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Solar Geoengineering and the Montreal Protocol

A Case for Global Governance

Shikha Bhasin, Bhuvan Ravindran, and Eleonora Moro

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This brief undertakes a legal analysis of the Montreal Protocol's structure, institutions and jurisdiction to govern solar geoengineering.

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"Governance frameworks are key in not just how technology is used, but who in fact decides its usage- and where it's impacts are felt."

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"A governance framework will guard not only against the unknown impacts of geoengineering but also against our hubris and techno-centrism."

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Eleonora formerly worked with the Technology, Finance, and Trade team at The Council. She is presently a researcher in E3G's Brussels office, covering broad-based areas of research and innovation, renewable energy, and energy systems.

"The importance of achieving a robust geoengineering governance framework cannot be overstated. A consistent and transparent system to govern geoengineering research is critical to avoiding unregulated deployment."

Assessment Panels under the Montreal Protocol term geoengineering as a 'new threat' and single out stratospheric aerosol injection.

Image: iStock

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Acronyms

AR6	Sixth Assessment Report
CBD	Convention on Biological Diversity
CCT	cirrus cloud thinning
CDR	carbon dioxide removal
COP	Conference of Parties
EEAP	Environmental Effects Assessment Panel
E-PEACE	Eastern Pacific Emitted Aerosol Cloud Experiment
GRGP	Geoengineering Research Governance Project
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
IAEA	International Atomic Energy Agency
IMPCOM	Implementation committee
IPCC	Intergovernmental Panel on Climate Change
MARPOL	International Convention for the Prevention of Pollution from Ships
MCB	marine cloud brightening
MOP	Meeting of Parties to the Montreal Protocol
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
ODS	ozone-depleting substances
OEWG	Open-Ended Working Group
SAI	stratospheric aerosol injection
SAP	Scientific Assessment Panel
SCOPEX	Stratospheric Controlled Perturbation Experiment
SRM	solar radiation management
TEAP	Technology and Economic Assessment Panel
TOC	Technical options committees
UNEA	United Nations Environment Assembly
UNEP	United Nations Environment Programme
UV	ultraviolet
WMO	World Meteorological Organization

Efforts in different international fora to regulate geoengineering research have failed to yield a binding governance framework.

Image: IStock

Executive summary

As the climate crisis compounds globally, geoengineering is emerging as a prospective technology cohort to try and slow, or reverse, climate change. Broadly classified into solar radiation management (SRM) and carbon dioxide removal (CDR) technologies, these are drawing increasing attention for their predicted ability to rapidly reduce the impacts of global warming. Unregulated use of SRM technologies could potentially redistribute climatic patterns globally, reduce the availability of sunlight, stunt the growth of plants, increase health risks, and have other unexpected transboundary implications. Stratospheric aerosol injection (SAI), a type of SRM technology which directly injects aerosols to reflect sunlight, has been proven to adversely impact the ozone layer protected under the Montreal Protocol.

This uncertainty, severity, and ubiquity of potential impacts makes SRM research and governance an absolute pre-requisite for conclusively determining its viability. Currently, however, there is an absence of any overarching global environmental agreement to govern these technologies and its research. It is therefore essential to determine a governance framework that prevents SRM from going down the slippery slope of deployment or unregulated spatial experimentation.

This issue brief analyses the link between solar geoengineering research and the Montreal Protocol in an attempt to explore the Protocol's scope for monitoring such research, either wholly or partially, as suggested by few Parties at the 30th Meeting of Parties (MOP) to the Montreal Protocol in November 2018, namely the Federated States of Micronesia, Mali, Morocco, and Nigeria (Ripley et al. 2018).

The lessons from various attempts to regulate SRM research under different international fora have been assimilated to explore possibilities of governance of geoengineering research under the Montreal Protocol. These fora include the United Nations Environment Assembly (UNEA), the Convention on Biological Diversity (CBD), and the London Protocol. The legal coherence of the Montreal Protocol to govern SRM is examined in this issue brief based on three criteria: (i) congruence, between the mandate of the Protocol and the scope of SRM research, (ii) institutional capacity, and (iii) jurisdiction. The Protocol as a legally coherent instrument is suggested specifically for the governance of SAI technologies, in addition to other SRM technologies that may employ ozone-depleting substances as aerosols, where the term 'ozone depleting substances' includes the 'controlled substances' listed in the Annexes to the Montreal Protocol.

While advancing this suggestion, and notwithstanding the challenges that it poses, we also nudge the global community to explore possibilities of an independent and overarching framework for SRM governance that transcends the structural constraints of a limited mandate, avoids the overlapping applicability of multiple legal conventions, and overcomes the existing fragmented attempts to regulate research in geoengineering technologies. We highlight the potential global ecological and geopolitical impacts of unregulated SRM experimentation. To overcome possible imbalances, we emphasise on the centrality of transparency as a governance principle for SRM research governance. We further identify key factors that enhance the legitimacy of transparency processes, such as ease of access to information, targeted information, public participation, and reliability. We clearly state that the research, development, and potential deployment of SRM technology must be regulated by the preventive mechanisms of international law as enshrined in the precautionary principle, the principle of transboundary harm, and inter- and intra-generational equity.

We therefore establish the basis for SAI research in particular to be governed under the Protocol, in the absence of a holistic and overarching framework that governs SRM technologies as a cohort in its entirety.

We further suggest that the scope of governance under the Protocol could extend to ozone depleting substances, including 'controlled substances', employed as aerosols for SRM technologies. This legal congruence, between the scope of SAI research, the nature of ozone depleting aerosols, and the Protocol's mandate of ozone protection forms the foundation of our proposition.

> **The uncertainty, severity, and ubiquity of potential impacts makes SRM research and governance an absolute necessity.**

Figure ES1 **Analytical framework to understand the overlapping scope of SRM Governance under the Montreal Protocol**

Identifying the Overlapping Scope of Governance

Montreal Protocol		SRM Research
• Aimed at protecting the ozone layer from ozone depleting substances (ODS) • It fulfills this objective by inter alia regulating the production and consumption of ODS	**Congruence** The mandate of the Protocol to prevent any damage to the ozone layer can extend to *governing SRM research that may impact the ozone layer*	• Research assesses potential impacts of SRM deployment on human health, climate, ozone layer, marine and terrestrial habitats, biodiversity, agriculture, etc. • Types of SRM technologies like SAI are directly deployed in the ozone layer and proven to have negative impacts.
• Review scientific knowledge of ozone layer and related atmospheric science (SAP) • Examines impacts of ozone depletion (EEAP) • Studies alternative technologies that eliminate or reduce the use of ODS (TEAP) • The Secretariat is empowered to take any necessary action for protection of the ozone layer • Consists of Ozone Research Managers i.e., government researchers and scientists who have deep domain knowledge on ozone modification • Can regulate the phase-out and phase-down of ODS or high GWP substitutes mentioned in its Annexes	**Institutional Capacity** Institutions under the Protocol possess the scientific, administrative, and technical expertise to study, oversee, and regulate SRM research (especially SAI) which *uses ODS, including all annexed substances mentioned in the Protocol.*	• Studies the type of aerosol most suited for spatial injection and its stratospheric interaction • Examines optimum amount, site, and speed of aerosol injection • Explores non-aerosol based SRM techniques such as the option of surface albedo modification or increasing reflectivity of surfaces • Organised research will require setting terms of reference for conducting experiments • Such ToR will also serve to regulate the exchange of information and research outcomes between Parties to ensure transparency
• The Protocol possesses exclusive jurisdiction on matters related to the ozone layer and any substance that impacts the ozone layer. • The Protocol enjoys universal ratification, and has already undertaken research on the impacts of stratospheric aerosols.	**Jurisdiction** In the absence of any international convention to govern the impact of geoengineering activities on the ozone layer, the Montreal Protocol is the only option.	• London Protocol extends to ocean fertilisation activities, with an amendment to expand its scope to other geoengineering activities that may impact the ocean. • The Convention on Biological Diversity imposes a moratorium on all geoengineering activities that may impact biodiversity. • Attempts to govern SRM under the UNEA have failed.

Conclusion

The Montreal Protocol may govern all ozone depleting aerosol based SRM technologies, particularly stratospheric aerosol injection (SAI), including those substances mentioned in the Annexes to the Montreal Protocol.

Source: Authors' analysis

1. Introduction

Climate geoengineering is a combination of different technologies employed with the aim of altering the climate to reduce the impacts of increasing global warming (IPCC 2013). Two types of technologies are broadly applied for climate geoengineering: (i) solar radiation management (SRM) technologies, which reflect sunlight or solar irradiance into space so as to reduce surface temperatures, and (ii) carbon dioxide removal (CDR) technologies, which directly remove carbon dioxide from the atmosphere so as to eliminate this principal agent of anthropogenic climate change (C2G 2021). More specifically, solar geoengineering seeks to modify the Earth's radiation budget through a climate change intervention that reflects more solar radiation back into space than what is absorbed by the Earth (IPCC 2021). In the wake of a global failure to intervene against climate change, these technologies are finding more appeal as potential solutions to slow and possibly reverse the problem (Nature 2021). It is precisely this increasing interest that is translating into greater attempts at global research. This heightening traction warrants a governance framework that could prevent unregulated experimentation and its subsequent detrimental impacts.

Most controversial among these SRM techniques is stratospheric aerosol injection (SAI), which involves injecting aerosols into the stratosphere to reflect solar radiation back into space to partially offset the impact of global warming (C2G 2021). At the 30th Meeting of Parties to the Montreal Protocol (MOP30), few Parties (the Federated States of Micronesia, Mali, Morocco, and Nigeria) voiced their concerns (Ripley et al. 2018) on the management of stratospheric aerosol injection (SAI) technologies and emphasised the importance of further ascertaining the impact of solar geoengineering technologies on the ozone layer (UNEP 2018b). Despite pushback from the United States, the European Union, Canada, and China on several grounds, the proposal was finally considered by the Open-Ended Working Group (OEWG) in its 41st meeting. Parties noted that considering that SRM technologies are in the early stages of development, for the moment, the focus of the Montreal Protocol should be on "monitoring any developments, building knowledge, and raising awareness of the possible future implications of such activities" (UNEP 2019).

