GOVERNING SOLAR RADIATION MODIFICATION UNDER THE VIENNA CONVENTION

iFOREST
INTERNATIONAL FORUM FOR ENVIRONMENT, SUSTAINABILITY & TECHNOLOGY

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Summary for Stakeholders

Geoengineering refers to a suite of technological interventions aimed at slowing or halting some of the effects of climate change. Two of the major kinds of geoengineering that are at present gaining traction rapidly are Solar Radiation Modification (SRM) and Carbon Dioxide Removal (CDR). SRM approaches focus on deliberately cooling the planet by reflecting a small amount of sunlight to space or by allowing more of Earth's infrared radiation is to escape to space. SRM methods include utilizing mirrors in space to reflect sunlight (Space Based Reflectors), increasing the reflectivity of land or ocean surfaces (surface albedo), increasing the reflectivity of marine clouds (Marine Cloud Brightening), and increasing the reflectivity of the stratospheric aerosol layer via Stratospheric Aerosol Injection or SAI.

SRM, and in particular SAI, is likely to have a host of unintended consequences on planetary systems such as rainfall and weather patterns. Most notably, recent scientific assessments conclude that SAI (and possibly MCB) are likely to have significant impacts on the health of the ozone layer. However, some governments and companies are accelerating towards deployment by conducting empirical research and experimentation, without any global oversight or governance.

This report asserts that SAI research both needs to and can be, effectively governed under the Vienna Convention for the Protection of the Ozone Layer, which has been universally ratified.

- Article 2(1) of the Vienna Convention has a wide scope and covers all human activities which "modify or are likely to modify the ozone layer". This will include SAI as it will likely modify the Ozone layer.
- Article 2.2(a) of the Convention requires parties to "co-operate by means of systematic observations, research and information exchange in order to better understand and assess the effects of human activities on the ozone layer and the effects on human health and the environment from modification of the ozone layer". This will include SAI research and associated activities.
- Article 2.2(c) requires parties to "co-operate in the formulation of agreed measures, procedures and standards", which will extends to procedures and standards for SAI research.
- In Article 3, parties commit to co-operate in, directly or through competent international bodies, the conduct of research and scientific assessments on "climatic effects deriving from any modifications of the ozone layer" and more specifically "substances, practices, processes and activities that may affect the ozone layer, and their cumulative effects". This again will require countries to cooperate directly or through competent international bodies on SAI research.

Conducting SAI research activities, such as outdoor experimentation, without transparently sharing information and clarifying the research's scope and associated risks violates the duty to cooperate as outlined in Article 2.2(a), 2.2(c), and 3. There is, therefore, no ambiguity around the fact that the Vienna Convention is an appropriate convention to govern those SRM that affect the ozone layer, specifically SAI. In fact, the duty to cooperate under the Convention creates a strong basis to create a cooperative framework to manage SAI research.

To effectively govern SAI research under the Vienna Convention, we propose the adoption of a research assessment framework. This framework can be established through existing institutions under the Convention, including the Conference of the Parties, the Ozone Secretariat, the Ozone Research Managers, and the Vienna Convention Trust Fund for Research and Systematic Observation. This framework should incorporate the following key norms:

1. **Information Sharing and Consultation:** Governments must share information and consult with one another when proposing outdoor experiments.

2. **Environmental Impact and Risk Assessment:** Projects should undergo a thorough environmental impact and risk assessment, including the development of risk management plans based on a precautionary approach.
3. **Independent National Regulatory Frameworks:** Countries hosting SRM experiments should establish national regulatory frameworks with independent scientific bodies to oversee research, separate from government agencies funding such research.
4. **Support for Developing Countries:** SRM research in developing countries should be supported through the Trust Fund, focusing on studying adverse transboundary or global impacts and building global scientific capacity in SRM equitably.
5. **International Approval Process:** Develop an international approval process for outdoor research, integrating all the aforementioned norms, under the Vienna Convention.

These norms can be instituted through COP decisions, recommendations of subsidiary bodies and/or operational policies of implementing agencies.

In conclusion, the governance of SRM research, particularly SAI, under the Vienna Convention provides a robust legal framework to address the potential environmental and transboundary impacts of these technologies and should be pursued to ensure responsible and coordinated research in this field.

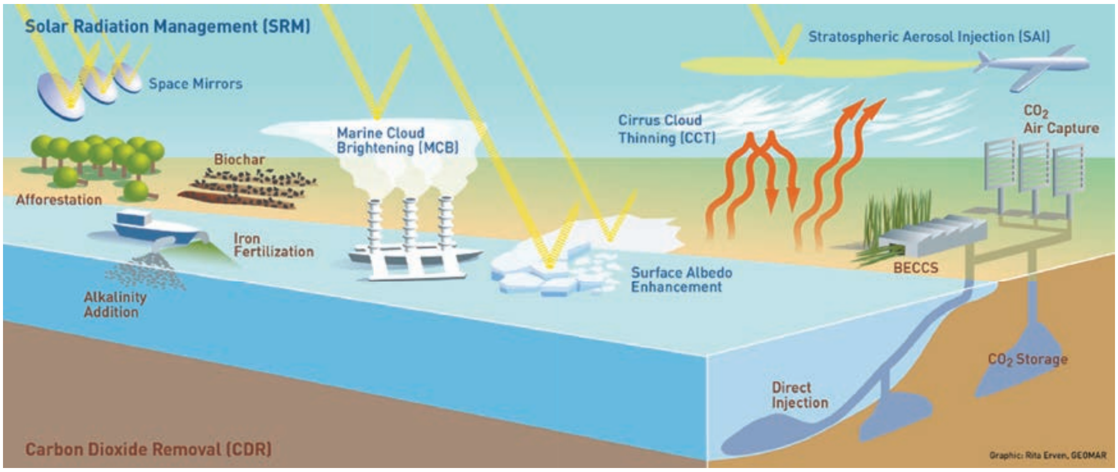
Introduction

Geoengineering, in the context of climate change mitigation, refers to deliberate and large-scale interventions in the Earth's climate system with the aim of slowing or halting the effects of climate change. These interventions are proposed as potential solutions to counteract global warming and some of its associated impacts. Geoengineering can be categorized into two main approaches: Solar Radiation Modification (SRM) and Carbon Dioxide Removal (CDR). This report is focused on the challenge of governing SRM at the international level, specifically those that impact the Ozone layer.

