nothing worse than taking decisions—or is it the other way around? Should regulation wait for more data or would that be too late? Is research separable from testing? In what follows, we draw on perspectives from the humanities and social sciences to point out three major traps on this steep path. In doing so, we will not dissipate the frightening aspects of geoengineering but—because there are no turn-key solutions—attempt to provide readers and decision makers with a compass to address geoengineering, inform your understanding and investigations, and help you reclaim the definition of the issue and what is at stake.

First, what is geoengineering? The scientific community involved in geoengineering research remains hesitant about definitions, the distinction between basic and applied science, or between categories of techniques and projects, and even on the need for experiments. Such equivocation is a reminder that we should not assume neat definitions will stick, like those in official reports, and is an encouragement to delve further into ongoing debates. There are different varieties of geoengineering from a technical perspective (e.g., solar geoengineering, soil carbon sequestration, direct air capture, ocean alkalinization) but also from an operational perspective (e.g., academic research programs, national strategic imperatives, industrial decarbonization, start-ups in stealth or launch mode). When it comes to the question of what makes something a geoengineering experiment, the funding structure and types of technique involved offer no single answer—in many ways, experiments are incommensurable even as they claim to address one and the same earth. Evidence-based policy must not only ask what counts as relevant evidence, but also question who does the counting and why.

Geoengineering presents similarities with the debate on genetically modified organisms (GMOs). Lab researchers and entrepreneurs presented GMOs as a way to solve one of humanity's grand challenges: world hunger. They were, however, vehemently challenged by farmers, consumers, and ecologists when planted in open fields. From a war of words to acts of propagation and uprooting, this controversy shifted the meaning and value of GMOs and helped define what they actually are and for whom. In the case of geoengineering, it is precisely because the divide between lab (or testing site) and field (or planetary atmosphere) is frequently invoked but rarely articulated (let alone troubled) that we must take a broader view.

This calls for paying careful attention to competing ways of understanding and relating to geoengineering, indeed, it calls for expecting and facing disagreement every step of the way. What if there is no predictable, manageable, or enforceable line that separates prototype from deployment?

Second, who is the public of geoengineering? Calls for regulation and social scientific expertise on emerging technologies tend to imply that rules, norms, and ethics can be elaborated independently and consequentially to ensure public ownership, define responsibility, tie up loose ends and bring controversy to a close. But who is “the public” in the first place? We are all members of the public, although with highly contrasted means of agency, experiences of power asymmetry, and visions of the good life. Who gets the first or the last word on these technological issues and why? Who gets excluded from public deliberation and for what reasons?

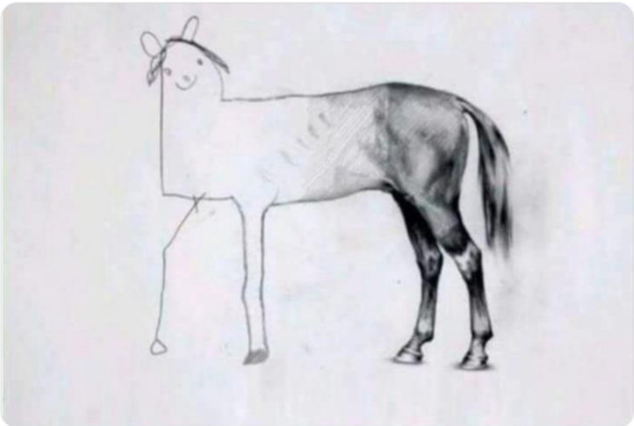
Often enough, it is assumed that political authorities or everyday people reject proposed solutions to a technical problem because they lack a full and proper understanding of “the facts” as a would-be independent reality. Too focused on the election cycle to make the hard decisions or too concerned about paying the bills to change their bad habits, they are viewed as obstructing progress towards the “right” outcome because of a lack of insight, will, or courage regarding what is really at stake. Far from being ignorant or unreasonable, ordinary users and observers of emerging technologies are full of resources to thematize and inscribe them in broader views and already intricate worlds.

It seems easy to say that the earth’s oceans are vast deserts bubbling with carbon removal potential, but in reality they are a dynamic interface filled with human activity and to which people are attached through different ideas and practices. If island nations have been consistently at the forefront of international climate negotiations, it is not only because of their exposure to sea level rise but also their first-hand experience with the impositions of colonization, modernization and industrialization. Solar geoengineering resonates with the highly contested dissemination of substances in the air, food and bodies (GMOs, pesticides, electromagnetic waves, vaccines) and concomitant controversies about imbalances of power, the influence of lobbies and obscure corporate accountability. The question of what makes geoengineering harmful or not, innocuous or not is above all political and philosophical; it cannot be fixed in advance and will play out in the turbulence of words, deeds, and feelings.

Third, what’s in an emergency? Geoengineering is an attempt to respond to climate change as an emergency. It is not the only one and will develop in concert and conflict with others, such as good and bad faith supranational negotiations, genuine and disingenuous corporate transformation, direct action, geopolitical unrest, and mass migration. There is an urgent danger that geoengineering will aggravate lines of global injustice as countries and people who continue to bear a disproportionate burden when it comes to the effects of climate change are denied the epistemic, political, and financial dividends that will accrue from climate change solutions.

The effects of geoengineering, by definition, will not be limited to one territory or jurisdiction but have knock-on effects for near and distant neighbours. It is not possible to isolate the climate consequences of geoengineering from its potential as a geopolitical weapon. No matter how many “guardrails” are put in place, geoengineering will not evolve in a vacuum. Like all other alliances of technics and politics, it will be exposed to the orderly and disorderly forces of human and more-than-human nature. Even if researchers and decision makers establish criteria of justifiability and agree on ways to regulate geoengineering, they will not have the last say on how it is received nor how climate action is defined.

When the deadline comes too close



Geoengineering techniques might be stolen and hacked, accelerated and sabotaged, venerated and mistrusted. We can follow recent scholarship in the environmental humanities and distinguish between urgencies and emergencies. Emergencies involve responding to an imminent danger and oscillating between despair and will to power. Urgencies denote times of uncertainty that push us to think deeper, expand our sensibilities, and “stay with the trouble” rather than grab at solutions. Rather than evaluate geoengineering as a technological abstraction, our questions are invitations to resist framing the stakes of climate action in terms of an emergency. As geoengineering continues to emerge as a political challenge, we urge you to stop and think, listen and reflect, and so forge your own perspective, questions, and reasons for acting.

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Solar Geoengineering: A Policy Perspective

Mattijs Van Miert, Advisor - Climate, Environment, and Agriculture, Belgian Deputy Prime Minister, Government of Belgium

The threat climate change poses to our planet, our health and our societies is by now well known. A growing group of people, especially of generations Y and Z, is becoming more and more pessimistic about our ability to reach net zero in time to stop catastrophic warming, to stay under the 2 degrees, let alone the 1.5-degree, threshold. Guided by this despair, some are reviving the idea of solar geoengineering: large scale human intervention in the earth's natural regulatory systems to reflect sunrays into space to reduce heating.

Be careful what you wish for: a treatment with side-effects requires precaution

Different approaches to climate breakdown are similar to different ways to treat an illness. When a patient is sick because of continued exposure to a certain poison, the fundamental solution would be to stop the patient's exposure to that poison, just like the fundamental solution to climate breakdown is mitigation. Just like adaptation, you could teach the patient to live with the symptoms, a body that functions worse because of the toxins, which is a clear deterioration in the quality of life. Or, like CCUS, you could filter the poison from the patient's blood to stabilise the situation, without actually stopping the exposure. Finally, you can find a drug to just treat the symptoms. That is what solar geoengineering is.

Even if geoengineering were used as such a medicine of last resort, it is crucial to make sure the treatment isn't worse than the disease. First, it shouldn't detract the attention from what needs to be done: stopping emissions at the source. Second, medicines can have extremely harmful side-effects, like the Thalidomide scandal demonstrated in the fifties. Increased emphasis on prevention lead to strong testing requirements in the European medicine policy and the precautionary principle in the General Food Law Regulation. Article 191 of the Treaty on the Functioning of the European Union requires environmental policy to be based on the precautionary principle.