Parties to the Montreal Protocol acknowledge the need to monitor developments and build knowledge on the impacts of SRM technologies.

Building on this growing emphasis, this issue brief seeks to examine the scope of the Montreal Protocol (hereinafter referred to as the 'Protocol') to govern the research, development and potential deployment of SRM technologies. The research has been presented as six chapters. Following on from this introductory chapter, Chapter 2 highlight the possible global ecological and geopolitical impacts of unregulated SRM experimentation and the accompanying scientific uncertainties. It cites previous attempts at SRM along with the increasing advocacy for in situ experimentation as the last straw to push for urgent and effective governance of SRM research.

Chapter 3 maps the previous attempts at governance of geoengineering research across different conventions by undertaking a study of the key actors and negotiations at relevant international fora to draw lessons for future Montreal Protocol negotiations on the topic. The Fourth Session of the United Nations Environment Assembly (UNEA), the Convention on Biological Diversity (CBD), and the London Convention and Protocol are the international fora considered in this brief for the governance of climate geoengineering research.

In Chapter 4, specific legal criteria for evaluating the appositeness of the Protocol for the governance of SRM research has been suggested. This analysis includes examining the congruence between the objectives of the Protocol and SRM research, assessing the institutional capacity under the Protocol to oversee and regulate SRM research, as well as analysing the Protocol's jurisdiction to regulate the potential impacts of SRM research vis-à-vis other environmental instruments. To find common ground the chapter suggests governance of SAI research under the Protocol, in addition to other SRM technologies that use ozone depleting aerosols and 'controlled substances', in the absence of an overarching governance framework to regulate climate geoengineering in its entirety.[1]

1 Inclusion of other aerosol-based SRM technologies that do not adversely impact the ozone will muddy and transgress the mandate of the Protocol, which is limited to protecting the ozone layer. It is for this reason that the scope of SRM governance under the Protocol has been limited to SAI technologies, in addition to other SRM technologies that deploy ozone depleting substances or other 'controlled substances' mentioned in the Annexes to the Protocol.

> **Congruence, institutional capacity, and jurisdiction constitute the analytical framework used to analyse the appositeness of the Protocol.**

Finally, the brief focuses on transparency as a governance principle in Chapter 5, identifying four key factors that enable the legitimacy of transparency processes: (i) ease of access to information; (ii) targeted information; (iii) public participation; and (iv) reliability. This chapter also provides the legal principles of global governance on which the proposed research framework must be designed, namely the precautionary principle, the principle of transboundary harm, and inter- and intra-generational equity.

The brief concludes in Chapter 6 that given the currently fragmented legal landscape, the Protocol may be well suited to regulate research on SAI and other SRM techniques that rely on ozone depleting aerosols. This suggestion is consistent with the Protocol's existing mandate, institutional capacity and jurisdiction that extends to protecting the ozone layer; and its universal membership will ensure that such a ratification to regulate climate geoengineering research attempts are not geographically biased.

2. Establishing the need for governance of SRM research

The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR6) unequivocally observes with high confidence that SRM could lead to substantial and overcompensating climate change at a regional and seasonal time scale, in addition to other adverse impacts that science is yet to decipher (IPCC 2021). Notwithstanding the potentially dangerous and unascertained implications of this relatively nascent technology, attempts to deepen SRM research and conduct spatial experiments are gaining momentum. The scientific understanding of how interventions brought about by SRM are going to impact the Earth is still relatively low (IPCC 2021), and this gap is sought to be bridged by organised and regulated SRM research.

Broadly, four kinds of SRM technologies are deployed for climate change interventions: SAI, marine cloud brightening (MCB), cirrus cloud thinning (CCT),[2] and surface albedo enhancements (IPCC 2021). Each of these SRM technologies impacts the environment in largely unascertained ways. As mentioned above, stratospheric aerosol injection (SAI), seeks to create an albedo effect that will reflect solar radiation back into space (C2G 2021). Mimicking the cooling effect of its natural analogue, namely volcanic eruptions, the anthropogenically introduced sulphuric aerosols eventually react with atmospheric oxygen and water to form sulphuric acid that damages the ozone layer. Similarly, cirrus cloud thinning is another technique that aims to thin cirrus clouds, which absorb more long-wave radiation than they reflect so that a greater amount of radiation can be sent back into space than what is absorbed (Geoengineering Monitor 2021a).

Apart from noting the unknown potential dangers of deploying various SRM techniques, research also seeks to answer various complex modalities of the techniques themselves. This includes the amount and type of aerosol injection, the optimum spatial and temporal pattern of injection, the resulting stratospheric dynamics and chemistry, and the varying cooling efficacy of different aerosols, among other issues. The very nature of this research risks unchecked spatial in situ experimentation, which can eventually have disastrous consequences across the globe.

Anticipatory governance is, thus, necessary to govern SRM research (Geden et al 2019). Such governance would include assessing the technical competency of the research institutions pursuing SRM, authorising research based on sound scientific assessment, ensuring equity through co-participation when research is undertaken between countries, manage funding, resolving disputes in case of compensation claims, sharing of information, and causal attribution in case of transboundary impacts, to name a few (Blackstock et al. 2011).

2 Some research considers CCT as a third category of climate geoengineering, as technically it reduces the retention of long-wave radiation in the atmosphere vis-à-vis facilitating the deflection of solar or shortwave radiation like other SRM techniques.

Box 1 SRM technologies: Precaution is critical

IPCC AR6 confirms (with high confidence) that SRM could lead to substantial and overcompensating climate change at a regional and seasonal scale in addition to various adverse impacts that science is yet to decipher (IPCC 2021). Large amounts of sulphur aerosols released into the atmosphere via SAI will reduce the content of ozone precursors such as NOx, necessary for ozone formation (EC 2006). This phenomenon is further aggravated when sulphate aerosols reflect sunlight back into space, thereby reducing its availability for the formation of ozone. Reduction of ozone in the stratosphere translates into a reduction in tropospheric ozone due to reduced stratosphere-to-troposphere transport (SAP 2018). This exposes life on Earth to large amounts of UV radiation and the accompanying risks of skin cancer, eye cataracts, immune deficiency disorders, etc. (EC 2022)

Reports also suggest that the sudden cessation of SRM could lead to a temperature change two to four times greater than what would ensue from climate change itself (Trisos, C.H. et al 2018). This will aggravate and redistribute the impacts of climate change as we know them today. Such non-linear impacts include altering existing temperature and weather patterns with regional variations, global reductions in precipitation, stunted plant growth and changes in crop yields, reduced availability of direct sunlight for solar power generation, etc. (UNEP 2016) Sudden changes in temperature could have devastating impacts on ecosystems and biodiversity, that will be forced to either adapt to rapid temperature changes at an unprecedented rate, or possibly perish (Trisos, C.H. et al 2018).

Sulphate aerosols could have varying impacts depending upon the amount, type and site of injection and its interactions with pre-existing atmospheric elements. It is also pertinent to note, that SRM cannot offset other currently irreversible and sustained impacts of historic greenhouse gas emissions, such as ocean acidification, terrestrial impact of increased CO2 concentrations, melting of the Arctic permafrost, etc. Moreover, much less is known about the impacts of non-sulphate aerosols which have been suggested for use in different SRM techniques. Added to this, is the possibility of SRM weaponisation to inflict unforeseen climate disruptions on 'enemy' countries, that will have other socio-economic and environmental consequences.

Source: Authors' analysis and compilation

2.1 Transboundary impacts of unregulated experimentation

Various possible impacts of SRM perturbation experiments include a delay in ozone recovery, in addition to the non-linear effects of altering the temperature and precipitation patterns with regional variations, changes in crop yields/reduced plant growth, and decrease in direct and increase in diffused sunlight (IPCC 2021). What makes the impacts even more inequitable is that they could be unevenly distributed. Even regions that have not participated in developing SRM techniques may face the consequences (C2G2 2021).

The cross-border nature of SRM, from the dimensions of research, development, and deployment, necessitates international coordination and regulation based on shared principles that institutionalise scientific and informed decision-making (C2G2 2019). The proposed site for SAI is the stratosphere, and the need for in situ or outdoor research via 'perturbation experiments' beyond laboratory confines is gaining traction (Dykema et al., 2014). This trend exponentially magnifies the environmental and geopolitical risks, pointing to the urgency and inevitability of a framework to regulate SRM research (Long and Parson 2019a).

> **The cross-border nature of SRM research, development, and deployment, necessitates international coordination and regulation which institutionalises informed decision-making.**

2.2 Need for governing research: constituents, boundaries, and conditions

Attempts at governing geoengineering technologies have been made under different fora and have been touched upon in detail in the next section. It is felt that previous attempts at SRM governance under the United Nations Environment Assembly (UNEA) failed because the governance of both CDR and SRM geoengineering techniques was to be collectively addressed. A similar deadlock was observed in negotiations under the Convention on Biodiversity (CBD) as well, where the scope of the term 'geoengineering' failed to generate consensus.

Therefore, governance principles that are inclusively adopted and widely recognised are currently not in place and are urgently needed to guide the formulation, implementation, and monitoring of solar geoengineering research (C2G2 2019). This view is shared by multiple stakeholders, including national governments, international organisations, and academicians (Ghosh 2019). As a result, it has been suggested that research activities that pose such risks should not be allowed until appropriate governance frameworks are put in place, which implies a moratorium on further research. The looming threat of weaponising SRM technology or the possibility of big players monopolising the research arena and acting with impunity in the absence of a regulatory framework also poses a major risk (Fuhr 2021).