SRM refers to a set of proposed techniques that seek to deliberately cool the planet by reflecting a small amount of sunlight to space or by allowing more of Earth's infrared radiation to escape to space. These methods are intended to counteract global warming by increasing the portion of sunlight that the Earth reflects. SRM is a controversial and potentially risky approach to climate change mitigation. Its implementation raises concerns of ethics, morality, legality, equity, justice, and geopolitics.[1] Some of the main methods of SRM that have been proposed or studied include:

- **Stratospheric Aerosol Injection:** This method involves releasing aerosols, such as sulfur dioxide (SO_2) or calcium carbonate ($CaCO_3$), into the stratosphere. These particles would reflect a portion of sunlight back into space, leading to a cooling effect on the Earth's surface. It is in part inspired by volcanic eruptions, which if large enough, temporarily cool the planet on account of the massive amount of sulfur aerosols they inject into the Stratosphere. It is the most advanced SRM technology and could be deployed in under ten years.[2]
- **Marine Cloud Brightening:** This technique focuses on making marine clouds more reflective by injecting small saltwater droplets into them. This increases their albedo (reflectivity), which can reduce the amount of sunlight absorbed by the oceans and, in turn, cool the planet.
- **Space-Based Reflectors:** This idea involves placing large mirrors or reflective objects in space to intercept and reflect sunlight away from Earth. While technically feasible, it would be extremely costly and logistically challenging.
- **Surface Albedo Modification:** This approach seeks to make natural surfaces, such as deserts or rooftops, more reflective by applying materials that increase their albedo. This would reduce the amount of heat absorbed by the Earth's surface.
- **Cirrus Cloud Thinning:** Cirrus clouds are high-altitude clouds that traps heat. One proposal involves reducing the coverage or thickness of cirrus clouds to allow more longwave radiation to escape into space.
- **Ocean Surface Brightening:** Similarly to marine cloud brightening, this method involves applying substances to the ocean surface to increase its reflectivity and reduce heat absorption.
- **Forest Management:** Promoting afforestation and reforestation can increase the Earth's albedo by replacing dark surfaces with more reflective ones. However, this approach is primarily aimed at carbon sequestration, with albedo modification as a secondary benefit.

Figure 1: Different methods of Geoengineering



Courtesy: Rita Erven, GEOMAR

THE STATE OF SRM RESEARCH

SRM is a rapidly developing field of study because it is the only known approach to cool the planet within a few years. However, it also presents new challenges for international governance and relations since most techniques of SRM are global in their impact, even if developed and implemented by a single nation. Of its numerous techniques, SAI is the most concerning because it targets the Stratosphere –the layer of the atmosphere responsible for complex earth system services such as the generation and maintenance of the Ozone layer. SAI technology is also the most advanced, with some experts suggesting that it could be successfully developed in under a decade3. Worldwide, there are numerous SRM projects at various stages of development; most of these are SAI projects. A list of prominent SRM projects, including SAI, is provided in Annexure 1. The list in Annexure 1 demonstrates many challenges in governing SAI research. For instance, what is the boundary between climate adaptation and geoengineering, the responsibility and liability of the private sector and individual researchers involved in SAI research, and the dividing line between climate research and SRM research, etc? The list also shows that many SAI projects stall due to a lack of clarity on international law as well as the protestations of local communities who fear unintended consequences.

There is currently no single comprehensive international treaty or agreement that specifically addresses SRM research. While there are existing international treaties - such as the Convention on Biological Diversity 1992, the London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972, and the Vienna Convention for the Protection of the Ozone Layer 1985 – that are likely to be relevant to some SRM activities, there are uncertainties regarding whether these treaties can comprehensively regulate all SRM. Further, there is no consensus about whether different agreements would create different or contradictory regulatory standards.

Similarly, there is no international body responsible for overseeing SRM research, resulting in a lack of clear international guidelines on how to conduct such research safely and responsibly. In addition, there are no specific institutional arrangements governing liability and compensation for unintended consequences or damages resulting from or disputes or conflicts arising from SRM research *(see Annexure 2)*.

This report makes the case that (a). there is no need for a single comprehensive international treaty for SRM research, and (b). that SRM research, particularly that which will have an impact on the Ozone layer such as Stratospheric Aerosol Injection, can be regulated by the 1985 Vienna Convention for the Protection of the Ozone Layer, partially through existing obligations under the Convention, and partly by extending those obligations through a negotiation process.

Vienna Convention

Recognizing the Ozone Layer's critical role in shielding the planet from harmful ultraviolet (UV) radiation and the growing impacts of human activities on it, the Vienna Convention for the Protection of the Ozone Layer was adopted in 1985, came into effect in 1988 and reached universal ratification in 2009. It was created with a stated purpose to "protect human health and the environment against adverse effects resulting from modifications of the ozone layer."[3]

The Convention is a framework for cooperation on research, information exchange, national regulation and standard setting. It emphasizes the importance of cooperation in scientific research, scientific assessment and systematic monitoring of the ozone layer. To this end, Article 3 of the Convention requires parties to co-operate in, directly or through competent international bodies, the conduct of research and scientific assessments on (emphasis added):

(a) ***The physical and chemical processes that may affect the ozone layer***;

(b) The human health and other biological effects deriving from any modifications of the ozone layer, particularly those resulting from changes in ultra-violet solar radiation having biological effects (UV-B);

(c) ***Climatic effects deriving from any modifications of the ozone layer***;

(d) Effects deriving from any modifications of the ozone layer and any consequent change in UV-B radiation on natural and synthetic materials useful to mankind;

(e) ***Substances, practices, processes and activities that may affect the ozone layer, and their cumulative effects***;

(f) Alternative substances and technologies; and

(g) ***Related socio-economic matters***.

The Convention paved the way for the subsequent adoption of the Montreal Protocol in 1987, which established legally binding commitments to phase down/out the production and use of ozone-depleting substances. The Montreal Protocol has been proposed elsewhere as the best framework within which to govern SRM globally[4]. This report makes the argument that the Convention itself, independent of the Montreal Protocol, provides an appropriate framework to govern SRM, specifically Stratospheric Aerosol Injection.

SAI and Ozone depletion

Stratospheric Aerosol Injection (SAI) is the most advanced/significant sub-field of Solar Radiation Modification[5]. SAI is the process of introducing tiny, highly reflective particles into the stratosphere, typically by aircraft at altitudes of 20-25 km. Research so far includes theoretical analysis, social studies, climate modeling, and cost assessments. While small outdoor experiments have been proposed to enhance understanding, none have been conducted yet. Continuous SAI could lower global temperatures by 1-5°C, although the technology for large-scale injection doesn't currently exist. Some experts believe SAI technology could be developed in under a decade, with an estimated annual cost of around $ 20 billion per 1°C of cooling[6]; this is a relatively low cost. While SAI has the potential to reduce global mean temperatures, it also has the potential to produce consequences that might have devastating effects on global systems such as weather and the Ozone layer.

The 2022 Scientific Assessment of Ozone Depletion, published by the Scientific Assessment Panel (SAP), a subsidiary body under the Montreal Protocol, includes a chapter on Stratospheric Aerosol Injection, noting that it "produces unintended consequences, including effects on ozone". These effects depend on the specifics of the SAI scenario and SAI injection strategy. The assessment found that "despite the limited number of model studies, some robust impacts of [Stratospheric Aerosol Injection] on ozone have been identified, driven by 1) an increase in aerosol surface area, 2) stratospheric halogen concentrations, and 3) aerosol-induced heating of the stratosphere, which changes both stratospheric ozone chemistry and stratospheric dynamics." Model results available so far-which the SAP emphasizes likely do not cover all risks- indicate that stratospheric aerosol injection rates sufficient to achieve 0.5 °C of global cooling over the period 2020–2040 would result in a reduction of total column ozone close to the minimum values observed between 1990 and 2000[7].