For geoengineering we thus need to understand the science first, before considering whether to allow any large-scale deployment. It is the only way to prevent disastrous side-effects and to get a view on the reversibility of proposed actions, so we can pull the plug if unforeseen negative side-effects appear. We are living a climate urgency and we do need to act fast. However, if we act without sufficient scientific knowledge and precaution, we are acting stupidly and uninformed. Good intentions might lead to bad outcomes. As Albert Camus wrote in *La Peste*: "*Le mal qui est dans le monde vient presque toujours de l'ignorance, et la bonne volonté peut faire autant de dégâts que la méchanceté, si elle n'est pas éclairée*."[1]

To whose benefit? A collective problem requires a collective solution

The lack of sufficient scientific knowledge is a first reason for precaution. A second one is socio-economic and geopolitical. Stratospheric aerosol injection, a geoengineering method that tries to mimic the cooling effect of large volcanic eruptions, could have very different local impacts, meaning there are winners and losers. Global benefits can generate local costs. The 1815 Mount Tambora eruption on Sumbawa has been linked to the defeat of Napoleon, as it led to local weather conditions that gave his opponents an edge.[2] What if the intervention in the atmosphere effectively changes weather patterns in unpredictable ways? It may cause droughts in some areas, and floods in others. Both could take lives, increase poverty, and be catastrophic for the local agriculture.

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[1] "The evil that is in the world almost always comes of ignorance, and good intentions may do as much harm as malevolence, if they lack understanding."
[2] C. Brogan, 'Napoleon's defeat at Waterloo caused in part by Indonesian volcanic eruption', *Imperial College London*, 22/08/2018 (https://www.imperial.ac.uk/news/187828/napoleons-defeat-waterloo-caused-part-indonesian/).

Are we going to sacrifice some regions in the name of saving the climate as a whole? If yes, this creates the potential for conflict. Especially if such an intervention doesn't come from a global consensual agreement, but rather from a limited group of countries, other countries might feel overly disadvantaged and resort to sanctions or even war. Such conflicts could easily undo all the intended benefits. Therefore, a globally concerted approach is crucial.

Even if sufficient science and precaution would inform the global community that a proposed measure is safe and desirable, it still needs to be guaranteed that deployment is exclusively in the general interest of humankind and nature. If, however, geoengineering efforts become private revenue models, similar to carbon credit systems, it creates a profit incentive that would not necessarily align with the scientifically attested environmental needs and safety precautions. It's a conflict of interests. Companies that start off with good intentions might end up pushing the wrong quantity or quality of intervention to increase revenue or reduce costs. If geoengineering becomes a business, it's no longer about saving the climate. It will become about saving the company's bottom line.

Another risk is that multiple uncoordinated initiatives interfere with each other in ways that cannot be sufficiently modelled, leading for example to too high concentrations of sulphates. A disorganised approach can prove disastrous, similar to a tragedy of the commons. Given the scale of the impact of messing with our atmosphere and the risk of enormous irreversible damage, just managing these risks would be largely insufficient. If geoengineering were to be undertaken, a coordinated and systemic approach is a necessary condition to ensure the intended effects are reached without major harmful side-effects. This requires internationally agreed rules and guidelines, elaborated with all stakeholders on board. The atmosphere is a common public good.

Approaching geoengineering with humility

The climate crisis can be overwhelming and staying below the 1.5 degree limit is a daunting task. This may lead to some people panicking and jumping to what appears as big solutions. Given the high risks of unforeseen consequences, a few persons or companies alone will, however, not be capable of judging what's best for all of humankind. That would be hubris: pretending you can know and control everything. But you can't. Even with sufficient scientific knowledge, they can never fully predict how other organisations or countries would react, leading to interfering interventions, destruction of necessary equipment or even war. In the past it has happened quite often that we found a wonderful new technology that later on turned out to be detrimental, such as Thalidomide, asbestos, tobacco as a medicine, food cans sealed with lead, or even burning coal for energy. Given the high stakes of such an enormous, unprecedented undertaking, the cost of being wrong is simply too high not to approach geoengineering with humility.

Policy recommendation

In its approach to solar geoengineering, European and member state authorities best consider the following principles:

- Mitigation first. Emission abatement is the only fundamental solution, and thus needs to remain the cornerstone of climate protection. It should thus have the priority of investment.
- Put the precautionary principle and scientific knowledge central, taking into account possible side-effects, inequality in socioeconomic impacts, and reversibility.
- Align with the international community to avoid conflicts and a disorganised approach. There is a need for a governance of research experiments. This cannot be the Wild West.
- Favour global cooperation in research to avoid a race for the technology and to make sure the interests of all of humankind are taken into account.

- Put a moratorium on all private initiatives for deployment, while scientific knowledge is being collected, and don't allow any deployment without strict, internationally agreed regulations.
- Leverage the restoration and self-regulating potential of the earth system to avoid human intervention where nature-based solutions are possible.

Solar geoengineering is merely treating the symptoms, with potentially big side-effects, so it should never be the priority of any climate policy. Given that researchers and private companies are experimenting in this field, it is however necessary to ensure European policy remains up to date to prevent individual initiatives from doing more damage than good.

Disclaimer
The views expressed in this contribution only reflect the author. They do not necessarily reflect the views of the author's employer.

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The Moral Hazard and Moral Duty

Dr. Shaun Fitzgerald OBE FREng Director, Centre for Climate Repair at Cambridge | Fellow, Girton College

The IPCC Sixth Assessment Report (AR6) [1] shows human activity warming the climate at a rate unprecedented at least in the last 2,000 years. Each of the last four decades has been successively warmer than any prior decade since 1850, and since 2011, average temperature rise has been 1.6°C and 0.9°C over land and ocean respectively. Human-induced climate change is recognised 'with high confidence' as the main cause of the now routine extreme weather events on every continent. Within the next fifty years sea level is expected to rise about 2 metres if current emissions levels continue. These changes are being driven by radical and rapid increases of the three most important greenhouse gases (GHGs) in our atmosphere; carbon dioxide (CO2) concentration is at its highest for two million years, with methane (CH4) and nitrous oxide (N2O) at an 800,000 year high. Averting irreversible instabilities in multiple ecosystems and their potentially disastrous effects on humanity requires that the levels of these GHGs be significantly reduced.
The need for deep and rapid emissions reduction, a major issue for each COP, is unarguable.

However, the climate has already changed and the evidence is now incontrovertible that emissions reductions alone cannot be sufficient to stay within the 1.5°C limit; additional actions such as greenhouse gas removal (GGR) are needed. Indeed, some form of greenhouse gas removal is included in the scenarios considered by the IPCC which keep the world with the 1.5°C limit by the end of the century. However, even the most ambitious and aggressive emissions reductions scenario considered in AR6 involves temperatures exceeding 1.5°C during this century. One conclusion from these observations is that if global society wishes to actually keep temperatures below 1.5°C, then something else is needed. The only option which could be available, but isn't yet because we don't know enough about it, is some form of solar radiation management (SRM).

Some have voiced concerns that GGR and SRM, sometimes referred to collectively as 'geoengineering', might lead to reduced efforts on emissions reduction. This is referred to as the 'Moral Hazard', a term originating in the insurance sector, but latterly applied to a wide range of behaviours where people act more riskily because, if things turn out badly, the negative consequences are borne by others [2].
Moral hazard became a concern in relation to climate change because some fossil fuel producers argued for policymakers to reduce focus on emissions reduction, and instead to shift to hi-tech GGR and SRM approaches (industrial carbon-capture, mirrors in the sky, sulfuric acid in the atmosphere, for example) [3–6]. However, there is limited evidence of moral hazard in other actor categories and in fact several studies have indicated a possible 'galvanizing' effect. In these studies participants were generally cautious or hostile towards interventions described as geoengineering, but thought they would be more motivated to reduce their personal carbon footprint if they saw government and industry investing in such research or deployment [7–9].

There is an urgent need to extend the scope of existing research on different approaches to GGR and SRM to determine what could safely and beneficially be deployed at scale. SRM techniques, in particular, need careful evaluation for benefits and for any deleterious effects; further studies are essential. There are promising strategies that appear scalable and acceptable. These include cloud brightening through the generation of more sea spray, the evaporation of the droplets, and the transport of the resulting salt crystals into the marine boundary layer to provide more cloud condensation nuclei. A further method is stratospheric aerosol injection which involves injection of aerosol such as sulfur dioxide into the stratosphere. Both of these concepts build on natural processes; sea spray is generated by wind naturally, and sulfur dioxide is sometimes lofted into the stratosphere by volcanic eruptions. However, there are still large knowledge gaps which range from the potential impact on the climate (positive and negative) through to the practical engineering delivery mechanisms for any deployment.