Box 2 Gaps in SRM Research and Previous Attempts

While building the case for outdoor research, scientists argue that climate modelling cannot accurately represent atmospheric chemistry and climate variabilities (such as seasonality, altitude, water content, etc.). In the absence of mutually agreed research methodologies, terms of reference, or the condition of prior approval, what ensues is a laissez-faire of countries and private players to tamper unconditionally with Earth's natural systems that work together to create the global climate, which is already at the brink of irreversible collapse. The enormous uncertainties of the impact of such interventions aggravate the dangers of such unregulated exploration. Some of the following gaps (CBD Secretariat 2012) that potential research on climate geoengineering will seek to uncover have been identified:

- Absence of palaeo-climatic precedents to understand the altered planetary dynamics of warming due to high greenhouse gas emissions and simultaneous cooling due to sunlight reflection;
- Difficulty in assessing the totality of changes due to potential geographical redistribution of climate impacts due to solar geoengineering;
- Uncertainties in highly variable regionality of temperatures due to uniform dimming;
- The unassessed extent of the potential impacts of reduced sunlight (specifically, photosynthetically active radiation) on plant growth and hence the distribution and population of biodiversity, agricultural productivity, and generation of solar power;
- Considerable uncertainty on the disruptive impact on the hydrological cycle and regional weather patterns, including reduced precipitation globally;
- Greater understanding of the atmospheric chemistry of the interaction of aerosol with ozone and sunlight and other catalysts present in the stratosphere;
- Assessing dangers of a sudden cessation in SRM deployment and the possible 'temperature shocks' or bouncebacks.

The purpose of SRM research governance is to improve our understanding of these uncertainties without furthering them. This implies preventing the transgression from research to deployment at all costs, an act of precarious funambulism possible only through a governing framework. The limited scope of research must focus on determining beyond doubt whether the benefits of deploying SRM far outweigh the costs of non-deployment while ensuring that the exercise itself is environmentally benign.

Some examples of geoengineering research have been listed below:

- The Yuri-Izrael Outdoor Experiment conducted in August 2008 injected sulphuric aerosols using a car and a helicopter at a height of 2.5 km in the troposphere across an area of 2.5 sq. km about 300 miles south-east of Moscow, Russia. On account of the lead author's opposition to the Kyoto Protocol and scepticism of human-induced warming, the empirical results of the said experiment were not globally accepted (Doughty 2019).
- The E-PEACE (Eastern Pacific Emitted Aerosol Cloud Experiment) was conducted to examine the interaction of ship tracks with clouds and not termed as SRM research. The data results, however, had clear implications for marine cloud brightening (MCB), which is a solar geoengineering method, whereby increased cloud formation could reflect solar radiation back into space (Doughty 2019).
- Another example is the Stratospheric Controlled Perturbation Experiment (SCOPEX) by Harvard University that aims to send a device using a propelled balloon into the stratosphere, which will inject about a kilogram of aerosol particles to form a plume few kilometres in length. The balloon will then be propelled through the plume to obtain data for understanding the stratospheric dynamics of aerosol interactions, particle microphysics (coagulation, condensation, or other reactions), and other aspects of stratospheric chemistry (Harvard University 2021).

Source: Authors' analysis and compilation

What is needed is an international consensus on answers to the following questions such as: What constitutes solar geoengineering research? Who can conduct such research? What are the spatial confines for conducting such research? Which agency is responsible for authorising and monitoring such research? The credibility of independent research will remain fragile in the absence of established processes. Examples enlisted in text box 2 illustrate this point. Simultaneously, proposals for further outdoor solar geoengineering research are gaining momentum, and the time is ripe to institutionalise an appropriate framework before unforeseen climate impacts unfold (Tollefson 2018).

Given the global implications of SRM research and lack of necessary oversight at present to govern this research, a global scramble to identify platforms for effective governance of such research is unfolding. It therefore becomes relevant to ask whether the Montreal Protocol is a competent instrument for the governance of SRM research.

Taking cue from this, if the Montreal Protocol is to indeed be considered as a potential forum to address SRM research governance issues, it is necessary to have a clear picture of the existing geoengineering governance landscape as well as identify the Protocol's institutional set up and membership to check for its appositeness. Previous proposals of governance pathways that could regulate geoengineering research, can broadly be categorised into those suggesting: (a) a polycentric approach wherein different existing international treaties are applicable; or (b) that an entirely new regime be established exclusively for the governance of geoengineering or its specific types; or (c) an ad hoc code of conduct be adopted that guides research based on certain principles (IPCC 2011). The brief alludes to the second approach as it suggests that SAI technologies, in addition to other SRM technologies employing ozone depleting substances, may be governed under the Montreal Protocol. The brief also goes on to suggest the creation of an overarching international governance framework to regulate geoengineering research in its entirety in the long-term. The next chapter maps previous attempts under three main international fora to address overall geoengineering governance.

> **Proposals for outdoor SRM research are gaining momentum, and time is ripe to institutionalise an appropriate governance framework.**

3. Mapping previous attempts at governance of geoengineering research

This chapter delves into previous decisions on climate geoengineering made under various international fora. The objective is to glean the relevant learnings that can be internalised in future attempts at geoengineering governance under the Montreal Protocol. This chapter draws on the negotiation records provided by the International Institute on Sustainable Development's *Earth Negotiations Bulletin*, publicly available resolutions, and civil society reports. The following international agreements are studied:

1. The Fourth Session of the United Nations Environment Assembly (UNEA-4)—Nairobi, March 2019
2. The Convention on Biological Diversity (CBD)—COP10, Nagoya, October 2010
3. London Convention and Protocol—amendments in 2008, 2010, and 2013

The limitation of this study is that most international climate negotiations are consensus based, and therefore the only publicly available record is of actors that were vocally for or against specific measures. In the case of the London Convention and Protocol, our analysis drew on the text of the official resolutions, civil society reports, and academic literature. Further, positions of the governments on these topics may have changed substantially since the negotiations. Finally, none of these negotiations addressed SAI specifically, and policy positions on a certain geoengineering technology may not necessarily imply that they apply to other technologies or geoengineering as a whole.

Nevertheless, it is helpful to analyse the lessons learned from each of these negotiations, including key players, points of discussion, and topics covered to provide the context for any future discussions and negotiations on SRM research within the Montreal Protocol.

3.1 The Fourth Session of the United Nations Environment Assembly—Nairobi (Kenya), March 2019

The United Nations Environment Assembly (UNEA) is the governing body of the UN Environment Programme (UNEP) and meets every two years to set the priorities

Analysis of negotiations at the UNEA

Key actors

Switzerland was the key actor working towards increased governance in this instance, as it put forth the resolution. The Swiss resolution was supported by Burkina Faso, Georgia, Liechtenstein, Mali, Mexico, Micronesia, Montenegro, Niger, Republic of Korea, and Senegal (UNEA 2019). When the resolution was withdrawn, Switzerland was joined by Georgia, Mali, Mexico, Morocco, New Zealand, Niger, and Senegal in "expressing regret" on the fate of the resolution due to disagreements from a "small number of members" (IISD 2019). Parties opposing the resolution were led by the United States and Saudi Arabia (IISD 2019).

Points of discussion

According to negotiation reports, parties disagreed on various issues, including the venue of the proposed study, its remit, and its ultimate aim (Harvard Solar Geoengineering Research Program 2019). Parties did not agree on whether UNEA was the appropriate venue for assessing the status of geoengineering technologies and raised concerns about the duplication of efforts in other fora, particularly the IPCC (IISD 2019). Another point of discussion was on the remit of the resolution, with the parties failing even to agree on the technologies captured by the term geoengineering (IISD 2019). Finally, parties also disagreed on the extent to which the resolution should set a foundation for governance of geoengineering research while avoiding undue restrictions (Harvard Solar Geoengineering Research Program 2019). Many argue that a strong reason behind the resolution's failure was the clubbing of CDR and SRM discussions, both of which have different risks and politics. Countries like the United States, a major player in CDR, sought a clear distinction between SRM and CDR while also attempting to categorise geoengineering under climate mitigation. In the absence of any substantive discussion on the topic at UNEA 5, countries must integrate lessons from the past for a better result in UNEA 6.

Source: Authors' analysis

> **The failure of the UNEA resolution is noteworthy, as it is the broadest environmental organisation capable of governing SRM research.**

for global environmental policies within the UN system (UNEA 2021). At the Fourth Session of UNEA (UNEA-4), the Swiss government put forth a resolution (UNEA 2019) requesting the UNEP to assess the status of geoengineering technologies with regard to the current state of science; the actors involved; current knowledge on potential risks, uncertainties, and benefits; governance frameworks for research, deployment, and control of each technology; and also conclusions on potential governance frameworks (FCEA 2019). This resolution addressed geoengineering as a whole and therefore included both SRM and CDR techniques. The resolution went through several drafts in the UNEA-4 negotiations but was ultimately withdrawn as no consensus could be reached (IISD 2021).

The implications of this failure are noteworthy, as it is relatively recent and is emerging from the broadest environmental organisation with the potential to govern cross-cutting non-linear impacts of geoengineering (i.e., the UNEP). Moreover, the resolution was only aimed at reducing information asymmetry rather than proposing a binding framework, so its failure comes as a jolt to attempts at cohesive governance of geoengineering research.

3.2 The Convention on Biological Diversity (CBD)—COP10, Nagoya (Japan), October 2010

The CBD has a record of tackling important technological threats to biodiversity in a timely manner; in fact, it is the only institution with near universal participation to have successfully addressed geoengineering in its entirety (IISD 2012). At the 10th CBD Conference of the Parties (COP10) in 2010, countries agreed to impose a moratorium on all climate-related geoengineering technologies that may affect biodiversity, which was to be upheld until adequate scientific evidence justifies such activities (Convention on Biodiversity 2017). However, an exception permits small-scale research in controlled settings, subject to prior assessment of their potential environmental impacts (Convention on Biodiversity 2017). This decision was reaffirmed at the following COP in 2012 and expanded as a moratorium on a specific geoengineering technology, namely ocean fertilisation, that was agreed on at the previous COP in 2008 (Appleton et al. 2008). Though this decision is not legally binding and leaves space for interpretation, it represents a broad consensus of 193 countries and sends a strong political signal (Tollefson 2019).