These findings were presented to the Open-Ended Working Group (OEWG) under the Montreal Protocol, which reviews reports of the Assessment Panels and prepares draft decisions for the parties to decide. At the July, 2023 meeting of the OEWG, an author of the SAP report explained that[8]:

> "[I]njection of stratospheric aerosols that caused a meaningful change of global temperatures would almost certainly have a meaningful effect on stratospheric ozone within a year. Such changes had been seen in the case of volcanos causing explosive injections of aerosols into the stratosphere, a good example being the Hunga Tonga volcano, which was expected to increase the Antarctic ozone hole in the current season, although, as mentioned previously, this would not be long-lived. Discussion on the possibilities of conducting stratospheric aerosol injection in order to cool the planet had recently increased. From a scientific perspective, that could be seen as an indication of the urgency of providing the scientific foundation for any decision on whether to conduct climate intervention, and, as the Panel had pointed out in the 2022 assessment, there were substantial uncertainties with regard to the effects on stratospheric ozone, and on the environment more broadly. As more theoretical studies were conducted on the topic, there was increasing detail and comprehension of the potential unintended effects of such climate interventions. A global legal framework was lacking and did not appear imminent, but scientists would welcome the opportunity to carry out a comprehensive international scientific assessment on the topic to support a future legal framework."

There is also evidence to suggest that marine cloud brightening (MCB) -the next most advanced SRM sub-field- has ozone impacts as well[9].

Regime Appropriateness

In the last few years, there has been some discussion and initiative around the need to create a new global framework to regulate all geoengineering. Attempts have been made at international fora, such as the Swiss proposal to the UN Environment Assembly in 2019, to create a new global framework to regulate all geoengineering. It has also been suggested that all SRM, at least, requires more comprehensive international framework (such as a new treaty) and that relying on existing regimes will result in a combination of fragmentation and overlap, reducing clarity and effectiveness[10].

However, as the failure of the Swiss proposal in 2019 showed, a singular, unified framework for all geoengineering is both politically and technically undesirable. Geoengineering includes technologies which evolved from distinct scientific fields such as geology and oceanography rather than climate science (e.g.: CDR and ocean fertilization), some of which are much closer to deployment than SRM (particularly CDR). Their risk and reward profiles are significantly different from SRM. It makes sense for these technologies to be regulated by distinct scientifically/technically appropriate regimes.

The same logic extends to different technically distinct SRM proposals such as SAI, space reflectors and ocean brightening. These technologies intend to intervene in specific areas of the planet and hence have different impact profiles. They, therefore, are being considered under different existing international regimes, such as the Outer Space Treaty and the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention and London Protocol). The fact that several treaties are potentially applicable to SRM is perceived as a problem – termed a "scattered legal landscape" or "ad hocism"[11].

THE FAILURE OF THE 2019 SWISS PROPOSAL AT THE UN ENVIRONMENT ASSEMBLY

At the fourth UN Environment Assembly (UNEA) in 2019, the Swiss delegation proposed a resolution to establish a preliminary governance framework for CDR and SRM response options but encountered opposition on various fronts. It failed for three reasons: the lumping together of different types of geoengineering, the choice of forum, and disagreements over the precautionary principle.

Some countries questioned UNEA's mandate to make governance recommendations, while others worried about the potential for UNEA's activity to weaken existing international efforts under different conventions. Timing disputes arose with the US and Saudi Arabia objecting to the UNEP studying the issue before the release of the IPCC's sixth Assessment Report in 2021–2022. There was also a debate over the terminology, with many objecting to grouping SRM and CDR under 'geoengineering' due to their differing risks and challenges.

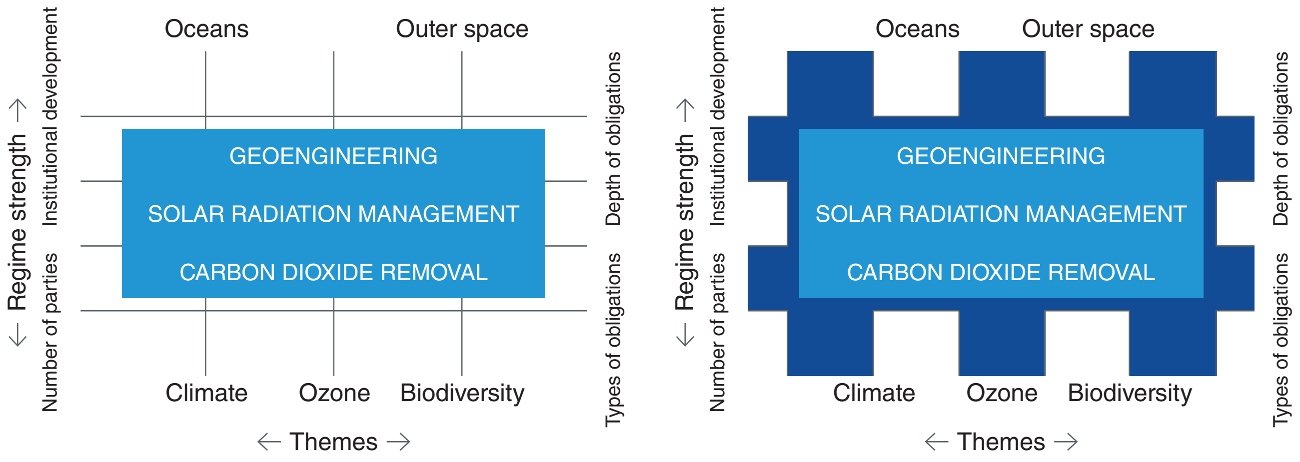
In response to these concerns, a substantially revised version of the resolution was prepared. The revised resolution scaled back UNEP's mandate by removing references to assessments and governance recommendations. Instead, it requested a report compiling information from relevant UN entities and international organizations on SRM and CDR. The term 'geoengineering' was removed, and SRM and CDR were separated, recognizing the involvement of other intergovernmental organizations like the IPCC. However, the revised resolution introduced language emphasizing a "precautionary approach," a reference that ultimately led to the resolution's downfall. This disagreement over precautionary language reflected fundamental differences in interpretations of the state of SRM and CDR governance, with the United States seeking to maintain the status quo, while the European Union and Bolivia perceived existing decisions as imposing a de facto moratorium on these technologies and thus sought to protect against an increase in research.

However, rather than being considered a sub-optimal result, the emerging 'regime complex' governing SRM is recognized as a stable outcome in international governance[12]. In a regime complex, there are multiple international regimes operating simultaneously within a particular issue area. Each regime may focus on a specific aspect of the issue - for example, a regime complex addressing environmental issues might include regimes related to climate change, biodiversity, and ocean governance, among others. Regime complexes involve different sets of international actors, including states, intergovernmental organizations, non-governmental organizations, and multinational corporations. Each regime will have its own set of relevant actors, rules, norms, and principles that guide behavior and cooperation among those involved. When combined into a regime complex, these individual regimes offer a wider scope for regulations and include diverse actors than a single regime is capable of on its own.

Regime complexes result from deep uncertainty around the activities sought to be governed and diversity in the problems posed by different aspects of those activities. While they can lead to fragmentation and conflicts in the governance of global issues, regime complexes offer significant advantages compared to a centralized governance framework in the context of addressing complex global issues.

- They are inherently flexible and adaptable, which is crucial when addressing complex, multifaceted issues where solutions may need to be tailored to specific contexts and problems.
- They allow for experimentation and innovation within individual regimes - different approaches can be tested within specific regimes, and successful practices can be shared and adopted by others.
- Regime complexes also tend toward specialization - each regime within a complex can specialize in a particular aspect of an issue, which allows for the development of issue-specific expertise and tailored solutions within specific domains.
- They are also more inclusive, often involving a diverse set of actors, including states, intergovernmental organizations, NGOs, and private sector entities, which can promote broader participation and representation, ensuring that various perspectives and interests are considered when addressing global issues.