And probably most significantly, there is a need for a global conversation with many different communities to determine what constitutes 'acceptable' options. Without appropriate timely research, there is a risk that

accelerating climate change, and its unpredictable consequences, will lead to techniques being deployed later, at scale, with a 'hope for the best' approach. This would be a high-risk strategy and ideally should be avoided. From this perspective, Moral Hazard based claims that research on GGR or SRM should not be undertaken for fear of reducing efforts to abate emissions, become a Moral Hazard in themselves; they could have the unintended effect of increasing the risks from climate change for present and future generations. If this is the case, rather than downgrading such research for fear of a Moral Hazard impact on emissions reductions, should it instead be regarded as a Moral Duty, where every available option is explored to avert things turning out badly, with the negative consequences to be borne by others?

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Cooling Earther Together

Luke Iseman, Founder, Make Sunsets

"We are as gods and have to get good at it. Necessity comes from climate change" - Stewart Brand, 2009
"People are suffering. People are dying. Entire ecosystems are collapsing. We are in the beginning of a mass extinction... How dare you continue to look away and come here saying that you're doing enough..." - Greta Thunberg, 2019

We have been geoengineers since the first campfire, and we've been doing a bad job at it since 1760. Like it or not, we are in the Anthropocene. It feels good to pretend planting trees and buying solar panels will be enough to Save The World... but it won't. The only realistic solution to keep warming below 2C is solar geoengineering. We must reflect sunlight to buy the time needed to decarbonize industry and bring atmospheric carbon levels back to sanity.

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Like it or not, we are in the Anthropocene. It feels good to pretend planting trees and buying solar panels will be enough to Save The World... but it won't. The only realistic solution to keep warming below 2C is solar geoengineering. We must reflect sunlight to buy the time needed to decarbonize industry and bring atmospheric carbon levels back to sanity.

Some will question the safety of injecting sulfur dioxide into the stratosphere, but the natural record is clear: Mount Pinatubo's eruption cooled the world by .5C for a year. We can and should be injecting similar amounts of sulfur dioxide into the stratosphere now, measuring results and adjusting future injections accordingly. There is a clear, calculated mortality cost of carbon: the lifetime footprint of you and a friend = 1 extra death from heat this century. Every day we wait to geoengineer the stratosphere is a missed opportunity to save lives and prevent extinctions. Our geoengineering from our co2 emissions has created a catastrophe, and we must act now to save lives and buy time in this climate emergency.

Some ask "how dare we?" How can we claim the right to modify the planet for everyone with my reflective clouds? Unfortunately, nobody objects to my gas-burning pickup truck. I have benefited from gigatons of co2 pumped into the atmosphere as we built the modern world, and so have you. We have an obligation to fix what we broke; we must Cool Earth immediately. Calls for more "blah blah blah" are an abdication of responsibility: future generations will want to know why we delayed. Greta was referring to the transition away from fossil fuels. Future Gretas will ask why we waited to Cool Earth. The first nation to sponsor at-scale solar geoengineering will be condemned internationally... for about a year. Then, the world will be slightly but measurably cooler.

This moral high ground will bear economic benefits, too: preventing climate change saves the world billions in damages per year. Other countries will more than foot the bill. The first nation to sponsor at-scale solar geoengineering will be condemned internationally... for about a year. Then, the world will be slightly but measurably cooler. This nation will have started us down the path to becoming responsible geoengineers, and the question will quickly change from "should we Cool Earth?" to "how much should we cool Earth?" This nation will have been the first to do the hard but right thing. This moral high ground will bear economic benefits, too: preventing climate change saves the world billions in damages per year. Other countries will more than foot the bill.

But, this is a limited-time opportunity. I am far from the only individual to grow so frustrated with academics debating while the world burns that I decide to take matters into my own hands. Whether we like it or not, far more extreme actors will deploy much more aggressively after a few wet bulb events in major population centers. Imagine an Indian version of me, but smarter and having just lost her whole family in a Delhi heat wave. She will accuse us of having blood on our hands, both for our carbon emissions and our timidity about solar geoengineering. Will she be wrong? Will she have patience for our hand-wringing, or will she immediately take action to Cool Earth?

Solar geoengineering is an extreme measure. Compared to what will happen if we further delay deployment, solar geoengineering is nothing. Help us fix what we've broken. Let's Cool Earth together.

Luke Iseman *is cofounder of Make Sunsets, a start-up that launches reflective clouds to fight global warming. They have deployed over 3000 ton-years' worth of cooling for paying customers, and their mission is to Cool Earth by 1C before 2030. Previously, Luke was founder of several hardware start-ups and Director of Hardware at Y Combinator.*

Commercialization of Stratospheric Aerosol Injection

Andrew Song, Co-Founder, Make Sunsets

As entrepreneurs, we have always been passionate about nurturing innovations that have the potential to change the world. We've helped entrepreneurs who are building supersonic jets, 3D-printed rockets, smart mattresses, low-cost e-bikes, and self-driving cars. Today, we want to discuss our latest venture in the fight against climate change by commercializing stratospheric aerosol injection (SAI). SAI is a promising method of climate intervention that involves injecting reflective particles, such as sulfur dioxide, into the stratosphere to cool the Earth's temperature until humanity can transition off fossil fuels and remove the existing greenhouse gases (GHG) in our atmosphere. Our company is currently utilizing balloons to deploy these particles, and we will scale up our efforts as commercial demand increases.

With GHG levels continually rising, we must explore alternative approaches to mitigate the impacts of climate change. Since our company's incorporation in October 2022, we've offset the warming from 3,000 tons of CO2 for a year for our happy customers.

Starting Small and Scaling- At the outset of our venture, we have chosen to start small. This strategy allows us to fine-tune the technology and gather valuable flight data before increasing the scale of our deployments As interest and demand for SAI grow, our company plans to expand our operations, increasing the size and reach of each deployment. This approach helps us ensure that our methods are both environmentally and financially sustainable. We've also been intentional about our efforts by engaging with the public and press by hosting events in public places for people to learn more about SAI. In April 2023, we attended SF Climate Week and handed out biodegradable balloons filled with helium and chalk dust, creating 200 new solar geoengineers.

No Credible Path to Stay Below 2°C, Despite the valiant efforts of scientists, policymakers, and concerned citizens worldwide, there is no other viable way to keep global temperature rise below the critical threshold of 2°C. We are not cutting emissions fast enough and the promising technologies that will transition us away from fossil fuels are too little too late. We must start solar geoengineering at scale. The harsh reality is that our current trajectory is leading us toward more catastrophic climate events.

As entrepreneurs, we are proud to be at the forefront of the commercialization of stratospheric aerosol injection. We understand that our approach is not without controversy, but we are pursuing the only feasible path forward that can keep global warming below 2°C. We invite you to follow us on our journey by visiting our blog where we share our progress via monthly posts.

__Andrew Song__ is one of four siblings and was born and raised in San Jose, CA. He is a graduate of the College of Arts and Science at NYU. His career has been guided by curiosity which allowed him to work as an early employee or founder at various Y Combinator startups. When he's not working on cooling Earth with reflective clouds in the stratosphere, he enjoys spending time with his two sons and teaching them how things work.

The Conversation We're Not Having

Ben Kravitz, Department of Earth and Atmospheric Sciences, Indiana University

The historic Paris Agreement of 2015 held as its goals to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and "limit the temperature increase to 1.5°C above pre-industrial levels".[3] These limits were chosen because they represent thresholds of serious harm to the world.[2] Indeed, rallies around #1point5toStayAlive have continued since 2015, encouraging the IPCC to conduct a special report on the 1.5°C target.[3]

The IPCC's 1.5°C special report only seriously discusses mitigation and Carbon Dioxide Removal (CDR) as categories of solutions to climate change. Nevertheless, even if we rapidly phased out burning of fossil fuels, mitigation will not keep us from exceeding 1.5°C of global warming.[4] CDR does have the potential to get us below 1.5°C *eventually*. The largest demonstrated carbon capture project to date can sequester 7 Mt of CO_2 per year from the atmosphere, and the top 30 sites can remove a total of 42.6 Mt of CO_2 per year.[5] In contrast, anthropogenic emissions in 2022 were 37.12 Gt of CO_2.[6]

CDR won't keep us below 1.5°C either. And since mitigation and CDR are baked into our optimistic scenarios of future climate change, and those scenarios are based on consistent socioeconomic assumptions about the world and its future,[7] there is no scenario considered "plausible" by the community of experts on climate change that will limit global warming to 1.5°C. If we rely solely on greenhouse gas emissions mitigation and CDR, human suffering in the face of climate change will continue to be a reality.