Analysis of negotiations under the CBD

Key actors

Parties to the Convention (Costa Rica, Grenada, Philippines, Switzerland, and Tuvalu), regional groups (the African Group and the Alba Group), as well as civil society organisations requested for a moratorium on the use of geoengineering technologies until there exists a sound scientific understanding of its associated perils (Jungcurt et al. 2010). This issue was considered at the Meeting of Parties to the CBD at Nagoya in 2010, which ultimately adopted the moratorium. The moratorium received support from the Brazilian delegation, which proposed inserting language to specify that scientific activities can only be developed on a small scale and within national jurisdictions. The Norwegian delegation expressed support for the resolution by stressing the need for a more robust scientific basis before any experiments are conducted, and the European Union delegation urged the adoption of a cautious approach to geoengineering activities (Jungcurt et al. 2010).

The United States has not ratified the CBD and is technically under no obligation to honour any of the Convention's decisions (including the moratorium adopted in 2010). Nevertheless, the United States is a signatory to the CBD and generally adheres to its decisions (ETC Group 2010).

Points of discussion/factors for success

One key point of discussion throughout the negotiations at the COP10 was on the definition of geoengineering, which technologies are included in the definition, and whether to explicitly include carbon capture and storage[3] technologies (IISD 2010). Another point of discussion was on the conditions necessary to lift the moratorium in the future (IISD 2010). Finally, there was significant debate on the kind of scientific activities that would qualify for an exception to the moratorium (IISD 2010). The main reasons for the adoption of the moratorium were gaps in scientific knowledge of geoengineering activities and the potential environmental, social, and economic risks that are generated from them (Tollefson 2019).

Source: Authors' analysis

Image: iStock

3 Technologies that capture and store carbon dioxide before releasing it back into the atmosphere, mainly using pre-combustion, post-combustion, or oxyfuel methods.

3.3 London Convention and Protocol—amendments in 2008, 2010, and 2013

The London Convention against marine dumping entered into force in 1975 under the International Marine Organisation framework and was subsequently updated through the London Protocol in 1996. Read with the London Protocol, it provides a mechanism to oversee exploratory research on marine-based geoengineering technologies (Lin 2016). In 2008, Parties to the London Convention and the London Protocol adopted a resolution that only permitted legitimate research on ocean fertilisation[4] (C2G 2021) to the exclusion of deploying such technologies (Lin 2016). This decision was similar to the policy position adopted by the CBD in May of the same year (See section 3.2) (Ginzky and Frost 2014). Subsequently, in October 2010, Parties to the Protocol adopted an assessment framework to review and determine the legitimacy and risks of proposed ocean fertilisation activities. This includes detailed steps for environmental impact assessment, site selection, risk management, monitoring, and cooperation.

Then in 2013, Parties broadened the scope of this regulation beyond ocean fertilisation, to include other emerging marine geoengineering technologies that can damage the marine environment (Ginzky and Frost 2014). However, the said amendment (A-Khavari 1997) to the Protocol has not come into force (EPA 2021) as the required minimum number of countries have not ratified it yet. Therefore, such adoption remains ineffectual.

Analysis of negotiations under the London Protocol

Key actors

Information on the key actors that worked to advance or slow down negotiations on geoengineering issues within the London Convention and Protocol is not publicly available. Therefore, it is not possible to have a clear picture of the key actors involved (EPA 2021).[5] Nevertheless, academic literature states that Australia, the Republic of Korea, and Nigeria put forth the amendment in 2013 to expand the scope of regulation to all emerging geoengineering technologies that have the potential to adversely impact the marine environment (Ginzky and Frost 2014). The United States has generally opposed resolutions for the governance of geoengineering technologies within the London Convention and Protocol (Ginzky and Frost 2014).

Points of discussion/factors for success

Given the absence of publicly available negotiation reports, this section draws on relevant civil society reporting and academic literature exploring the factors that led to successful negotiations. Ocean fertilisation experimentation activities had been underway when the London Convention and Protocol Parties met in 2008. It was, therefore, viewed as urgent during the negotiations and has been identified as a major factor for the moratorium being successfully adopted (Ginzky and Frost 2014). Further, the London Convention and Protocol's institutional framework was deemed favourable, given its focus on one primary objective (protecting the oceans) and, therefore, the absence of any competing objectives. In addition, the development of a science-based interdisciplinary approach within the London Convention and Protocol institutions and the fact that ocean fertilisation had been discussed in detail at the preceding legal and technical working group meetings allowed the negotiators to work effectively (Ginzky and Frost 2014). Finally, the coincidental absence of the American delegation at these negotiations may have contributed to the success of the moratorium decision.

Source: Authors' analysis

4 A geoengineering technology that is administered in the upper layers of the ocean by introducing certain nutrients which increase growth of algae or phytoplankton, which in turn increase the carbon sequestration potential of the ocean.

5 The IISD Environmental Negotiations Bulletin does not report on London Convention and Protocol negotiations, and the adopted resolutions do not specify who advanced them.

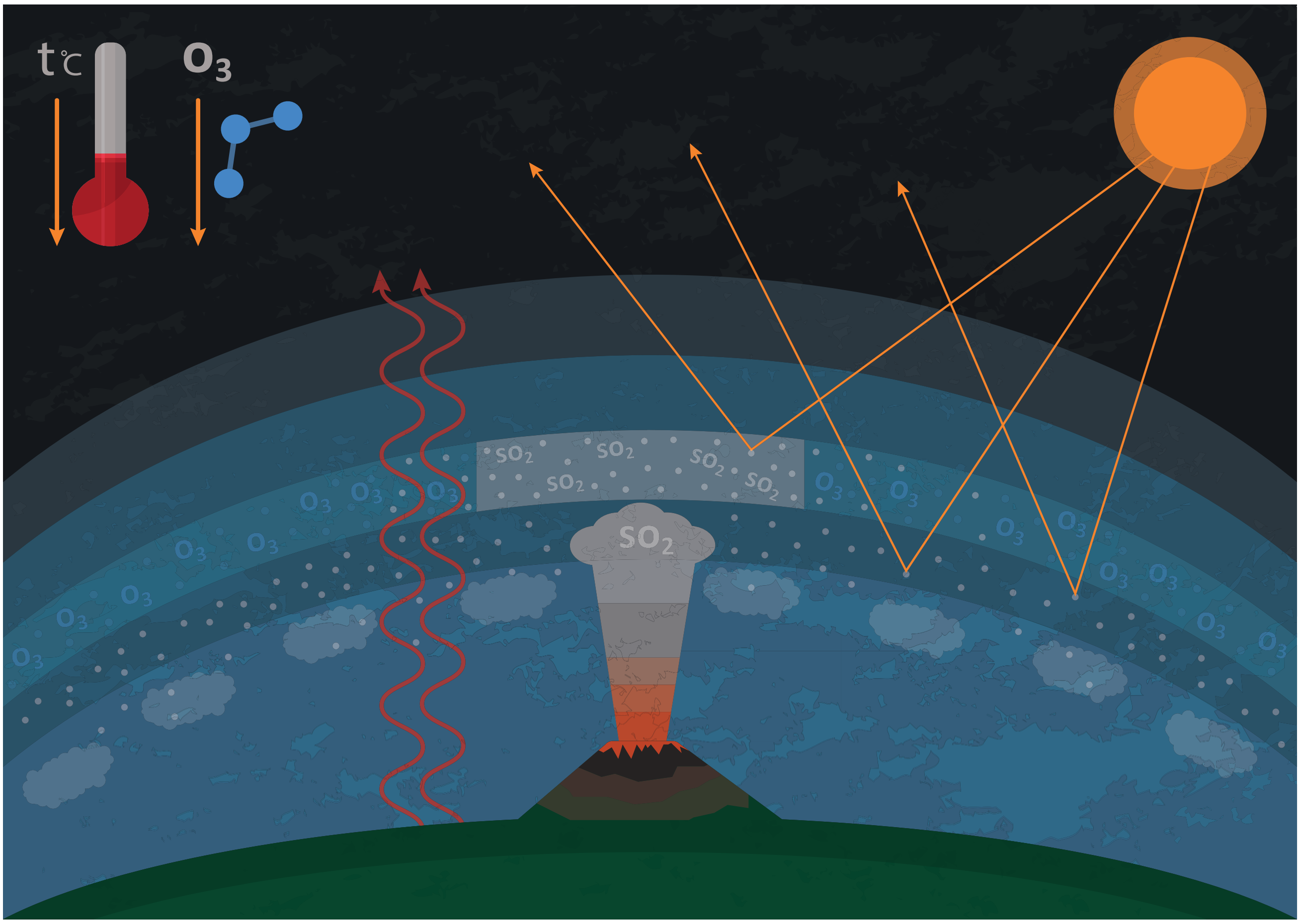


Image: iStock

Reflection of sunlight through the stratospheric injection of sulphate aerosols

4. Examining the legal mandate of the Montreal Protocol for the governance of SRM research

The Montreal Protocol has been identified as one existing international agreement that can govern SRM research (C2G2 2019). Having established the need for governance and analysed various attempts at guiding or restricting geoengineering research under other international conventions, it is important to demarcate specific criteria for evaluating the appositeness of the Montreal Protocol for SRM research. These include examining the congruence between the mandate of the Protocol and the scope of SRM research, assessing the institutional capacity under the Protocol to oversee and regulate SRM research, and analysing the relative coherence of the Protocol's jurisdiction to regulate the potential impacts of SRM research vis-à-vis other environmental instruments.

The nuances stated in the previous paragraph will be used to examine the linkages between the Protocol and the various risks of SRM research that warrant governance, namely spatial experimentation, covert deployment, weaponisation, and the potential ecological and geopolitical aggravations resulting from these moves.

> The link that draws SRM research under the Protocol's governance umbrella is its potential impact on the ozone layer.