Figure 2: New approach to governance: Thickening the international regime complex



In sum, considering the need for flexibility, inclusiveness and specialization, a regime complex is an appropriate governance approach and could bring results more rapidly than an omnibus regime. The Montreal Protocol, considered to be the most successful environmental treaty, is itself a classic example of a flexible, inclusive and specialized treaty. The key is effective management - addressing the challenges of coordination, coherence, and conflict resolution among the various regimes and their actors. While this does not require identical standards across different treaties, they can usefully borrow from each other to thicken the lattice of international governance. As things stand, several regimes are applicable to SRM, but gaps remain in individual regimes. As we discuss in the next section, by porting norms across regimes, the coverage and coherence of the regime complex to govern SRM as a whole can be made extremely robust.

The Regime Complex in SRM

Regulation of SRM research has been addressed under multiple global conventions and protocols.

Convention on Biological Diversity (1992)

The Conference of Parties to the Convention on Biological Diversity agreed in 2010 that:

> no climate-related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, with the exception of small scale scientific research studies that would be conducted in a controlled setting in accordance with Article 3 of the Convention[13], and **only if they are justified by the need to gather specific scientific data and are subject to a thorough prior assessment of the potential impacts on the environment**[14] [emphasis added]

This is strong and comprehensive language. Unfortunately, its utility is diluted by the fact that the United States – the jurisdiction responsible for many geoengineering attempts – is not a party to the CBD.

London Convention and Protocol on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1972)

The United States is party to the London Convention of 1972. In 2008, parties to that treaty resolved that ocean fertilization activities, other than for purposes of legitimate scientific research, should be considered contrary to its aims. They also called for the development of an ocean fertilization assessment framework to assess scientific research proposals on a case-by-case basis[15]. An Assessment Framework was adopted in a subsequent 2010 resolution[16].

The London Protocol of 1996 is intended to be a successor treaty to the London Convention. It places higher emphasis than the Convention on precaution and anticipatory pollution prevention, prohibiting all wastes that are not explicitly placed in a “reverse list”. However, its membership (53 countries) is not as wide as the Convention (87 countries) and does not include the United States[17]. In 2013, parties to the Protocol unanimously amended it to allow for the regulation of marine geoengineering more broadly, beyond ocean fertilization activities. The amending resolution includes the creation of a new reverse list for activities considered marine geoengineering and an assessment framework to guide the addition of activities to it[18]. This resolution provides an illustration of how regimes can usefully borrow from each other - as part of the justification for its precautionary approach, it quotes the conclusion of COP11 to the CBD that “there is no single geoengineering approach that currently meets basic criteria for effectiveness, safety and affordability”.

Table 1: Regime Complex in SRM

	Scope	Rule Strength	Membership
Convention on Biodiversity 1992	Broad	Strong – 2010 resolution banning all geoengineering with narrow research exception	Does not include the US
London Convention 1972	Moderately broad –ocean pollution or research	Moderately strong – prohibits ocean fertilization except for research approved under an assessment framework	87 countries; US, several EU states and China are parties; India is not a party
London Protocol 1996	Moderately broad –ocean pollution or research	Strong – creates a 'negative' list to govern marine geoengineering	53 countries, US not a party
Outer Space Treaty 1967	Narrow; could govern space reflectors	None at present	114 including all major spacefaring nations
Vienna Convention on for the Protection of the Ozone Layer 1985 and Montreal Protocol of 1987	Moderately broad – all activities affecting the ozone layer	None at present	198 (universal)

These regimes illustrate some variations in approach to regulating SRM. The most stringent is the precautionary approach prohibiting all activities – including research – unless expressly authorized. The second approach is to create a general prohibition on geoengineering, with an exception for "legitimate limited-scale research" and a procedure to establish what constitutes legitimate research. The key question regarding the second approach is – what is the legitimacy of research activities which are initiated but have not been established as "legitimate" through the treaty process? The 2008 resolution under the London Convention offers one approach example to squaring this circle, with the provision that "until specific guidance is available, Contracting Parties should be urged to use utmost caution and the 'best available guidance' to evaluate the scientific research proposals to ensure protection of the marine environment consistent with the Convention and Protocol."[19]

Given that the CBD does not include the United States, that the London Protocol is limited to marine geoengineering, and outer space treaty could govern technologies like space-based reflectors, using the Vienna Convention would fill a critical gap in global SRM governance. This is of SAI and other ozone-affecting SRM.

Vienna Convention and the governance of SAI

Article 2(1) of the Vienna Convention has a wide scope and covers all human activities which "modify or are likely to modify the ozone layer".

Article 2.2(a) of the Convention requires parties to "co-operate by means of systematic observations, research and information exchange in order to better understand and assess the effects of human activities on the ozone layer and the effects on human health and the environment from modification of the ozone layer".

Article 2.2(c) requires parties to "co-operate in the formulation of agreed measures, procedures and standards", which extends in principle to procedures and standards for research. In Article 3, parties commit to co-operate in, directly or through competent international bodies, the conduct of research and scientific assessments on "climatic effects deriving from any modifications of the ozone layer" and more specifically "substances, practices, processes and activities that may affect the ozone layer, and their cumulative effects".

These provisions are elaborated on in Annex I. Parties recognize that major scientific issues requiring cooperation are

i. Modification of the ozone layer which would result in a change in the amount of solar ultra-violet radiation having biological effects (UV-B) that reaches the Earth's surface

ii. Modification of the vertical distribution of ozone, which could change the temperature structure of the atmosphere and the potential consequences for weather and climate. **The word modification is wide enough to include "deliberate modification", such as through SRM research and deployment**.

The duty to cooperate is a recognized principle of international law with a long history obligating a source state to notify and consult a State potentially affected by a proposed activity. It is complementary to the duty to prevent transboundary harm laid out in Article 2[20] of the Vienna Convention and in many other international agreements. The duty to cooperate is somewhat weaker than the duty to prevent transboundary harm, in that it does not give a state a veto over activities in another state. However, the duty to cooperate is still strong enough because it does not require a high probability that harm will occur, and because states are required to notify and consult other states even if they believe that no harm will result or are taking reasonable steps to avoid harm.

Undertaking SRM research activities without making the scope of and risks associated with the research clear to other states is contrary to the duty to cooperate in various articles of the Convention. There is, therefore, no ambiguity around the fact that the Vienna Convention is an appropriate convention to govern those SRM that affect the ozone layer, specifically SAI. In fact, the duty to cooperate under the Convention creates a strong basis to create a cooperative framework to manage SAI research.

To further strengthen the regime appropriateness of the Vienna Convention, Annex 1 of the Convention, especially the list of chemical substance thought to have the potential to modify the chemical and physical properties of the ozone layer can be expanded to include:

(f). Sulphur and calcium aerosols or any other substances deliberately introduced to alter the composition of stratosphere, temporarily or permanently, for solar radiation modification.

VIENNA CONVENTION OR MONTREAL PROTOCOL

It has been suggested that the most promising regulatory approach is already present within the Montreal Protocol to the Vienna Convention. The difficulty is that the Protocol is designed to phase down controlled substances to levels considered safe, rather than preventing introduction of a new substance. And, a "controlled substance" is defined as one that is emitted during production and consumption and expressly included within a list annexed to the Protocol. In SAI, the aerosols are not being emitted during production and consumption, rather they are being deliberately injected in the stratosphere.

A more fundamental problem is that SRM activities are currently at the research stage. So, it is difficult to set a defined 'schedule' for phasing down of research inputs. Instead, a precautionary approach that regulates outdoor research is preferable.