This is why there is increasing attention being paid to climate engineering, or deliberate climate modification, to temporarily offset the harms of climate change.[8,9] The most commonly discussed and well-understood method is called Stratospheric Aerosol Injection (SAI).* This method mimics a large volcanic eruption by creating a highly reflective cloud of aerosols (microscopic droplets) in the upper atmosphere, reflecting a small portion of sunlight back to space, cooling the planet. Research conducted to date overwhelmingly concludes that, while imperfect, SAI could rapidly, substantially reduce the effects of climate change for the vast majority of people across the planet.[8,10,11]

Climate engineering, of course, imposes risks. Because the offset of climate change is imperfect, there will be side effects. There are also substantial risks related to geopolitics (who is doing climate engineering, and what are they trying to achieve?),[12] governance (who decides and how?),[13,14] economics (are there winners and losers, and how are losers compensated?),[15] and environmental justice (the countries most affected by climate change and climate engineering are likely the least empowered in negotiations),[16] among others. These risks have potentially serious and destructive consequences. All of this is why many people say we should never do climate engineering.[17]

Conversely, climate engineering is the only technology (that we know of) that will keep global warming from exceeding 1.5°C. Also, the risks of climate engineering cannot be discussed in isolation; the purpose of climate engineering is to alleviate the ongoing and potentially catastrophic risks of climate change. This is why many people say we need to consider climate engineering as an option and do the research.[18,19]

Regardless of whether society should use climate engineering as a strategy to combat climate change, one thing is abundantly clear: climate engineering has a communications problem. While there are many researchers and discussants involved with this topic who make a concerted effort to communicate responsibly, there are many instances of loaded language and fallacies, both for and against climate engineering.[20]

* There are many other proposed methods, such as marine cloud brightening and cirrus thinning. While the specifics of the effectiveness and side effects vary among technologies, the broad conclusions provided here do not.

Examples include:

- "Whose hand is on the thermostat?"[21] (Begging the question)
- "The exacerbation of global injustices perpetuated by [climate engineering] research should not be tolerated by anyone who is committed to advancing social justice in the world today."[22] (No true Scotsman fallacy)
- "Who is liable when millions of people go hungry because the monsoon rains get cancelled in East Africa?"[23] (Strawman argument)
- "Unless we reflect sunlight (albedo enhancement), 10s of millions of people will die and 20%+ of species may go extinct."[24] (False dilemma)
- "Will [climate engineering] kill us or save us?[25] (False binary)
- "We cannot solve our problems with the same thinking we used when we created them." * (Fallacy of relevance)

These rhetorical devices shut conversations down instead of open them up. They presume that we know the answer about whether to deploy climate engineering; while some people may have made up their minds already, many have not. The consequences of this decision are too dire to resort to tactics that terminate thinking.

I get it. Many feel that climate engineering is simply wrong,[26] and many others are afraid of what will happen if society doesn't do it. But if we are going to figure out this thorny issue, we need to stop talking past each other and have a genuine conversation. That means active listening, considering opposite viewpoints, and weighing evidence. Most importantly, it means respecting our audience's ability to make up their own minds rather than coaxing them with clever wording.

Let's have a conversation. There's too much at stake not to.

***Dr. Ben Kravitz** is an assistant professor in the Department of Earth and Atmospheric Sciences at Indiana University. He is an international expert in climate model simulations of climate engineering.*

* This quote is often attributed to Albert Einstein and was mentioned in Elizabeth Kolbert's recent book *Under a White Sky*. While Kolbert uses this quote ambivalently regarding climate engineering, there are numerous examples of it being repeated, either as an argument against climate engineering or as an argument to try out-of-the-box "solutions" to climate change.

Diplomacy, Democracy and Consensus in Geoengineering

Burgess Langshaw Power, PhD student - Global Governance program at the Balsillie School for International Affairs, University of Waterloo

Solar geoengineering may be a *necessary* idea, but that does not mean it is a *good* idea. As we continue to miss climate targets, and face increasingly severe environmental, economic, and social impacts, more extreme options will likely become publicly and politically viable. This may include Solar Geoengineering via techniques such as stratospheric aerosol injection, marine cloud brightening, and cirrus cloud thinning. Currently, the debate centers on a key issue: should we research solar geoengineering, or rush to deployment? While some are opposed to solar geoengineering for a myriad of reasons, many leading academic experts in the field argue for research following the precautionary principle. This is for good reason; we still need significantly more information and research – especially in inter and transdisciplinary contexts – to engage in evidence-based decision making.

What we do know is already sufficient to enable business actors to engage in small scale launches. This is exacerbated by the problem that there is no clear delineation between outdoor field testing and small-scale deployment, or that some of the potential effects of solar geoengineering (both positive and negative) would not be fully known until larger scale deployment is implemented. Some private sector proponents (who have ulterior, profit driven motives) have bypassed the many moral and ethical questions underlying this issue, proceeding straight to small scale field deployment, and developing business models to profit from an increasingly unstable climate. These parties have not considered the potential implications of their decisions on the public (such as health and safety).

The cavalier attitude presented by current private sector interests only represents those with power and means, whose own goals do not reflect the wants or needs of the global populace, and especially not those most vulnerable to the impacts of climate change. Meanwhile, these capitalist elites are likely to be the least impacted by the negative externalities of solar geoengineering (or most able to afford to mitigate or offset them) yet intend to profit off this process. Their actions clearly violate basic principles of scientific morals and ethics and do not reflect the recommended climate action recommendations by the IPCC or other international bodies.

Given the diversity of opinions and regulations on this subject, it will be all but impossible to ban the research and development (or deployment) of solar geoengineering entirely. The best course of action is to engage in research to better understand the potential and limitations of these technologies, including unintended consequences, and the variations between different types of interventions. This would enable informed decision making, by individuals with responsibility for the public good. One *possible* outcome of such research is to demonstrate that solar geoengineering is in fact not a viable strategy.

There is no question that conducting any kind of solar geoengineering will have externalities; the goal of solar geoengineering is, after all, to artificially modify the climate. As with anthropogenic climate change, some of the impacts are hard to predict, despite decades of research, monitoring, and real-world data. The known effects include changes to solar energy arriving to earth, which in turn will cause side effects including changes to local, regional, and likely global weather patterns – depending on the scale of solar geoengineering conducted. Other postulated effects include reductions to ozone levels in the stratosphere.

Research has demonstrated that many controllable factors of deployment (such as altitude, latitude, seasonality, etc.) will in turn change both the direct effects and the side effects of solar geoengineering. Those with the power and resources to conduct solar geoengineering will have incentives to deploy it in such a manner as to maximize their own benefits and minimize harms – likely turning the harms upon those least able to respond. Consideration of compensation for loss and damage is necessary to prevent Machiavellian strategies.

Given that harms are not only likely, but almost certain, a system must be in place to account for and likely compensate for those harms. This is the key issue currently neglected by the active proponents for deployment of solar geoengineering. Therefore, research into solar geoengineering must be multidisciplinary in nature, to include governance, ethics, morals, and justice in any resulting decision-making frameworks. These frameworks must be flexible enough to allow for research, but powerful enough to stop testing or deployment should it reach critical points where harms exceed any possible benefits, and to account for compensation for those harms.

From a governance perspective, most research has been examining how a global governance initiative could be implemented. While admirable, this is lacking in understanding that because harms and benefits are not equally distributed, different nations will also have different understandings of whether or how much solar geoengineering deployment they may want. Canada for instance must balance the threat of melting arctic sea ice against possible economic and resources opportunities presented by the warming arctic. Vanuatu on the other hand has called for discussion of compensation for loss and damage due to the possibility that their country be destroyed by rising sea levels – a process that could theoretically be prevented or at least delayed by the deployment of solar geoengineering. Nations must immediately begin consideration of the domestic costs and benefits of any potential solar geoengineering, before turning to an international stage.

This strategy also explains why calls for a ban on research (or deployment) of solar geoengineering are misguided. Organizations such as the Saami Council have objected to solar geoengineering (particularly the Harvard SCoPEx project), claiming in their open letter that, “There are therefore no acceptable reasons for allowing the SCoPEx project to be conducted either in Sweden or elsewhere.” It seems unlikely that there are not some peoples and organizations whose lives and future *may* be protected by possible deployment.