4.1 Congruence: Examining the overlap between the mandate of the Protocol and the scope of SRM research

Considering that it is the mandate of an instrument that determines the scope of its governance, an element of congruence between the mandate of the Protocol and the scope of SRM research seems to be a jurisprudential prerequisite. The mandate of an international legal instrument is enshrined in its preamble, which captures the Parties' intention at the time of drafting and is relied upon for the purposive interpretation of the remaining text. The Preamble to the Montreal Protocol clearly outlines its mandate, which extends to protecting the ozone layer by taking 'precautionary measures' to 'equitably' control the global emissions of substances that deplete it. The Protocol seeks to fulfil this objective by regulating the production and consumption of certain 'controlled substances', defined under Article 1 clause (4) and exclusively listed in Annexes A, B, C, E, and F to the Protocol. In contrast, the objective of SRM technology is not to protect the ozone layer or aid its formation but to modify the Earth's radiation budget to reverse the impact of anthropogenic global warming.

Structural challenges to expand the Protocol's scope

While these objectives may prima facie seem incongruent, what then brings the SRM research (and hence its governance) within the ambit of the Protocol is the use of ozone-depleting substances. SAI includes the introduction of aerosols or small reflective particles into the stratosphere, which increase the surface area available for deflecting sunlight. This desired result is not always achieved by directly injecting aerosols but by chemical precursors (like sulphur dioxide), which form aerosols (such as sulphuric acid, nitric acid, or carbonyl sulphide) through atmospheric chemical reactions (Llanos 2015). These reflective particles reduce the availability of sunlight, which is an essential ingredient for ozone formation (Xing et al. 2017). In the presence of sunlight, these particles also undergo photodecomposition, as a result of which the ozone layer is depleted (Heckendorn et al. 2009). Therefore, it is well established that among other risks, some SRM technologies damage the ozone layer and retard ozone formation (WMO 2010). Unchecked deployment could counter the ozone recovery achieved under the Montreal Protocol (Scientific Assessment Panel 2018). Further, the impact of various other aerosols on the ozone layer is largely unclear and remains to be ascertained.

> **Congruence between the mandate of the Protocol and the scope of SRM research is a jurisprudential prerequisite.**

Therefore, the link that draws SRM research under the Protocol's governance umbrella is its potential impact on the ozone layer. Academic literature on this evolving decision space holds a consensus that only ozone-impacting SRM technologies could be governed under the Protocol (Wieding, Stubenrauch, and Ekardt 2020), else the Protocol's coherence may get muddied (Redgwell et al. 2011). This is specifically true for SAI research that relies on ozone-depleting sulphate aerosols vis-à-vis other methods whose impacts on the ozone are yet to be clearly understood.

While some may argue that the scope of the Protocol has been broadened by the Kigali Amendment, which introduced hydrofluorocarbons (HFCs) that are not ozone-depleting substances (ODS), the fact remains that HFCs were transitioned to as alternatives to hydrochlorofluorocarbon (HCFCs), which was a scheduled ODS governed under the Protocol. Moreover, Article 9 clause 1(b) of the Protocol promoted the development of other alternatives to the 'controlled substances.' Therefore, it could be argued that the introduction of HFCs was envisaged, and perhaps encouraged, by the Protocol itself and hence, it is best managed within its mandate. This stance becomes even more clear upon examining the role of the Technology and Economic Assessment Panel formed under the Protocol, which is tasked with the mandate of inter alia reviewing non-ozone-depleting technology alternatives.

However, it will demand astute craftsmanship from the Parties to overcome certain structural constraints within the Protocol's existing framework. To be governed under the current make-up of the Montreal Protocol, any ozone-depleting aerosol that is not included in the existing list of 'controlled substances', would need to be included through an amendment. As per the Protocol's design, only the production and consumption of 'controlled substances' can be regulated and governed. All reporting, compliance, and financial and technological cooperation mechanisms are also centred around the eventual reduction or removal of these 'controlled substances'. If additional ozone-depleting aerosols were to be brought under this definition, it may require an amendment under Article 9 of the Vienna Convention, which is likely to be met with resistance from countries seeking to retain and increase their technological monopoly in the domain (National Academies of Sciences Engineering and Medicine. 2021).

It is further observed that some of the aerosols used in albedo modification may have various alternative uses and may need regulation only to the limited extent of their use in SRM techniques. Therefore, unlike the 'controlled substances' listed in the Protocol, these ozone-depleting aerosols may not need to be phased-down or phased-out in totality and across all their utilities but rather only in its selective utility for SRM. The proposal to govern SRM research under the Protocol goes much beyond the simple inclusion of aerosols as 'controlled substances' that deplete the ozone layer. It is an extensive process that will require new rules for monitoring, reviewing, coordinating, reporting, and regulating research to keep in check the possibilities of spatial experimentation and deployment. These will go beyond the existing structural framework of the Protocol that is centred almost exclusively around the governance of 'controlled substances.'

It is essential to address these complexities of statutory construction to comprehensively assess the scope and extent of integrating SRM research within the Protocol.

Excluding non-ozone depleting SRM technologies

Importantly, SRM technologies that do not use aerosols for deflecting sunlight, such as enhancement in surface albedo and techniques of MCB, also exist. Some examples of this SRM technique includes growing crops that are inherently more reflective, whitening rooftops with paint, and covering large swathes of barren/desert land with reflective materials (Geoengineering Monitor 2021b). Certain aerosol techniques have also proven to be non-ozone-depleting, though their impacts on the hydrological cycle, local climate, and biodiversity are yet to be ascertained (Yang et al. 2020). It is difficult to loop in such technologies within the scope of the Protocol without altering its existing mandate, which is limited to protecting the ozone and preventing environmental harms arising from its damage.

Moreover, the downside risk of potentially reopening a negotiated and extremely successful climate protocol, with major economies like the United States being fully committed to its success, cannot be discounted.

The task of partially governing SRM, to the extent of SAI and other techniques deploying potentially ozone-depleting aerosols, could therefore safely fall within the ambit of the Protocol, while the status quo on regulating non-ozone-depleting and aerosol-based SRM techniques under other appropriate conventions could continue. There may still be overlaps, but that could not be a reason to preclude the application of the Protocol as impacts on the ozone can only be addressed under the Protocol.

4.2 Institutional capacity: Assessing the institutional framework under the Protocol to oversee and regulate SRM research

The exclusivity of the Protocol's mandate essentially defines the functions of its institutions and bodies. For a basic overview, it is important to note that both the Convention and the Protocol have their respective governing bodies—respectively the Conference of Parties to the Vienna Convention and the Meeting of Parties (MOP) to the Montreal Protocol.

The Secretariat established under Article 12 of the Protocol is the nodal agency that coordinates the Parties' periodic meetings and facilitates the exchange of information inter se, and other administrative functions to further the Protocol's objectives. The MOP established a Bureau (Decision I/2) to review the documents prepared by the Secretariat for the MOP and consider any topics on the agenda for future meetings. It also set up an Open-Ended Working Group (Decision I/5), which inter alia reviews the reports of the assessment panels to integrate them as a synthesis report and suggest any amendments to the Protocol based on the panel assessment reports, if required.

The governing body of the Protocol or the MOP has been vested with power under Article 11 clause 4 thereof to discharge various functions, which include inter alia the power to review the implementation of the Protocol, decide on the addition or removal of 'controlled substances', establish and update guidelines for the reporting of information by the Parties, and consider and adopt proposals for amending the Protocol. What is pertinent to note for the purpose of this issue brief in particular is the last function indicated in Article 11 clause four sub-clause (j), which empowers the MOP to "consider and undertake any additional action that may be required for the *achievement of the purposes of this Protocol*."

> **The SAP and EEAP have specifically undertaken the scientific analysis of only those geoengineering techniques that impact the ozone layer.**

In addition to these governing bodies, however, the MOP in Decision I/3 decided to establish under Article 6 of the Protocol three assessment panels discussed below (Ozone Secretariat 2021). Of relevance to note here is that the role of these assessment panels is to provide technical (scientific, economic, technological) advice/review to the MOP and therefore do not have any binding or regulatory authority. The purpose of exploring their mandate here is to assess the scope of their advisory role and whether SRM research, either wholly or partially, falls within it.

1. **Panel for Scientific Assessment (SAP)**

   As per its original terms of reference detailed in Annex VI to Decision I/3, this advisory body must review the scientific knowledge of the ozone layer and related atmospheric science issues. Established alongside the other panels in 1988, it provides Parties with scientific information relevant for protecting the ozone and publishes a detailed report every three to four years.

   The latest findings of the Scientific Assessment Panel (SAP) were published in a report prepared by the World Meteorological Organisation (WMO)[6], UNEP, National Aeronautics and Space Administration (NASA), the European Commission, and National Oceanic and Atmospheric Administration (NOAA) in 2018. This report categorically notes the impact of only those geoengineering techniques that increase stratospheric aerosols. To this extent, it states that such technology would alter the stratospheric ozone layer (Scientific Assessment Panel 2018) and that much less is known about the impacts of geoengineering solutions that use non-sulphate aerosols. The report further calls for a better understanding of the potential impacts of SRM technologies on the ozone layer, which is expected to be addressed in the next Scientific Assessment Panel in 2022 (Scientific Assessment Panel 2018).

2. **Panel for Environmental Assessment (EEAP)**

   Known as the Environmental Effects Assessment Panel (EEAP), this panel examines the effects of ozone layer depletion and has experts from the field of photobiology and photochemistry as its members (Secretariat 2021).

   It published its latest report in 2020, which touches upon the interaction of UV radiation with climate change and the effects of ozone depletion on human health, biodiversity, food security, and ecosystem services. It is noteworthy that the 2018 report of the EEAP titled 'Environmental Effects and Interactions of Stratospheric Ozone Depletion, UV Radiation, and Climate Change' terms geoengineering technology as a 'new threat' and singles out stratospheric aerosol injection as likely to have important side effects on the ozone layer and UV radiation (UNEP 2018a). It confirms that sulphate aerosols could accelerate stratospheric ozone loss and compound the impacts of increased UV penetration.

3. **Panel for Technology and Economic Assessment (TEAP)**

   The TEAP provides technical information at the request of Parties on alternative technologies that have proven to help reduce or eliminate the use of ozone-depleting substances. As per its initial terms of reference, the panel must review knowledge on state-of-the-art technology for phasing out controlled substances, in addition to studying the economic effects of ozone modification. The TEAP further comprises five technical options committees (TOCs) that assess the technical and economic viability of different alternatives to the applied uses of ozone-depleting substances.