Proposed Governance Framework under the Vienna Convention

There are three distinct SAI activities that requires some form of international governance[21]:

- Indoor research such as theoretical analyses, estimates of SAI effectiveness and costs, climate model simulations of SAI approaches, assessments of the impacts of SAI approaches, model evaluation using volcanic and ship-track analogies, laboratory studies of potential injection materials and their reactivities, injector development and social science and humanities research.
- Outdoor experiments refer to field experiments conducted outdoors to study SAI climate processes such as aerosol microphysics, chemistry, aerosol-cloud interaction and transport. Several groups have proposed small-scale outdoor field experiments, but no such experiments have yet been reported in the peer-reviewed literature.
- Large-scale operational SAI deployment refers to the implementation of SAI at spatial and temporal scales large enough to have an observable cooling influence on the Earth. These deployments would be of a planetary scale, last for many years and produce a detectable climate effect. Because of the internal variability in the climate system, an SRM experiment (testing) of this scale cannot always be differentiated from an actual deployment – the near-term climate response to an SAI experiment (testing) and initial deployment would be the same.

The proposed framework, discussed below, is for indoor research and outdoor experiments, whether small-scale or large-scale.

Governance of indoor research

Indoor research doesn't require any formal regulation process. What it requires is norms, guidelines and codes of conduct for research and sharing information, which can be followed by countries/researchers worldwide. Sharing information on research outcomes would be the key component in indoor research to have a globally inclusive conversation around the risks and benefits of SAI.

Governance of Outdoor experiments

The independent expert review on SRM research and deployment, commissioned by UN Environment concluded that "governance of SRM indoor research, small-scale outdoor experiments and large-scale operational deployment should be differentiated." The difficulty is in differentiating between small-scale outdoor experiments and large-scale deployment – the expert review suggested that 'intent' is the "key distinguishing feature"[22]. Intent, however, is a state of mind and very difficult to objectively evaluate. It is generally used as a legal standard only when criminal activity is alleged. Building a cooperative framework to prevent the unintended consequences of outdoor experiments around the principle of intent does not seem feasible. What is required is a comprehensive framework for all outdoor experiments – big or small.

The outdoor experiments would require norms, guidelines, codes of conduct and best practices for research, which can be developed under the Vienna Convention. Most important is a National and International framework for oversight. We thus propose a governance framework for all outdoor experiments that would require

i. **Information Sharing and Consultation**

ii. **Structured Environmental Impact and Risk Assessment**

iii. **National oversight**

iv. **An International Approval Process.**

i. Information Sharing and Consultation

It is the bedrock of the Vienna Convention. It includes dimensions such as transparency between researchers, governments the scientific community in general and the public. It also accounts for associated principles such as ease of access to information, targeting of information, reliability and public participation[23]. An important aspect of transparency is the trigger point, i.e., when must information be shared? While maximum sharing of information at all stages of research is desirable, a reasonable trigger could be the point at which outdoor experiments are being planned.

An associated norm would be a requirement to consult with other states that may be affected by such experiments. In principle, because of the nature of proposed SAI solutions, this would include all parties to the Convention. The Outer Space Treaty, for example, provides that experiments that "would cause potentially harmful interference with activities of other States" are subject to prior appropriate international consultation[24]. The language in the Assessment Framework under the London Protocol[25] could be a useful basis for a similar principle under the Vienna Convention:

> "Where the [proposed activity] […] may have any effect in any area of the sea in which another State is entitled to exercise jurisdiction or in any area of the sea beyond the jurisdiction of any State, potentially affected countries and relevant regional intergovernmental agreements and arrangements should be identified and notified and a plan should be developed for ongoing consultations on the potential impacts, and to encourage scientific cooperation."

That framework also requires countries to encourage researchers proposing SRM experiments to initiate early consultations with stakeholders so that they can address any issues prior to submitting proposals for approval.

Information sharing could also include a multi-dimensional periodic scientific review under the Vienna Convention. Periodic scientific review, including both the natural and social sciences, is important for guiding future research and for covering the widest possible range of stakeholders in SAI governance.

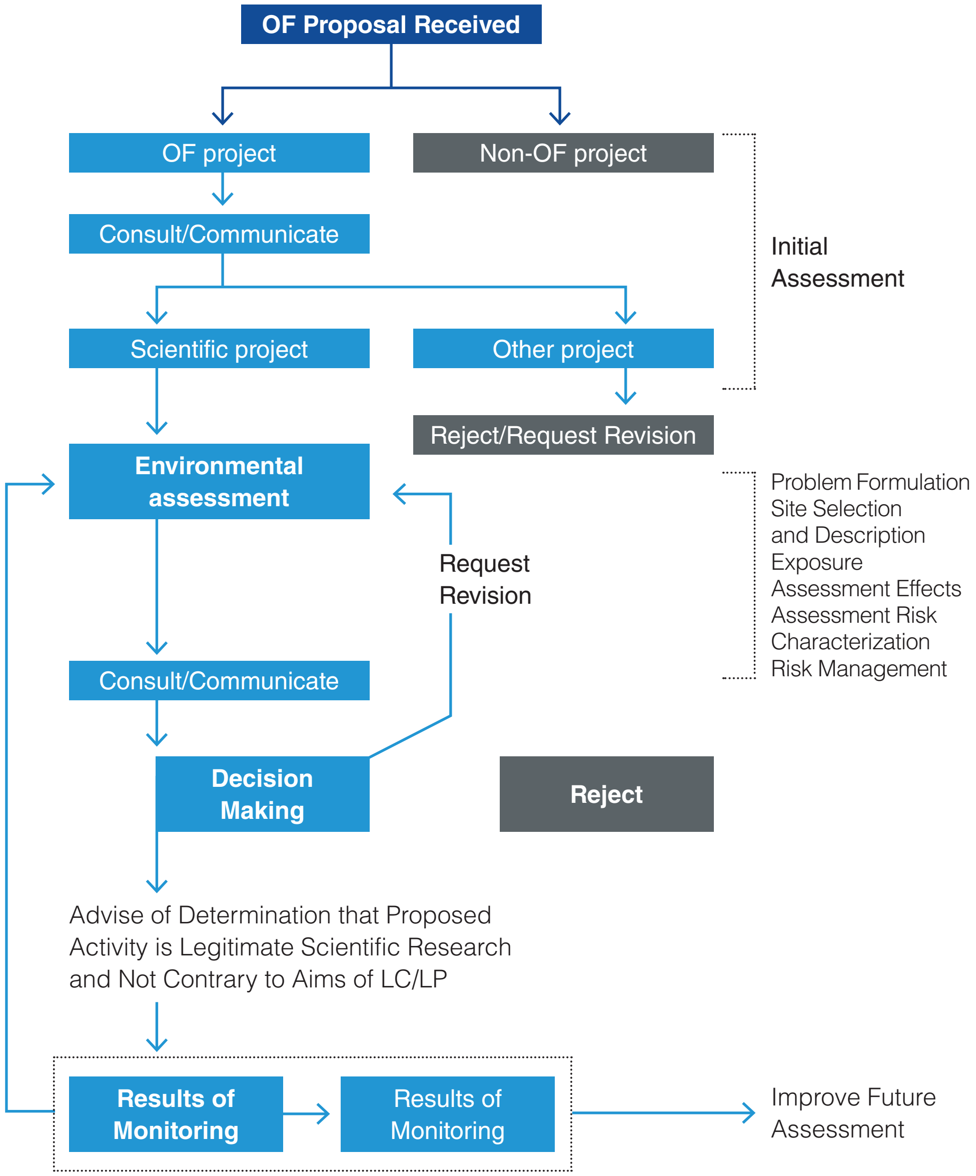
ii. Environment Impact and Risk Assessment