To assert without evidence that an undefined set of risks and harms exceeds an unquantified set of possible benefits is unreasonable and asserts a dogma and ontology upon all others without precedent. Such a perspective would effectively grant a single community (or group of communities) de-facto veto on an issue, prior to open debate, and discussion – in direct opposition of the democratic ideals that are supposedly used to justify such a ban. As such a blanket ban on solar geoengineering would be counterproductive, forcing research and deployment out of the public eye where it could be democratically discussed and managed, and into legal and moral grey areas. It is important to reiterate that solar geoengineering is not a climate solution. At best, solar geoengineering can buy time for mitigation and adaptation measures, to prevent or lessen the most extreme heat related effects of anthropogenic climate change, and/or to allow time for the scaling and deployment of carbon dioxide removal systems. Solar geoengineering must never be considered as an option to allow for continued greenhouse gas emissions, or the erosion of climate targets.

Additionally, there will be winners and losers to any possible deployment of solar geoengineering. Creating and enforcing a ban on solar geoengineering is implausible if not impossible in contemporary geopolitics (imagining unanimity between the US, China, and Russia is laughable in current circumstances), and therefore the best course of action is to conduct open and public research such that research and deployment is not pushed into covert or private sectors. It is only with diplomatic and democratic global interaction that there is any hope of reaching some semblance of a governance regime.

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ENMOD: The Critical Center Piece in a Geoengineering Security Regime

Tracy Raczek, Senior Adviser, United Nations

Policy craft takes time. Thus, shoring up international policy in anticipation of potential security risks of climate and weather modification technology is prudent. China, the United State, the United Arab Emirates and Saudi Arabia among others are already rolling out these technologies. India, Iran and Mexico have, simultaneously, raised concerns over similar activities by neighbouring states. A US National Intelligence Council assessment, as early as 2018, notes that the current lack of governance keeps a door open for independent, unilateral, and covert development and deployment of this technology – risking blowback and conflict.[5]

Security risks associated with the research, deployment, and tactical use of Solar Radiation Management (SRM) and related cloud seeding technology are especially significant. They include threat of use, real and perceived political and economic manipulation, and tactical hostile use that may provide military advantage, ignite flashpoints, and fuel conflict. (Figure 1) And as with all conflict, actions are not limited to state actors. Non-state actors including terrorists, private military companies, and the private sector could play roles. Without good governance – soon – we are marching into a new world with this ungoverned weapon at its disposal.[6] A SRM security regime is urgently needed and the Convention on the prohibition of military or any other hostile use of environmental modification technique (ENMOD Convention) should be at the centre.

Fig. 1
Security dimensions & risks

Research	Testing	Deployment	Tactical Use
▪ **Control** of technology	▪ **Control** of technology ▪ Real or perceived **political or economic uncertainties**	▪ Geo-political **influence** by technology leaders ▪ **Reliance** of non-leading actors on actors leading in technology ▪ **Social and economic instability** [7] ▪ Adverse impacts (real or perceived) **exacerbate tension or ignite flashpoint** ▪ Geo-engineering **arms race**	Use or threat of use by state and non-state actors: ▪ **Escalating tensions** ▪ **State-based conflict** ▪ **Intra-state conflict** Use or threat of use by non-state actors in acts of **terrorism**

Source: Tracy Raczek

Security dimensions & risks: Security risks increase in each progressive stage noted in figure 1: research, testing, deployment (large and small-scale), and tactical hostile and military use. Research (green) and testing (yellow) have the fewest and most indirect security risks. Large and small-scale deployment (orange) present multiple yet still indirect security risks such as exacerbating social and economic instability, fuelling a geo-engineering arms race, and wielding or benefiting from this technology to gain geo-political advantage. Tactical use with military or hostile intent (red) presents the most direct security risks such as using or threatening to use this technology with intent to exacerbate tension, ignite a flashpoint, or gain military advantage in a conflict.

In the face of these and other risks, calls for governance are often repeated. Among the most resolute is a call for an "international non-use agreement on solar geo-engineering" made by over four hundred academics from 60+ countries.[8]

[5] National Intelligence Council, National Intelligence Estimate, Climate Change and International Responses Increasing Challenges to US National Security Through 2040 (NIC-NIE-2021-10030-A), 2018. Page 11.
https://www.dni.gov/files/ODNI/documents/assessments/NIE_Climate_Change_and_National_Security.pdf
[6] Good governance aims to reflects cross-cutting governance principles of transparency, participation, and accountability among others.
[7] Social and economic factors (e.g. reduced climate driven migration, reduced costs of disasters) may diminish social and economic stability and exacerbate tensions or contribute to flashpoints.
[8] Solar Geoengineering International Non-Use Agreement. https://www.solargeoeng.org/non-use-agreement/open-letter/

Other civil society groups and institutions offer guidance for governance, such as the eponymous Oxford Principles and recommendations by the Union of Concerned Scientists among dozens more.[9] Undoubtedly good governance of this technology, if crafted, will be complex and form a virtually new regime to address the varying technologies – their possible applications and their risks.[10]

The Convention on the prohibition of military or any other hostile use of environmental modification technique (ENMOD Convention) has unparallel potential to be a centerpiece in this emerging regime. Crafted amid the Cold War in response to the United States use of weather modification technology in southeast Asia with the intent to provide a military advantage, the ENMOD Convention explicitly aims to address tactical military and hostile use of "any technique for changing – through the deliberate manipulation of natural processes – the dynamics, composition or structure of the earth, including its biota, lithosphere, hydrosphere and atmosphere, or of outer space." [11] This could readily apply to SRM technology available today and in the near future. Perhaps most critically, concerns are brought to the UN Security Council where compliance mechanisms are available.

Common to UN Treaties, consideration for a review of the Convention at regular intervals is embedded in the text. Such consideration requires support by at least ten States which is, realistically, more likely to occur with support from a handful of influential government, the UN Secretary General and President of the General Assembly, and public pressure. Support from leaders of other UN bodies could also help however is unlikely given the conflict of interest as some UN bodies are currently vying for their own governance authority. An opportunity is ripe however for the ENMOD Convention to be reviewed, revisited and updated – and this is urgent given the risks at hand.

Addition complimentary policies are also available to fill gaps as this security regime is fleshed out.

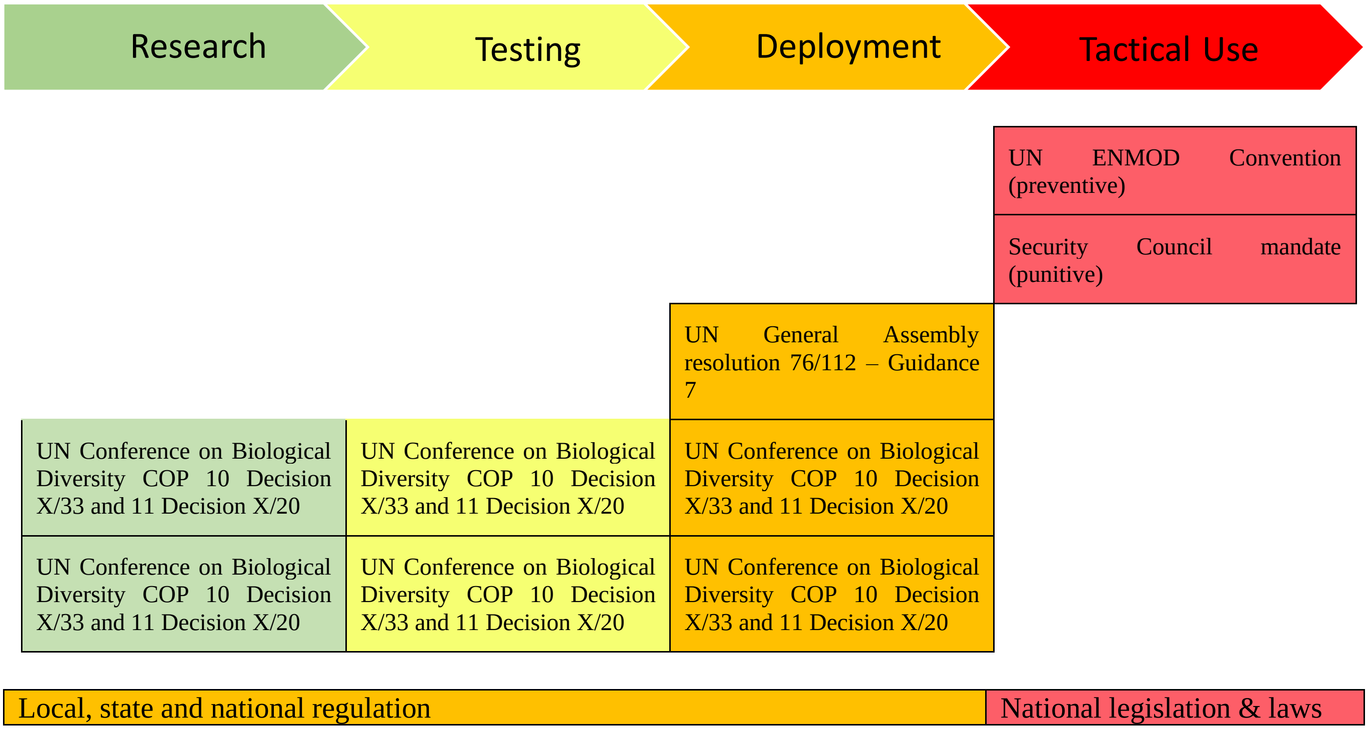
International humanitarian and human rights laws such as UN Security Council Resolution 2417 (2018), which aims to address food insecurity due to armed conflict, has some potential – albeit limited – to address impacts to food systems by SRM.[12] As it currently stands, the resolution focused on humanitarian needs and access to relief without any reference to climate or geo-engineering. But as these impacts unfurl, the Resolution could potentially be reviewed and updated to address related risks due to SRM.