   In addition to the above Panels, another research arm under the Vienna Convention is called the Ozone Research Managers, which consists of government atmospheric research managers and scientists who have deep domain knowledge in ozone modification[7]. Meeting every three years, these Managers publish a report with recommendations for future scientific research and cooperation between the Parties to the Protocol. The Protocol also has an implementation committee (IMPCOM), which must consider the reports, information, and other submissions by Parties to assess any non-compliance with the production and consumption requirements under the Protocol (UNEP, n.d.).

The work of each of the above-mentioned panels is in furtherance of the Protocol's central objective—protecting the ozone layer. The SAP and EEAP have specifically undertaken the scientific analysis of only

6 It is worth mentioning that the WMO has been conducting scientific ozone monitoring and research much before its formalisation under the SAP of the Montreal Protocol.

7 Ozone modification is the science which studies the atmospheric interactions of different elements with the ozone layer and the impact such interactions may have on its composition.

those geoengineering techniques that impact the ozone layer. Therefore, the institutional mandate and capacity of the Protocol to assess and monitor SAI technologies exist, even though the same cannot be confidently said about other SRM technologies. SAI technologies impacting the ozone fall directly within the Protocol's ambit, but another reason for its proposed candidature is the Protocol's near universal membership, historical achievement, and acclaimed legitimacy among actors from both the Global North and South (Redgwell et al. 2011). Moreover, non-sulphate aerosol techniques for SAI could also be brought within the purview of the Protocol in light of the SAP's observation that the impacts of non-sulphate aerosols on the ozone remain largely unknown. Since non-sulphate aerosols are also part of 'atmospheric science' and its potential effects on the ozone layer, studies of other non-sulphate aerosol techniques of SAI could also be undertaken within the Protocol's mandate.

4.3 Jurisdiction: Analysing the Protocol's relative jurisdiction to regulate the impact of SRM research vis-à-vis other environmental instruments

In the case of SAI, both the space of deployment and primary effect is almost exclusively the stratospheric ozone. The precursors for ozone depletion that go on to form aerosols are released into the stratosphere and then impact the ozone layer. However, other technologies of SRM such as MCB, CCT, and surface albedo modification are not limited to the stratosphere for their deployment and therefore have multiple potential primary effects. Research has been undertaken also on non-sulphate aerosol alternatives for SAI that do not deplete the ozone layer despite their stratospheric deployment, such as calcite, salt, alumina, silicon carbide, titanium oxide, zirconium oxide, diamond powder, and other nano-particles under development (Yang et al. 2020). This raises two fundamental questions:

- If non-sulphate aerosols used in SAI are found to have no adverse impact on the ozone layer, will they still fall under the purview of the Protocol?

> **The overlapping applicability of different conventions is a real possibility given the largely unascertained impacts of SRM.**

- If ozone depletion is not the primary or only adverse effect of deploying SRM technology, will the Protocol be the best instrument for overarching environmental governance?

For example, techniques like MCB or cloud reflectivity enhancement also include the use of sea salt aerosols or other non-sulphate aerosols for increasing the albedo effect of clouds that go on to reflect more sunlight. While some studies do suggest that the sea salt may react with sunlight and other pre-existing catalysts to damage the ozone, it may also go on to cause even more disastrous effects such as fall in the global mean precipitation levels, especially over the Amazon rainforest (Jones, Haywood, and Boucher 2009), which would sound the death knell for the natural ecosystem and its biodiversity, in addition to having disastrous economic consequences on forest dwellers and industries relying on the region and its rain-dependent produce.

Drawing the causal linkage of the resulting damage to the Protocol in such cases would be difficult. Therefore, bringing SRM technology in its entirety under the Protocol's purview could restrict the mandate of governance. In such a scenario, is the governance framework under the Protocol best suited to assess, regulate, and penalise the deviant actors for such non-linear impacts? For this reason, attempts at regulating solar geoengineering research and technologies have been placed under different international conventions (see Chapter 3). The mechanisms of these various global environmental treaties would apply in individual contexts depending upon the impact attribution of SRM research and deployment that is sought to be regulated. MCB techniques could have potential impacts on oceans, in which case the London Protocol and the International Convention for the Prevention of Pollution from Ships (MARPOL) would become applicable. Similarly, due to potential impacts on biodiversity, mechanisms and Party obligations under the CBD may apply. The overlapping applicability of conventions is a real possibility given the largely unascertained ecological and geopolitical impacts of SRM. Therefore, no governance framework can be prepared without taking cognisance of this legal and operational difficulty.

In the absence of such compartmentalisation of mandates inter se international conventions, utter confusion would prevail on the law applicable to different issues. To maintain this sanctity of international environmental jurisprudence, it is, therefore, crucial that we assess the applicability of a Convention and its Protocols to any specific issue from

Figure 1 **Analytical framework to understand the overlapping scope of SRM Governance under the Montreal Protocol**

Identifying the Overlapping Scope of Governance

Montreal Protocol | **SRM Research**

- Aimed at protecting the ozone layer from ozone depleting substances (ODS)
- It fulfills this objective by inter alia regulating the production and consumption of ODS

Congruence
The mandate of the Protocol to prevent any damage to the ozone layer can extend to *governing SRM research that may impact the ozone layer*

- Research assesses potential impacts of SRM deployment on human health, climate, ozone layer, marine and terrestrial habitats, biodiversity, agriculture, etc.
- Types of SRM technologies like SAI are directly deployed in the ozone layer and proven to have negative impacts.

- Review scientific knowledge of ozone layer and related atmospheric science (SAP)
- Examines impacts of ozone depletion (EEAP)
- Studies alternative technologies that eliminate or reduce the use of ODS (TEAP)
- The Secretariat is empowered to take any necessary action for protection of the ozone layer
- Consists of Ozone Research Managers i.e., government researchers and scientists who have deep domain knowledge on ozone modification
- Can regulate the phase-out and phase-down of ODS or high GWP substitutes mentioned in its Annexes

Institutional Capacity
Institutions under the Protocol possess the scientific, administrative, and technical expertise to study, oversee, and regulate SRM research (especially SAI) which *uses ODS, including all annexed substances mentioned in the Protocol.*

- Studies the type of aerosol most suited for spatial injection and its stratospheric interaction
- Examines optimum amount, site, and speed of aerosol injection
- Explores non-aerosol based SRM techniques such as the option of surface albedo modification or increasing reflectivity of surfaces
- Organised research will require setting terms of reference for conducting experiments
- Such ToR will also serve to regulate the exchange of information and research outcomes between Parties to ensure transparency

- The Protocol possesses exclusive jurisdiction on matters related to the ozone layer and any substance that impacts the ozone layer.
- The Protocol enjoys universal ratification, and has already undertaken research on the impacts of stratospheric aerosols.

Jurisdiction
In the absence of any international convention to govern the impact of geoengineering activities on the ozone layer, the Montreal Protocol is the only option.

- London Protocol extends to ocean fertilisation activities, with an amendment to expand its scope to other geoengineering activities that may impact the ocean.
- The Convention on Biological Diversity imposes a moratorium on all geoengineering activities that may impact biodiversity.
- Attempts to govern SRM under the UNEA have failed.

Conclusion

The Montreal Protocol may govern all ozone depleting aerosol based SRM technologies, particularly stratospheric aerosol injection (SAI), including those substances mentioned in the Annexes to the Montreal Protocol.

Source: Authors' analysis

the lens of the very mandate bestowed by its Preamble and subsequent provisions to reduce duplicity and enhance the exclusivity of its intended outcomes. In the absence of any other specialised institution to assess the impact of SRM on ozone, the Protocol may be developed to regulate SAI research to prevent the depletion of the ozone layer. Other conventions may be applied in cases where such research or deployment is established to be stratospherically benign.

4.4 Finding common ground

It is clear from the discussion so far that the Protocol's mandate could be extended to govern research of only those SRM technologies that use potentially ozone-depleting substances. SAI technologies that deploy sulphate aerosols clearly fall within this domain, but it is slightly tricky to include other SRM methods , namely SAI, MCB, and CCT, which could employ non-ozone-depleting aerosols. This limitation is on account of the structural, institutional, and jurisdictional setup of the Protocol.

First, the structural make-up of the Protocol provides little or no leeway to incorporate such a governance framework. The potentially ozone-depleting substances under research could be added as a 'controlled substance' in an Annex to the Protocol to ensure that the production and consumption of such substances for the limited purpose of SRM is regulated. However, the addition of these substances to the Protocol could become enforceable only through an amendment and its subsequent ratification by the Parties. Even if such an amendment were achieved, the ambit of SRM research and technology development under the Protocol would still remain circumscribed by its mandate, which is limited to preventing ozone depletion and its impacts. During the course of research, if any substances were found to be non-ozone-depleting yet have adverse impacts on other natural systems such as the hydrological cycle, crop yields, and biodiversity, it may be difficult and perhaps even unnecessary to apply the Protocol to these substances as more specialised and authorised institutions have been created to govern disaggregated impacts. The congruence between the primary effects of geoengineering technology and the mandate of the Convention was also an important factor during the discussions on governing ocean fertilisation under the London Protocol.

> **A central authority for current and prospective geoengineering technologies may help transition from the current adhocism in governance.**

The potential non-linear impacts of SRM deployment would attract different specialised environmental conventions with different member Parties and mandates, leading to jurisdictional overlaps, conflicts, and doubling of efforts. This was also one of the reasons why the attempt at governance of geoengineering research under the UNEA failed. Further bifurcating SRM based on its impact on the ozone only perpetuates the compartmentalisation of different SRM techniques in an already fragmented and scattered legal landscape.