Any assessment of outdoor SAI experiment must be built around Environment Impact and Risk Assessment. The duty to conduct an Environmental Impact Assessment is a recognized principle of international law, with the norm now expanding to include climate impacts[26]. The Assessment Framework under the London Convention *(see Figure 3)* fleshes out this duty, including the following elements, which can be usefully applied through the Vienna Convention to govern SRM:

- **Problem Formulation** describing the proposed activity and setting the bounds for the assessment carried out in subsequent steps;
- **Site Selection and Description** outlining the criteria used for site selection and data necessary for describing the physical, geological, chemical, and biological conditions at the site proposed for the experiment;
- **Exposure Assessment** describing the movement and fate of added/redistributed substances within the marine environment;
- **Effects Assessment** assembling the information necessary to describe the response of the marine environment resulting from ocean fertilization (or SRM) activities, taking into account short- and long-term effects;
- **Risk Characterization** integrating information on exposure and effects to provide an estimate of the likelihood for adverse impacts and the magnitude of those impacts, including a description of the uncertainties associated with its conclusions; and
- **Risk Management**, a structured process based on a precautionary approach designed to minimize and manage risk and implement appropriate monitoring and intervention and remediation strategies, including mitigation and contingency planning.

To these, it would be useful to add a requirement to document categories of risks that are known but currently unquantifiable. It would also be useful to add a requirement to conduct an assessment of the balance of risk and reward in conducting the experiment.

Figure 3: Assessment Framework for Scientific research involving Ocean Fertilization under the London Convention that can be ported into the Vienna Convention



Source: https://cdrlaw.org/wp-content/uploads/2020/04/OF-Assessment-Framework.pdf

iii. Independent national scientific oversight

The Assessment Framework under the London Convention lays down a requirement to establish a research project as legitimate scientific endeavor. But the proposed activity should be designed to answer questions that will add to the body of scientific knowledge. Hence proposals are required to state their rationale, research goals, scientific hypotheses and methods, scale, timings and locations with clear justification for why the expected outcomes cannot reasonably be achieved by other methods. Economic interests are not to influence the design, conduct and/or outcomes of the proposed activity. There should not be any financial and/or economic gain arising directly from the experiment or its outcomes. The proposed activity is supposed to go through scientific peer review with the review methodology and outcomes made publicly available.

Independent scientific assessment has been useful in the past in slowing down geoengineering research pending wider consultation. For example, in 2021, the scientific advisory committee for a Harvard University geoengineering research project recommended that the team suspend plans for its first balloon flight in Sweden[27]. In terms of government oversight, despite the US government allocating increasing amounts of funds toward SRM research, a research oversight structure is lacking. It is unclear whether government agencies such as the National Science Foundation are meant to be research supporters or watchdogs[28]. Hence, we propose that a key norm to govern outdoor SAI experiment should be independent research oversight at the national level, ideally through the creation or designation of a regulator with a distinct mandate from agencies responsible for funding research. In the absence of a national framework in line with this norm, outdoor SAI experiment should be presumed to be unsafe.

iv. International approval process

As SAI is likely to affect all countries, it is important to develop an international process for approval of outdoor experiments under the Vienna Convention. This process could build upon national oversight as shown in Figure 4.

Figure 4: Proposed governance framework for outdoor experiment

Norms to govern SAI research -drawing from similar norms established under other regimes- should be implemented through a COP decision clarifying the substantive content of Article 3 of the Convention as it relates to SRM that affects the ozone layer. The key norms that should be established through this route are:

a) agreeing upon triggers for information sharing and consultation;

b) enforcing a duty to conduct an environment and risk assessment;

c) independent national research oversight; and

d) the international approval process of the Vienna Convention.

Institutional framework

The institutional framework for governing SAI research does not need to be created from scratch. It can build on existing institutions available under the Vienna Convention.

Scientific Institutions

The main institution is the Ozone Research Managers (ORM), a scientific forum comprised of government identified atmospheric research managers and scientists who specialize in research related to ozone modifications.[29] Reports from their meetings include recommendations for future research and co-operation between parties, which are presented at the Conference of the Parties to the Convention for its consideration. At the July 2021 meeting of the ORM, key recommended research needs included "climate intervention (aka geoengineering) proposals"[30]. The ORM, therefore, could be rebooted as the key institution for the governance of SAI research, including developing guidance and framework for the conduct of SRM research in a safe and ethical manner, developing the assessment framework and framework for Environmental Impact and Risk Assessment and developing a sub-platform for international approval process.

Two complementary institutions are the Scientific Assessment Panel (SAP), which assesses the status of the depletion of the ozone layer and relevant atmospheric science issues and the Environmental Effects Assessment Panel (EEAP), which assesses the various effects of ozone layer depletion. They publish reports every three or four years.

The SAP and EEAP are institutions under the Montreal Protocol, however, nothing prevents it from undertaking collaborative scientific studies, developing guidelines and best practices and supporting ORM in general. SAP and EEAP can also be the platform to host a multi-dimensional periodic scientific review of SAI research.