An even less direct route towards SRM governance is the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). It has nonetheless been proposed as a template for reconstructing a similar treaty with the aim to monitor and step down production of geo-engineering technology.[13] However valuable the outcome would be, doing so would take precious time, face tall hurdles to pass in the Security Council, and face even taller hurdles to be implemented. If successful, however, such a treaty would certainly contribute to mitigating security risks.

[9] Oxford Principles. http://www.geoengineering.ox.ac.uk/www.geoengineering.ox.ac.uk/oxford-principles/principles/; and Solar-Geoengineering-022019.pdf and UCS Strengthening Public Input on Solar Geoengineering Research
[10] Good governance aims to reflects cross-cutting governance principles of transparency, participation, and accountability among others.
[11] United Nation Convention on the prohibition of military or any other hostile use of environmental modification technique https://treaties.un.org/Pages/ViewDetails.aspx?src=IND&mtdsg_no=XXVI-1&chapter=26&clang=_en
[12] United Nations Security Council Resolution 2417 (2018), Articles 5, 6 and 9. https://digitallibrary.un.org/record/1627380?ln=en
[13] Council on Foreign Relations. *An Internationalism that Protects: Why We Need to Reboot the Baruch Plan for Geoengineering.* https://www.cfr.org/blog/internationalism-protects-why-we-need-reboot-baruch-plan-geoengineering

Other policy tools, while invaluable on their own, present unfortunate loopholes and misplaced expectations as they relate to security. The UN Framework Convention on Climate Change (UNFCCC) is dedicated to greenhouse gas emissions reductions and adaptation, lacks a security mandate, and lacks a compliance mechanism. The UN Environment Assembly has virtually identical limits. The UN Biodiversity Convention (CBD) aims to limit the impact of geo-engineering activities "that may affect biodiversity". However activities where activities fall outside of impacting biodiversity, the CBD decisions do not apply. And the Intergovernmental Panel on Climate Change (IPCC), while indispensable on providing climate science is by no means the place to hammer out international governance on security. Figure 2 illustrates how the scope of some of these mechanisms falls short of addressing the security challenge.

Fig. 2
The reach of potential SRM governance



Source: Tracy Raczek

Reach of Governance: International policies aimed to guide research, testing, deployment and tactical use of SRM technology are listed underneath the stages that they address. None of the policies related to the scaling-up of SRM technology – research, testing, deployment – are suited to govern their tactical use by military or with hostile intent. Policies most suited to do so are underdeveloped or under-utilized and thus depicted in faded red. Similarly, local and subnational policies that aim to guide research, testing, and deployment are not appropriate to govern tactical military or hostile use, which falls under national control and also remains weak.

Governance is, almost invariably, one step behind technology. SRM governance could be an exception however, if the opportunity is seized. Currently there is political momentum behind meeting the climate challenge; lessons are retrievable from processes that have hammered out a climate agreement; attention, time, and peace – perhaps unavailable once this technology is fully unleashed – is available now; financial interests that can skew political positions are at their lowest. And equally important, the ENMOD Convention – dedicated to the challenge at hand – is up for review. Even though certainty of SRM remains unclear, negotiations should begin on ENMOD. This is one of the few times it is imperative to put the cart before the horse.

__Tracy Raczek__ is a climate and sustainability policy and partnership expert. She served as a climate advisor to United Nations Secretary-General Ban Ki-moon in lead up to the Paris Climate Accord as well as to two Presidents of the UN General Assembly, and currently advises global companies and civil society to identify and deliver robust climate and sustainability goals.

Geoengineering From a Geo- and Environmental Scientist's Point of View

M H Stephenson, Director, Stephenson Geoscience Consulting Ltd.

'Geo-engineering' or 'climate engineering' means engineering man-made solutions to upcoming climate and other environmental problems. In the terms of classical earth system science, geo-engineering is the creation of measured and calibrated interventions that slow down or stop harmful environmental and climate changes. There are a whole host of ideas for interventions, some more practical than others, and climate geo-engineering is broadly divided into two types: management of the amount of solar radiation reaching the ground, and removal of carbon dioxide from the atmosphere. In this short article I don't propose or advocate any particular geo-engineering solution – but what I do advocate is sound and rigorous earth system science that allows us to understand the earth system so that we design the very best interventions. Scientists, policymakers and regulators have done this before - for example in the development of solutions to the atmospheric ozone hole - but for more and better geoengineering interventions we will need more environmental measurement and more and better computer modelling and simulation of the earth system.

Main methods of climate geo-engineering

I mentioned that there are two broad classes of geo-engineering. In the first, solar radiation management techniques aim to diminish sunlight absorbed by the atmosphere and ground by deflecting it away, or by increasing the albedo of the atmosphere or the Earth's surface. These techniques would not reduce greenhouse gas concentrations in the atmosphere, and so would not reduce ocean acidification, for example. Some proposed methods include installing reflective roofs on buildings or increasing the cultivation of crops that give the ground a high albedo, increasing the reflectivity of clouds using sea spray, and spreading reflective aerosols in the atmosphere.

In the second category greenhouse gases, mainly CO2, are removed from the atmosphere via an agent (like newly planted trees) or by chemical or physical means. Examples include the manufacture of inert stable carbon, known as biochar, which can be mixed with soil; afforestation and reforestation; and ocean fertilisation to increase carbon drawdown. Some technologists might regard carbon capture and storage, and bio-energy with carbon capture and storage (BECCS), as geo-engineering.

Earth system science basis of geo-engineering

In the broadest terms we have to understand global biogeochemical cycles. Perhaps most important is the carbon cycle which controls the sources and sinks of carbon across the globe, from sequestration due to photosynthesis, to emissions due to land use change, to emissions due to fossil fuels, to name but a few. Understanding these cycles requires measurement and modelling – frequently measuring things that are difficult to measure. This along with computer modelling and simulations helps to understand how the environment might be changing when things have gone wrong, so that we can design our intervention – which could be a geo-engineering solution – to fix the problem. Once the intervention is in place, we can monitor its effectiveness, as it acts, using our measuring and monitoring system, and our models.

This process can be summarised most simply in a flow diagram. In this diagram (Fig. 1), human activities cause earth system consequences, which are monitored and measured and then understood; then interventions can be designed which become part of general human activities. This is sometimes known as a teleological feedback system.

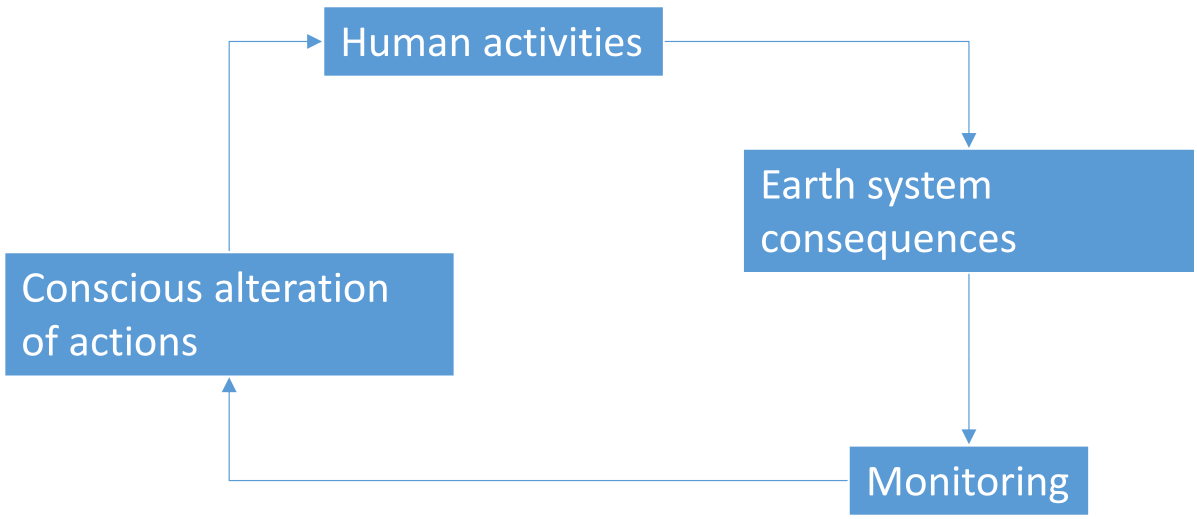


Fig. 1. A teleological feedback in the earth system. Human activities produce changes in the Earth system, these are detected and measured, and conscious changes to activities are then made (Stephenson, 2018)