A central governance framework for geoengineering

Ideally, what may be worked out is an independent body to govern geoengineering technologies as a separate cohort in all its forms—carbon dioxide removal technologies, SRM, and any other geoengineering methods that may be developed in the future. Considering that the impacts of these technologies cut across the mandates of different environmental conventions, a central authority could be vested under a separate statute with exclusive regulatory jurisdiction. Constituting such a body would also provide an avenue for accommodating newer geoengineering technologies that may be developed in the future, thereby transitioning away from the current ad hocism to a more robust and consolidated framework for regulation. Nations need to arrive at a consensus on governing climate modification technologies, as was done in the case of nuclear technology.

The International Atomic Energy Agency (IAEA) is a precedent worthy of emulation for a proposed geoengineering governance body. The IAEA was created in 1957 under the aegis of the United Nations as a response to the apprehensions and expectations arising from the diverse uses of nuclear energy (IAEA 2021), a setting quite similar to the emergence of geoengineering technologies. The Statute of the IAEA under Article III prescribes the functions of the agency, which include inter alia the research and development of atomic energy for peaceful purposes, the establishment, administration, and need-based application of safeguards to the peaceful use of atomic energy or any information related thereto, fostering exchange of scientific and technical information among parties (IAEA 2016). The membership to the IAEA is open to all member countries of the United Nations who may do so by signing the statute and to those non-members who may deposit an instrument of accession. However, this is

> Governance of geoengineering research must incorporate transparency to reassure the public about the integrity and legitimacy of the process.

not to suggest that the IAEA offers a perfect institutional set-up that could be mirrored for SRM governance.

It will be important for any such consolidated framework or institution to constitute inter alia a technical committee made up of specialised scientific organisations or its representatives, such as the WMO, NOAA, the United Nations Environment Programme, and NASA, which have been pioneering the research on the impact of certain solar geoengineering methods upon the ozone layer and environment. Such a committee must also be aided by relevant findings across different official sources such as the IPCC and the SAP and EEAP under the Montreal Protocol. Notwithstanding the difficulties in arriving at such a regulatory construct, there is no doubt that it would best serve the needs for universal governance of solar radiation research.

In view of the geopolitical complexities between nations as witnessed in Chapter 3, arriving at such an independent regulatory statute and institution any time soon is difficult. It is therefore advisable that in view of its universal membership, robust institutional capacity, scientific assessment competence, and mandate, that the Montreal Protocol be identified as an appropriate institution to govern SAI techniques in addition to other techniques deploying ozone depleting aerosols. This will help overcome the current regulatory uncertainty while pursuing longer-term negotiations for a more trans-disciplinary and all-encompassing regulation for SRM in its entirety.

Such a governance framework and body, in both cases, must be based on certain principles that shall be explored in the next chapter.

5. Key governance principles for solar geoengineering research

Transparency is one governance principle recognised as necessary for ensuring the legitimacy of geoengineering research, as it exposes vested interests, increases public trust, and qualitatively enhances the research outcomes (Reynolds 2019). Beyond being a core normative principle, a high level of transparency is also likely to lead to better decision-making, as it increases accountability and public participation in decision-making (Lin 2016). Indeed, transparency is a consistent feature of all non-governmental initiatives and wider transparency literature has already proposed principles for the governance of geoengineering research (Oxford principles, Asilomar principles, Tollgate principles, Geoengineering Research Governance Project Code of Conduct) (Silverman 2010). It is precisely for this reason that we propose transparency as the inalienable foundation of any proposed SRM/geoengineering governance framework.

This is particularly important for SAI technologies, a topic that is publicly perceived as being deeply controversial and characterised by the emergence of conspiracies (Tingley and Wagner 2017). Chemtrail conspiracies (the idea that the airplanes are spraying a toxic mix of chemicals through contrails), in particular, have been a contentious topic of discussion on social media (Tingley and Wagner 2017). As a result, any process for governance of geoengineering research must incorporate transparency to reassure the public about the integrity and legitimacy of the process. A truly transparent governance process has the potential to catalyse other features of legitimacy, including public participation, accountability, and independence (Lin 2016).

5.1 Dimensions of transparency as a governance principle

Three essential dimensions of transparency emerge from the geoengineering literature:

The first dimension is transparency between researchers, as it is important for the research community to be aware of and have information about other ongoing experiments in order to avoid duplication, build on past experiments, and ensure the reliability of results (Kruger 2019). The fact that transparency between researchers is currently fostered at conferences and workshops poses questions of legitimacy, as the majority of researchers are concentrated in the Western world (Ghosh 2019).

The second dimension of transparency is between nations, as sovereign nations must be involved in inclusive information-sharing processes to make informed decisions on research related to geoengineering (Hubert 2017). Without this dimension of transparency, there is a risk of advanced research in certain countries becoming a political advantage to determine the direction of future research and governance frameworks (Ghosh 2019). This is problematic, as geoengineering research (especially SRM) has been a majorly Western enterprise, and perspectives from the Global South are largely missing (IC Centre for Governance 2019).

The final dimension of transparency is towards the general public, as geoengineering is a high-risk technology that affects the public interest (Ghosh 2019). Effective transparency has the potential to foster public participation in geoengineering research governance policy, as well as increase accountability to the public (Lin 2016).

5.2 Principles for effective transparency

The following section explores a few principles for effective transparency that emerge as a consensus across these above-mentioned sets of principles: (i) ease of access to information; (ii) targeted information; (iii) public participation, and (iv) reliability.

1. **Ease of access to information**

   For transparency measures in climate geoengineering research to be effective, the relevant information must be shared with the appropriate actors in a timely and easily accessible manner. A centralised clearing-house mechanism (Convention on Biological Diversity 2010)[8] has been proposed (Hubert 2017). In a similar vein, the Oxford principles advocate for open publication of research results, and both the Asilomar principles and the GRGP Code of Conduct emphasise the importance of making information widely available and accessible (Silverman 2010).

Figure 2 Stakeholders in transparency

Source: Authors' compilation

Nevertheless, full transparency of geoengineering research activities could create risks of rogue actors and activities with problematic consequences (Gardiner and Fragnière 2018). As a result, full disclosure is not appropriate in all settings, and the functional meaning of transparency will partly be a matter of judgement, as confidentiality may need to be maintained in certain instances, given the security implications of solar geoengineering

> **A functional meaning of transparency must be adopted to mitigate the security risks from complete disclosure.**

Attempts at defining principles of geoengineering research governance

Previous non-governmental attempts to define geoengineering research governance principles have been the following :

- **The Oxford principles (2009):** Five principles proposed to guide research of geoengineering techniques
- **The Asilomar principles (2010):** Five principles to promote the responsible conduct of geoengineering research, drawing on the Oxford principles (Keith et al. 2015)
- **The Tollgate principles (2018):** Ten principles building on the Oxford principles, focusing on ethical dimensions of geoengineering
- **The Geoengineering Research Governance Project (GRGP) Code of Conduct for GE research (2017):** Guidance on the conduct of geoengineering research

8 A two-way platform for seekers and providers of information, aiming to promote cooperation within and between countries, and develop a mechanism and network for exchanging and integrating information. The CBD has such a mechanism in place.

activities (Gardiner and Fragnière 2018). In this case, the governance structure itself should review and ensure that the research community has done its due diligence in making its work transparent, as appropriate (Long and Parson 2019b). The Tollgate principles emphasise that in the case of confidentiality being necessary due to security reasons, geoengineering research information should be subject to a review process involving stakeholders or their representatives. This review process must address the specific concerns of stakeholders that cannot be physically represented, including future generations and the natural world (Gardiner and Fragnière 2018).

2. **Targeted information**

   For transparency to be effective, the information on geoengineering research should be packaged differently for different audiences (for example, the general public, policymakers, or researchers). In practice, this means that a summary should complement raw information to verify credibility and to ease the processing burden that is otherwise likely to hinder transparency (Hubert 2017). For example, the GRGP Code of Conduct proposes that geoengineering research projects submit information on research plans, programmes, objectives, methodologies, results of peer review, assessments, authorisations, monitoring, research results, and compliance reporting. It also suggests a brief, non-technical summary on all of these points in both a local language and English (Hubert 2017). Similarly, the Asilomar principles recommend that geoengineering research results be effectively communicated, including a few public education activities (ASOC 2010).

3. **Public participation**

   This set of principles unanimously underscores the requirement to consult with communities that could bear the potential impacts of albedo modification, with a specific focus on the most vulnerable groups. The Asilomar principles suggest that information should be provided in an accessible form about the nature of the proposed field experiment, its reasons, and the potential impacts, while also engaging with the public to improve the programme design (ASOC 2010). The Oxford principles also emphasise on the condition to inform, consult, and seek prior consent of the people depending upon the technique deployed, suggesting that methods like albedo modification likely require global consent (Oxford University 2021). The GRGP also requires that, wherever practicable, including the interested public at relevant levels of decision-making about SRM research (Hubert 2021).

> **Public consultation, especially with the most vulnerable groups, is a crucial pillar of transparency.**

4. **Reliability**

   Finally, information on geoengineering research that is reported must be reliable so that it is useful for further action. To ensure a reliable transparency process, the governance processes themselves must be transparent (Lin 2016).

   Lessons can be drawn from the field of pollution disclosure and weaponry conventions. These bodies of literature show that independent monitoring, verification efforts, and scrutiny at various checkpoints can improve reliability and ultimately make transparency efforts more effective (Lin 2016). Indeed, both the Oxford and Asilomar principles emphasise the importance of independent assessment of research activities and their impacts (Silverman 2010). Nevertheless, the Tollgate principles raise questions on what defines an independent evaluation (whether assessments from within the same research community or country can be deemed independent) and the difficulty in assessing the impact of geoengineering activities given the lack of a certain baseline (Gardiner and Fragnière 2018).