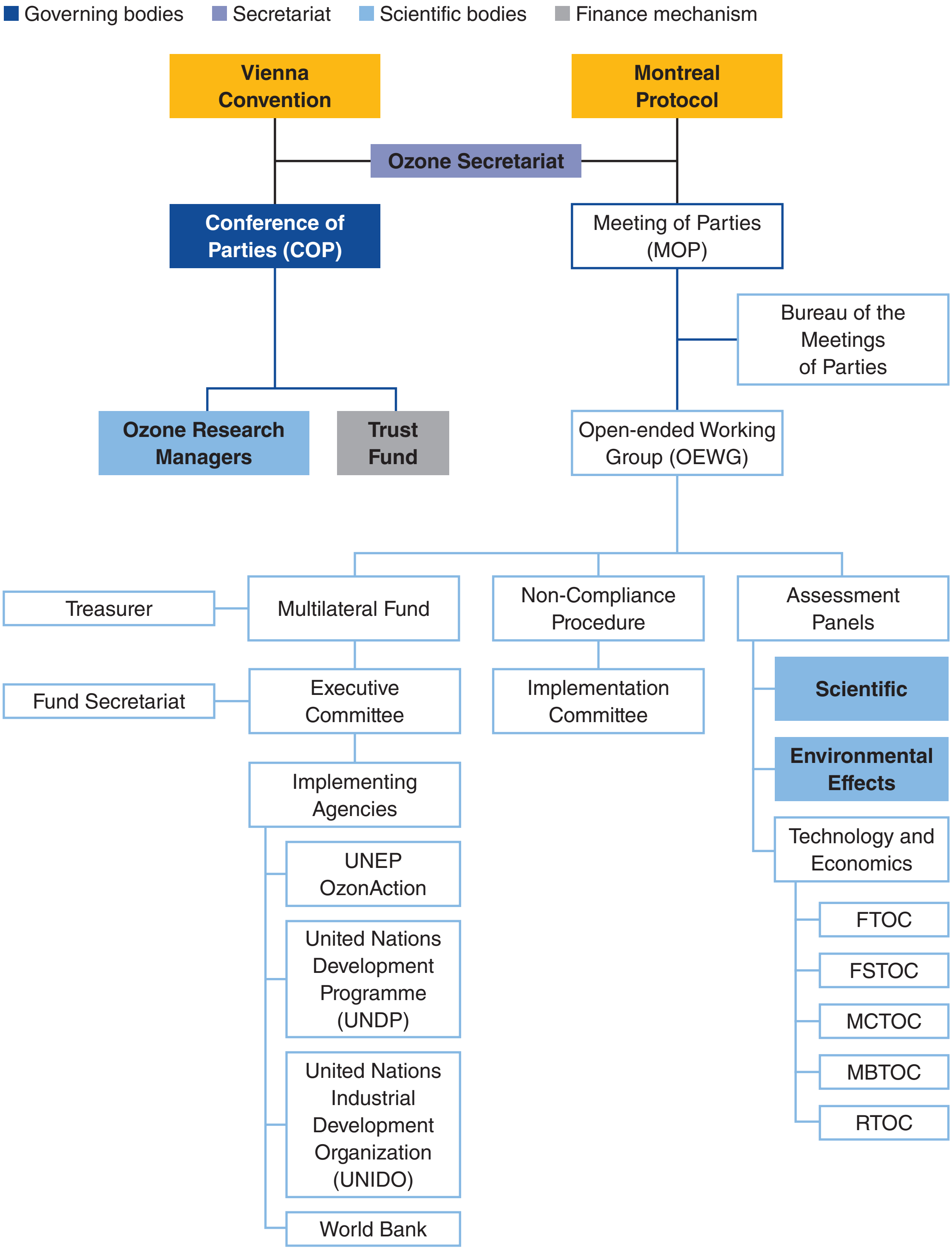
Financial Mechanism

The Vienna Convention Trust Fund for Research and Systematic Observation could be rebooted as the financial mechanism for supporting SRM research governance. The trust fund supports national and international research and monitoring activities in developing countries and countries with economies in transition. The scope of the trust fund can be expanded to include governance of SRM research and also used to support research to assess the impact of interventions like SAI on developing countries.

Administrative Mechanism

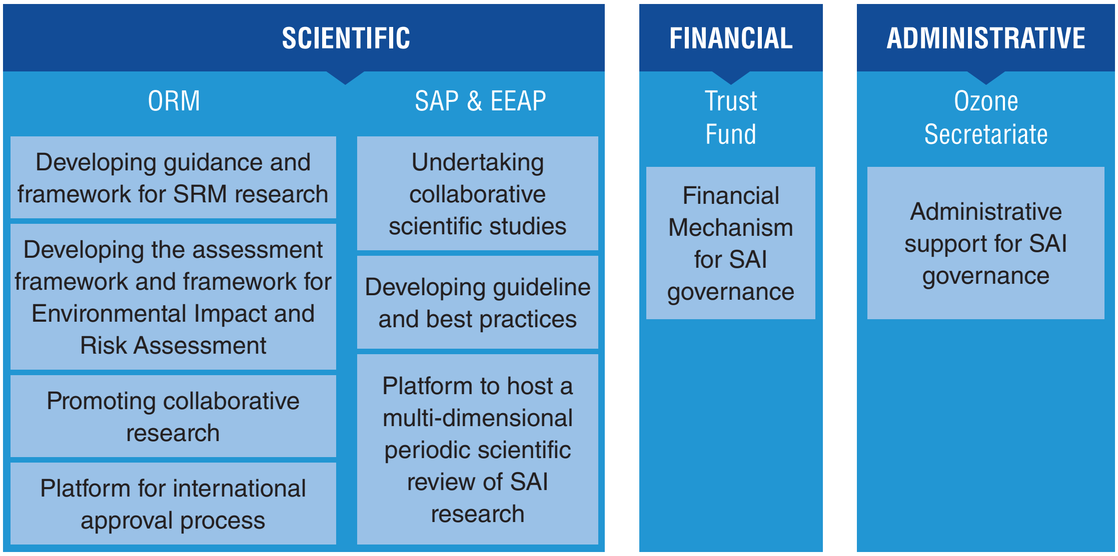
The Ozone Secretariate that is mandated by the Vienna Convention and the Montreal Protocol could be rebooted and given the additional responsibility of SAI governance.

Figure 5: Rebooting Existing Institutional Framework under the Vienna Convention and Montreal Protocol for SAI research governance



Source: Adapted from Ozone Secretariat

Figure 6: Proposed institutional framework for SAI and other ozone-impacting SRM research governance



Recommendations

Not so long ago, Solar Radiation Modification (SRM) was perceived as an impractical technology confined to the labs and researched by a handful of scientists. It then transitioned into a potential "emergency" solution to counteract drastic temperature rises. Currently, it is being discussed as a partial or complete substitute to the mitigation of GHG emissions, with some scientists advocating for its use alongside other GHG mitigation strategies. The swift advancement of this relatively uncharted technology warrants greater scrutiny and caution.

However, these concerns should not hinder the pursuit of rigorous research, including outdoor experiments, aiming to uncover both the benefits and drawbacks of SRM. Without such investigations, we risk resorting to these technologies blindly, unaware of their potential fallout. However, given the uncertainties, the potential for cross-border effects, and the ethical dilemmas SRM presents, it is imperative that any experimental undertakings are subjected to stringent oversight. To this end, we make the following recommendations:

Recommendation 1: SRM research must be governed at the global level with precautionary principles and public interest at its core

With increasing attention and funding dedicated to SRM research, including plans for outdoor experiments, it is clear that the implications are global, not just limited to the territories where research is being planned. The international nature of the potential risks mandates international governance. While the initial governance structures are emerging, the coming years are pivotal to ensure that research proceeds with caution, transparency and democratic oversight, with global public interest in mind—especially regarding the impacts on vulnerable populations and ecosystems.

Recommendation 2: Strengthen and utilize existing international treaties for SRM research governance instead of creating a new treaty.

The question of whether a new international treaty is required to regulate SRM research is crucial. We argue against the need for a new treaty because the basic architecture to regulate SRM already exists in multiple treaties. Also, pushing for a new treaty risks expending valuable political capital that could be better used in strengthening the existing architecture. We, therefore, propose to strengthen and utilize the existing frameworks in place in multiple treaties, such as the Convention on Biodiversity, the London Convention and Protocol on Marine Pollution, and the Vienna Convention for the Protection of the Ozone Layer.

The Vienna Convention is particularly important, as all countries are members, and it addresses the two most advanced SRM technologies: Stratospheric Aerosol Injection (SAI) and Marine Cloud Brightening, both of which could potentially harm the ozone layer. The Convention mandates cooperation, information sharing and transparency on research impacting the ozone layer, and these can be repurposed to govern SAI research. For this, the Convention can borrow norms and standards from the emerging research governance frameworks in other international treaties like the London Convention and Protocol.