A well-known example of a successful operation of a system like this was action to stop the growth of the atmospheric ozone hole. The hole above the Antarctic was first reported in a scientific paper in the journal *Nature* by scientists from the British Antarctic Survey following sophisticated measurement and analysis. An understanding of atmospheric physics and modelling and simulation using measurements made, meant that it was possible to determine that the hole (and other smaller ozone holes in other locations) was generated due to reactions in the stratosphere between ozone and halogens, mainly from photodissociation of man-made refrigerants, solvents, propellants, and foam-blowing agents such as chlorofluorocarbons (CFCs), freons and halons.

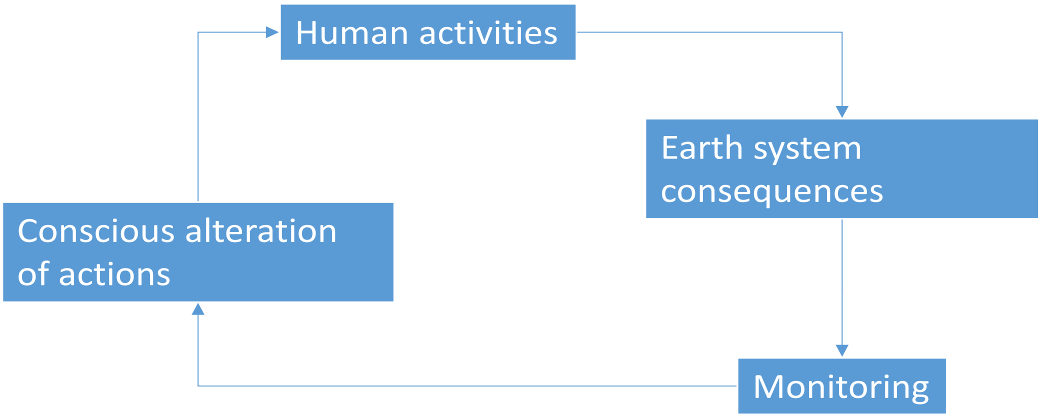
Action following the discovery of ozone depletion was swift. The Montreal Protocol on 'Substances that Deplete the Ozone Layer', agreed in September 1987, is an international treaty designed to protect the ozone layer by phasing out the production of substances that are responsible for ozone depletion. It entered into force on the first of January 1989. The Montreal Protocol has been described by many as a great success, with around 98% of ozone-depleting substances having been phased out (conscious alteration of actions). The ozone holes are smaller than they were, although it may take more than 30 years to return them to a more normal form. The Montreal Protocol also had unprecedented support with signatories from 196 states and the European Union.

But before we celebrate the establishment of these actions we need to realise that detection and intervention through geo-engineering if appropriate, won't always be so easy. We need to be able to measure and model in ever more sophisticated ways – for example monitoring all aspects of the hydrosphere (rivers, sea, lakes), atmosphere, and geosphere (rocks, sediments and soils). This increase in monitoring and measuring has been called the 'concept of the macroscope'. We all know that a microscope helps us to measure small objects, but a macroscope is a system or network of devices that might help us measure and monitor a large object, i.e. the Earth.

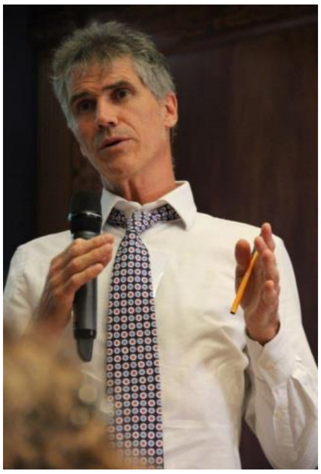
Our interventions can then be calibrated and proportionate, for example largescale carbon capture and geological storage, or alteration of planetary or atmospheric albedo. The intervention can continuously monitored to determine how effective it is.
In this brief summary I've tried to provide a wider background to the basis for geo-engineering. It requires much more than just a bright engineer or geologist with good ideas, because everything we might do to solve a problem can sometimes make a problem worse – if you don't understand the system. So geo-engineering - if we ever choose such solutions in the future - needs to be firmly grounded in science.

Further reading

Stephenson, M.H. 2018. Energy and Climate Change: An Introduction to Geological Controls, Interventions and Mitigations. Elsevier, Amsterdam, 218pp.



Carbon capture and geological storage of CO2 from a power station could be regarded as a geo-engineering solution



***Prof Mike Stephenson** has 25 years' experience in energy and geological science and research, including 8 years national level science leadership as the UK's chief geologist (Executive Chief Scientist and Director of Science and Technology of the British Geological Survey). Mike has been providing geoscience advice to Government for almost 15 years and has an excellent overview of Government policy, industrial activity and funding landscape in applied and energy geoscience, including CCUS, shale gas, geological radioactive waste disposal and geoscience data. Mike also has expertise in positioning organisations in controversial energy topics e.g. CCUS, shale gas and nuclear. Mike was adviser to Sir Mark Walport (when UK Government Chief Scientist) on shale gas and CCUS in 2016; a member UKRI's Energy Strategic Advisory Committee 2020 to 2021; and a Member of the UK Government's Hydrogen Advisory Council 2021. Widely recognised as an excellent scientist, he has over 100 peer-reviewed scientific papers including many on CCUS, and ~200 conference abstracts; in addition he was the Chief Editor of an Elsevier science journal for 12 years.*

His science excellence is recognised in his status as professor at three universities. He is Visiting Professor at the University of Nanjing, China, Karakoram International University, and the University of Milan, Italy. UK Mike is a well-known communicator of science and has published three single-author popular science books. His book on CCUS 'Returning Carbon to Nature' is widely seen as the go-to introductory text on CCUS, and reviews of the book include: 'a tour de force'; 'excellent review of an important topic'; and 'conversational prose that opens the book to nontechnical readers'. Mike has also delivered high profile lectures, for example in UK Parliament, and has been a science advisor for the BBC's 'Horizon' and 'Bang Goes the Theory' program.

It's Adaptation all the Way Down

Daniele Visioni, Department of Earth and Atmospheric Sciences, Cornell University

The debate around "geoengineering" is fraught and complex - and that's easy to tell already by the long discussions people who do research on the topic are ready to have on the term itself. Intergovernmental Panel on Climate Change (IPCC) jargon (to whom we all like falling back to when the need arises) defines geoengineering as "the deliberate modification of Earth's climate". Depending on where you decide the emphasis should be in that phrase you can get yourself to the rhetorical point that everything we do is geoengineering, even driving your car; you know that it emits CO2 and other substances, which you know are bad for the climate, therefore your trip to the grocery store is fundamentally the same as someone dumping mercury in a river (or sulfate in the stratosphere with silly balloons) for profit. Let him who is without sin cast the first stone.

I find it unhelpful to talk about geoengineering without clarifying what the background and motivations are. Global warming driven by an increase in concentrations of long lived greenhouse gasses is a problem, both on its own and as part of the multifaceted challenge of how humans interact and exploit the environment around them (from a Kessler syndrome to nitrogen pollution). These kinds of problems hardly ever cancel each other out, at best don't interact with each other, and at most tend to compound with one another. Their solutions also sometime tend to create new problems (look no further than ozone-depleting substances being replaced with substances with a large global warming potential). Many will argue that such a complex challenge can only be overcome with system-level solutions - overhauling our relationship with the environment, giving up overconsumption (or consumption altogether), rethinking our societal and political structures away from capitalism. Others will argue that our only way out is through - that only technological developement will save us, through a mix of space exploration and expansion, smart resource exploitation and novel technologies.

Likely or unlikely, desirable or not, these discussions are important and yet often miss one fundamental point. Global warming is a real problem now, slowly creeping up and getting worse on us (in a way, too slowly, hence why incentives to reduce emissions are not as strong as they should be) and mainly currently affecting the most vulnerable in the world (both geographically and in terms of economic status) - those who, sadly, have contributed less to the problem in the first place. Reducing emissions as fast as possible is a must to prevent the problem from getting worse. But it is not, in a time frame relevant to humans, a way to restore things to the way they were before. Put it simply: humanity may in the next decades turn around, peak global emissions (they're still growing), bring them to zero at an incredibly fast pace and manage to stay at 2.0ºC above pre-industrial times. That alone will prevent many risks from getting much worse - which is absolutely great, and incredibly crucial - but it won't materially reduce current and short term risks, nor will it protect vulnerable ecosystems and populations at risks from a mix of heatwaves, sea level rise and changes in other extreme events. What else will?

The main answer is, adaptation will reduce many of these risks. Technological transfers and funding programs aimed at reducing inequality and building resilient communities can go a long way towards mitigating suffering[14] and there is no doubt this is what governments should be focus on the most. But adaptation can also go wrong[15] - and the bigger the emergency, the more urgent the need, the higher the risk for the money and the planning to be spent wrongly and result in "maladaptation".

[14] https://www.brookings.edu/blog/the-avenue/2022/07/25/as-extreme-heat-grips-the-globe-access-to-air-conditioning-is-an-urgent-public-health-issue/

[15] https://www.sciencedirect.com/science/article/pii/S2590332220304838

The second answer is, restoring our environment to a previous state by removing greenhouse gasses directly. Many methods have been proposed, from the more benign sounding Afforestation to the more futuristic Direct Air Capture. Each of them is unlikely, alone, to be able to shoulder the unprecedented increase in CO2 concentrations. A synergistic approach that uses them all may potentially help us, over time, making sure we really are a net-zero society, and eventually also reduce concentrations to restore them to previous levels. But, given large uncertainties over both the technological and energy requirements, and the trade-offs in terms of land use necessary, the scalability of these methods up to the point where they could make a difference is not assured - nor is it likely in the first half of this century.

Methods that try to cool the planet by reflecting sunlight away before it reaches the surface (Solar radiation modification, SRM) come in at this point. They do not make sense as a substitute to emission reduction - quite literally, if you keep emitting, warming will continue, and while SRM might "hide" a part of it there are but plenty of robust reasons why it can't hide all of it for ever. The main (but not only) one being, ocean acidification will continue as long as CO2 emissions keep being greater than zero, and SRM does not affect that. Nonetheless, SRM might potentially prevent more warming from happening in a few decades - thereby avoiding some of the risks, while potentially creating some new ones. If the balance of these risks ends up, to the best of our knowledge, leaning towards doing SRM rather than not, doing SRM might end up being the preferable option. While this may sound tautological, it is very much not. If something treats the symptoms without solving the underlying causes, that something might still be worth doing - as long as it doesn't worsen the causes, or as long as it doesn't produce bad outcomes that are worse than the original ones.

This context is often implicit when describing SRM in the context of the 'Napkin diagram', originally described in Long and Shepherd (2014)[16] and then re-adapted numerous times, such as in Fig. 1. Scenarios A and B look identical at the beginning but are fundamentally different as time progresses and, eventually, diverge if SRM is considered as the only way to address warming from CO2. This brings me to my final point, which is: SRM only makes sense if considered through the lenses of *adaptation*, and not through those of mitigation. There is widespread agreement that we can't limitlessly adapt our way out of climate change, as risks can't be assumed to grow at the same steady pace and might eventually overcome our capacity to adapt, especially if considering low-likelihood but high-impact distribution tails. Nonetheless, we need to adapt, and make sure everyone can adapt keeping in mind principles of equity and justice, to reduce suffering. Similarly, we can't limitlessly geoengineer our way out of climate change. Nonetheless, in my view, we will most likely need to do SRM, and make sure we do so in a just way, also to reduce suffering. Adaptation can go wrong - especially if done as an act of last resort, if it ignores the needs of those it's supposed to protect, if badly governed and if its main driver is corporate profit. SRM can go wrong for the same reasons. Just like few would argue against adaptation now (but they have![17]), I expect there is the possibility for a future where protests against SRM will be sparse and it will just be considered "the new normal"[18]. And just in the same way as there are and will be opportunities where short-term thinking and greed have led to bad adaptation outcomes, I expect there is the possibility for a future where SRM might be used as a tool to deepen rather than lessen inequalities.

[16] https://link.springer.com/referenceworkentry/10.1007/978-94-007-5784-4_24

[17] https://www.economist.com/international/2008/09/11/adapt-or-die

[18] On this topic, I suggest the excellent book from Holly Buck "After Geoengineering: Climate Tragedy, Repair, and Restoration" https://www.versobooks.com/products/722-after-geoengineering

The difference between those futures will reside in how "deliberate" we will be with our collective choices, and not with any specific quality of SRM as a tool in itself.

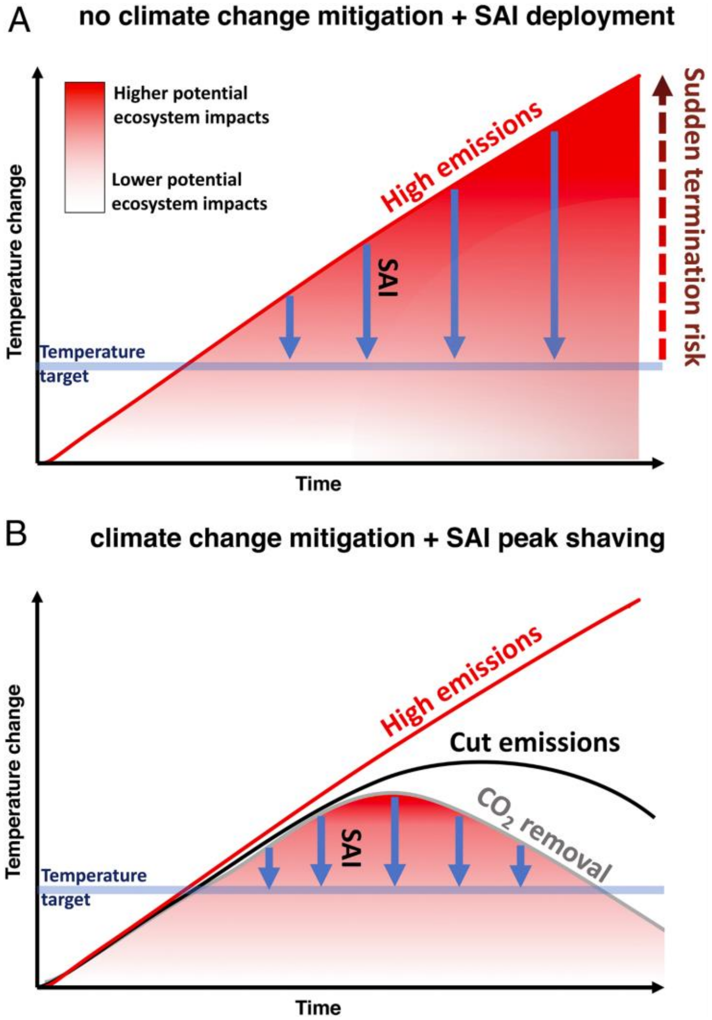


Fig. 1 From Zarnetske et al. (2021)[19], two different ways to consider SRM (here considered as Stratospheric Aerosol Intervention): as a way to completely offset a high emission scenario, with a continuous ramp-up that must go on indefinitely (A), and as a way to complement emission cuts and CDR in order to stay below a temperature target, with a clearer timeframe for wind-down (B). Here temperature change is linked to impacts to ecosystems, but it could be other things (e.g. mortality from heatwaves).

__Daniele Visioni__ is an Assistant Professor at the Department of Earth and Atmospheric Sciences at Cornell University. He obtained his PhD in Atmospheric Physics and Chemistry in Italy in 2018. He is the co-chair of the Geoengineering Model Intercomparison Project (GeoMIP), where he helps with the coordination of climate models simulations of Sunlight Reflection Methods, and their dissemination to the broader scientific community for analyses. His main focus is on the climatic effects of stratospheric aerosols, how they impact stratospheric composition and surface climate: in 2022, he was a co-author of the Scientific Assessment of Ozone Depletion for the World Meteorological Organisation, focusing on the chapter related to the potential effects on the Ozone layer of stratospheric aerosol injections.

[19] https://www.pnas.org/doi/10.1073/pnas.1921854118

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