Recommendation 3: Create a governance framework for SAI research under the Vienna Convention

To effectively govern SAI research under the Vienna Convention, we propose the adoption of a research assessment framework. This framework can be established through existing institutions under the Convention, including the Conference of the Parties, the Ozone Secretariat, the Ozone

Research Managers, and the Vienna Convention Trust Fund for Research and Systematic Observation. This framework should incorporate the following key norms:

1. Information Sharing and Consultation: Governments must share information and consult with one another when proposing outdoor experiments.
2. Environmental Impact and Risk Assessment: Projects should undergo a thorough environmental impact and risk assessment, including the development of risk management plans based on a precautionary approach.
3. Independent Regulatory Frameworks: Countries hosting SAI experiments should establish national regulatory frameworks with independent scientific bodies to oversee research, separate from government agencies funding such research.
4. Support for Developing Countries: SAI research in developing countries should be supported through the Trust Fund, focusing on studying adverse transboundary or global impacts and building global scientific capacity in SAI equitably.
5. International Approval Process: Develop an international approval process for outdoor research under the Vienna Convention, integrating all the aforementioned norms.

These norms can be instituted through COP decisions, recommendations of subsidiary bodies and operational policies of implementing agencies.

Annexure 1

Solar Radiation Modification Research and Field Experiments

Experiment name/Country	SRM technology	Objective	Current Status
Stratospheric Aerosol Transport and Nucleation (SATAN) Independent UK researchers	SAI	To evaluate a low-cost, controllable, recoverable balloon system. Such a system could be used for small-scale geoengineering research efforts, or perhaps for an eventual distributed geoengineering deployment involving numerous balloons.	Launched a high-altitude weather balloon that released a few hundred grams of sulfur dioxide into the stratosphere, a potential scientific first in the solar geoengineering field
Stratospheric Particle Injection for Climate Engineering (SPICE) project, UK	SAI	Demonstration of carrying materials to the stratosphere through a 1km long hose. The experiment attempted to carry 150 liter of water through a hosepipe connected to a balloon. Project has three parts: evaluating candidate particles; delivery systems; climate and impacts modelling.	Experimental deployment was halted in 2012 because of a patent row and the lack of rules that govern geoengineering experiments.
Stratospheric Controlled Perturbation Experiment (SCoPEx), Harvard University	SAI	Planning outdoor experiments to advance understanding of SAI, including small-scale experiments to quantify the risks posed by SAI to activation of halogen species and subsequent erosion of stratospheric ozone.	After several unsuccessful plans to conduct field tests, the field test flight to release calcium carbonate particles into the stratosphere was scheduled for June 2021 in Sweden, but again halted because of objections from local communities.
The Marine Cloud Brightening Project	MCB	Quantify how the addition of sea salt particles change the number of droplets in marine low clouds, and study how clouds behave when they have more droplets.	Field tests were initially planned for 2016, but have been delayed.
Reef Restoration and Adaptation program	MCB	To cool the ocean waters near the Great Barrier Reef to save the Corals. MCB is one component of the broader "Reef restoration and adaption program". The project is termed as local adaptation and not global geoengineering.	Experiments (injection of seawater) were conducted in March 2020 and March 2021. Results are not published yet. The principal investigator argues that the project is more akin to cloud-seeding operations that are designed to promote rain and that are not considered to be geoengineering. Such projects demonstrate the challenges in governing SRM.

Experiment name/Country	SRM technology	Objective	Current Status
ICE 911/ Arctic Ice Project	Surface albedo increase over ice	Deployment of millions of glass microspheres over the Arctic ice to reflect sunlight in the summer months and delay melting of ice.	The Arctic Ice Project is a Silicon Valley non-profit research organization that aims to slow climate change by restoring ice in the Arctic. The ICE 911 experiment that covered 17,500 square metres of ice was conducted in 2017 in Alaska. Results are not published.
	SAI	(1) Developing a complete understanding of stratospheric dynamical and chemical processes that determine aerosol microphysics, radiative properties and heterogeneous chemistry. (2) Evaluating the stratospheric response to natural and anthropogenic perturbations including climate change, volcanic eruptions, and potential climate intervention activities. (3) Strengthening the scientific foundation to inform policy decisions related to regulating global emissions that impact the stratosphere (e.g., ozone depleting substances, rocket exhaust) and the potential injection of material into the stratosphere to combat global warming (climate intervention).	The National Oceanic and Atmospheric Administration (NOAA) completing the first SABRE project stratospheric research flights over the Arctic in March 2023.
Safe climate research initiative By SilverLining, a US-based non-profit organization	SRM, primarily SAI	A collaborative effort among researchers and research centers, largely in the US, to define forward paths (roadmaps) for research and undertake critical studies to advance understanding of near-term climate risks and interventions.	

Annexure 2

Additional principles needed to govern SRM research

There are an additional set of legal issues which will require significantly more consensus building.

Liability: Liability is a difficult issue for two reasons. The first is establishing a chain of attribution or causation linking an activity to measurable isolatable harm to a particular state or person, which is very difficult for climate impacts generally, including through SRM.[a] Secondly, while national law allows for 'strict liability', which places a lower burden to prove causation when the activity is known to be inherently dangerous. However, strict state liability is not generally accepted under customary international law, the few treaties establishing such liability are not applicable to SAI, and neither the Vienna Convention nor the Montreal Protocol contain a strict liability standard.[b]

The Loss and Damage Fund model under the UNFCCC may offer a more constructive way forward. If SRM activities are allowed to proceed at scale, impacts over a region or number of communities could be estimated ex-ante as part of the deployment proposal, and compensation to affected categories set aside under an SRM Impacts Fund. In theory, this fund can build consensus on quantified impacts to benefit not only those at risk, but to also clarify the obligations of researchers, whose legal exposure could otherwise in principle be unlimited.[c]

Privatization of SRM: Less than a decade ago, those considering the question of SRM governance believed that "there is no current market for SRM, and few incentives exist for private firms to engage in solar geoengineering without strong (inter)governmental leadership. […] Even if SAI could be successfully commercialized, a privatized system of stratospheric SRM would probably be politically unacceptable. The notion of commercial or corporate control over SRM is highly controversial and subject to intense debate within the geoengineering community".[d]

The situation today, with several private teams driving the momentum on SRM research and the discourse on governance, poses a challenge to this perspective and to international governance. Who should conduct outdoor experiment? Should private companies be allowed? Should countries individually or jointly conduct experiments? How should developing countries and their interests be factored in the research? These are important questions that would require further deliberations and consultations.

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b Barbara Saxler, Jule Siegfried & Alexander Proelss (2015) International liability for transboundary damage arising from stratospheric aerosol injections, Law, Innovation and Technology, 7:1, 112-147, DOI: 10.1080/17579961.2015.1052645

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9 Horowitz et al. 2020. Effects of Sea Salt Aerosol Emissions for Marine Cloud Brightening on Atmospheric Chemistry: Implications for Radiative Forcing. Geophysical Research Letters. https://doi.org/10.1029/2019GL085838

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11 ibid

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13 States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.

14 CBD website (https://www.cbd.int/climate/geoengineering/)

15 Resolution LC-LP.1(2008) on the regulation of ocean fertilization. The Thirtieth Meeting of the contracting parties to the London Convention and the Third Meeting of the contracting parties to the London Protocol.

16 Assessment Framework for scientific research involving Ocean Fertilization (https://cdrlaw.org/wp-content/uploads/2020/04/OF-Assessment-Framework.pdf)

17 Membership Map of London Convention (https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/LC_LP/Map%20of%20Parties%202022.pdf)

18 Resolution LP.4(8) on the amendment to the London Protocol to regulate the placement of matter for Ocean Fertilization and other Marine Geoengineering activities.

19 Resolution LC-LP.1(2008) on the regulation of ocean fertilization. The Thirtieth Meeting of the contracting parties to the London Convention and the Third Meeting of the contracting parties to the London Protocol.

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