5.3 Legal principles of international law

Additionally, incorporating specific principles of international environmental law must underline the implementation of these transparency principles while also guiding national policy on the topic. These include the following:

1. **Principle of transboundary harm**

   The United Nations' International Law Commission has laid down principles that reconcile a country's sovereign right to exploit natural resources within its jurisdiction with its international responsibility to prevent any harm arising therefrom beyond its sovereign confines. This principle of *sic utere tuo ut*

Prevention is better than cure, as the science of causal attribution is especially complicated in the case of SAI.

alienum non laedas[9] has been crystallised in draft articles (United Nations General Assembly 2005) in consonance with Principle 21 of the Stockholm Declaration (United Nations 1972) to cover activities not governed by any existing framework. It is grounded on the premise that prevention is better than cure as reparations cannot always restore the status quo. Moreover, tracing the chain of causation and all non-linear effects thereof is complicated, even more so in the case of SAI.

2. **Precautionary principle**

   The widely accepted implication of this principle is that uncertainty vis-à-vis the possibility of environmental harm arising from an activity must not deter actions to avert it. The underlying rationale is that delaying preventive action in anticipation of compelling evidence may lead to irreversible damage. This principle necessitates extensive research as a preventive precursor to spatial experimentation or aerosol-based SRM technology deployment. Another actionable extension of this principle is the imposition of an international moratorium on any 'perturbation experiments', similar to that imposed under Article 14 of the CBD or in accordance with Principle 15 of the Rio Declaration on Environment and Development (United Nations 1992).

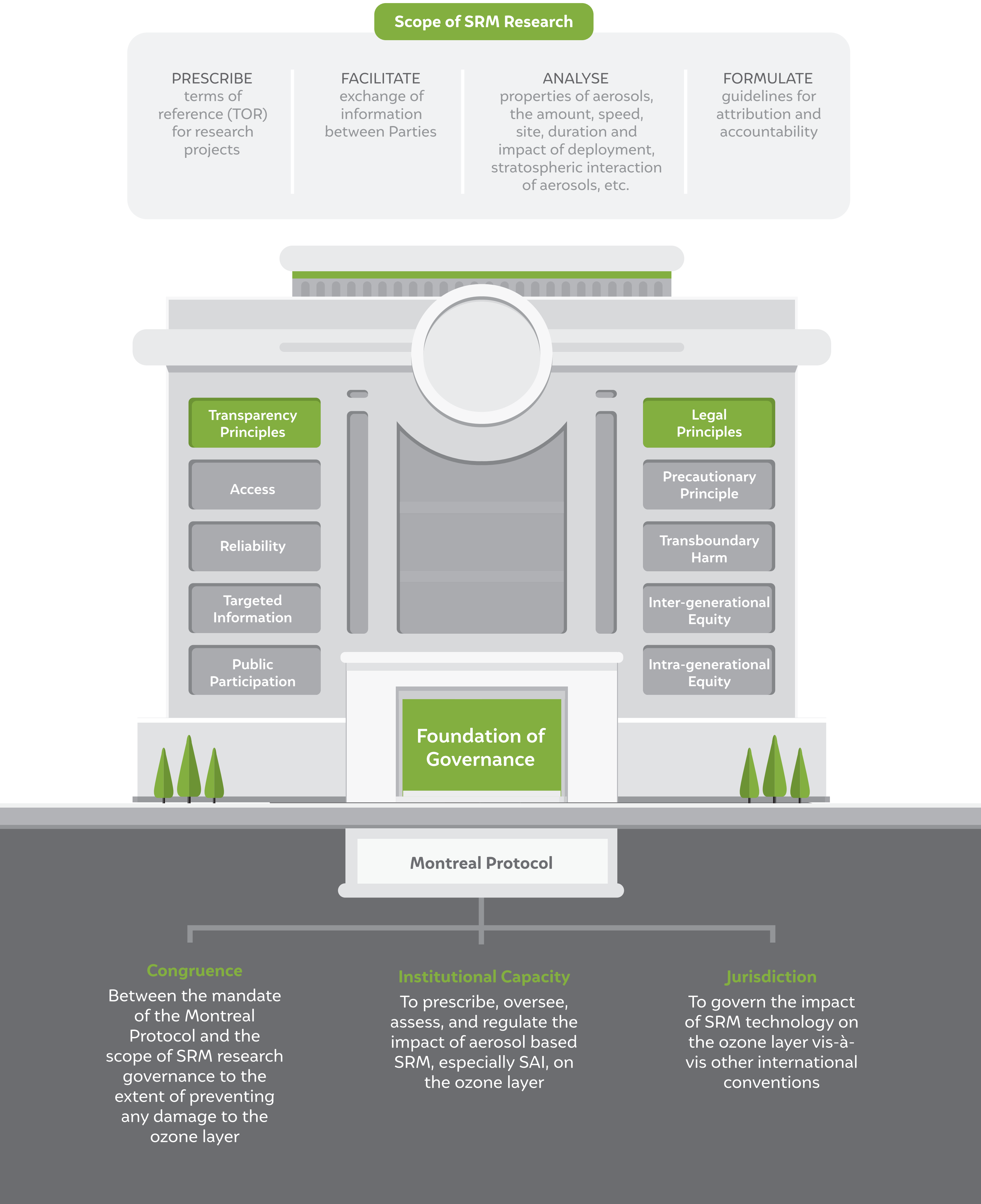
3. **Inter- and intra-generational equity**

   The "unknown unknowns" (Dykema et al. 2014) of solar geoengineering incomprehensibly threaten the stability of our climate. Any adverse impact on the existing and limited natural resources, therefore, could impair their availability for both the present and future generations. This principle stresses on the importance of research that investigates the non-linear impact of SRM technology across planetary boundaries (Stockholm Resilience Centre 2015), thereby streamlining sustainability as the main imperative.

   Any SRM governance framework, therefore, must integrate these dimensions and principles of transparency and international law, in order to remain effective, preventive, and equitable.

9 A Latin legal maxim that means 'one must use his property so as not to injure the lawful rights of another'.

Solar Radiation Management Governance Framework



6. Conclusions

In this issue brief, we have highlighted the urgent need for a governance framework to regulate research on solar geoengineering technology. We propose the Montreal Protocol as a suitable institution for governing SAI technology and other SRM techniques employing ozone depleting substances.

The potential transboundary impacts surrounding SRM, added to the increasing possibility of in situ experimentation necessitate a regulatory framework that advances reliable, responsible, and transparent research focussed on addressing these risks without furthering them. Given the scattered legal landscape for governing geoengineering under different international fora, we suggest the establishment of an overarching convention on geoengineering that aggregates relevant laws to replace the existing ad hocism and uncertainty surrounding its governance.

We, however, acknowledge the existing geopolitical challenges in arriving at such an independent institution. It is, therefore, suggested that the scope of governance under the Protocol could extend to SAI research and other SRM techniques which use ozone depleting substances, including 'controlled substances' mentioned in the Annexes to the Protocol. This legal congruence, between the scope of SAI research, the nature of ozone depleting aerosols, and the Protocol's mandate of ozone protection delineates the Protocol as a coherent governance framework. This research also assesses the existing structural challenges for integrating solar geoengineering into the Protocol, highlighting the institutional strengths that can be leveraged to assess and monitor the scientific, technological, and economic developments. It proposes transparency as an underlying principle for such a governance framework, in addition to principles of international law such as the precautionary principle, inter- and intra-generational equity, and the principle of transboundary harm.

In view of these factors, the Protocol qualifies as a robust and complementary regulatory mechanism for governing SAI research and other SRM techniques using ozone depleting substances, in furtherance of its objective to protect the ozone layer.

References

A-Khavari, Afshin. 1997. "The 1996 Protocol to the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter." *Asia Pacific Journal of Environmental Law*. 2: 207. https://eprints.qut.edu.au/125879/.

Appleton, Asheline, Stefan Jungcurt, Marie-Annick Moreau, Olivia Pasini, Nicole Schabus, and Elsa Tsioumani. 2008. "Summary of the Ninth Conference of The Parties to the Convention on Biological Diversity: 19–30 May 2008." *Earth Negotiations Bulletin* 9, no. 452. http://www.iisd.ca/biodiv/cop9/.

ASOC. 2010. "The Asilomar Conference Recommendations on Principles for Research into Climate Engineering Techniques Conference Report." Asilomar Scientific Organizing Committee. http://www.climateresponsefund.org/images/Conference/finalfinalreport.pdf.

Blackstock, Jason, Ken Caldeira, Paul Crutzen, Arunabha Ghosh, Steven Hamburg, Clive Hamilton, David W. Keith, et al. 2011. "Solar Radiation Management: The Governance of Research." https://royalsociety.org/~/media/royal_society_content/policy/projects/solar-radiation-governance/des2391_srmgi%20report_web.pdf.

C2G. 2021. "Glossary." Carnegie Climate Governance Initiative. https://www.c2g2.net/glossary/.

C2G2. 2019. "Geoengineering: The Need for Governance." Carnegie Climate Geoengineering Governance Initiative. https://www.ceew.in/publications/geoengineering-need-governance.

C2G2. 2021. "Governing SAI." https://www.c2g2.net/wp-content/uploads/governing-sai.pdf.

Convention on Biological Diversity. 2010. "What Is a Clearing House Mechanism?" https://bch.cbd.int/help/topics/en/What_is_a_Clearing_House_Mechanism.html.

Convention on Biodiversity, Secretariat. 2017. "Climate-Related Geoengineering and Biodiversity." Secretariat of the Convention on Biological Diversity. https://www.cbd.int/climate/geoengineering/.

Doughty, Jack. 2019. In *Geoengineering Our Climate ? Ethics, Politics and Governance*, edited by Jason J. Blackstock and Sean Low. London: Routledge.

Dykema, John A., David W. Keith, James G. Anderson, and Debra Weisenstein. 2014. "Stratospheric Controlled Perturbation Experiment: A Small-Scale Experiment to Improve Understanding of the Risks of Solar Geoengineering." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 372: 20140059. http://dx.doi:10.1098/rsta.2014.0059.

EPA. 2021. "Ocean Dumping: International Treaties." United States Environmental Protection Agency. https://www.epa.gov/ocean-dumping/ocean-dumping-international-treaties#US.

ETC Group. 2010. "The Geoengineering Moratorium under the UN Convention on Biological Diversity." https://www.etcgroup.org/sites/www.etcgroup.org/files/publication/pdf_file/ETCMoratorium_note101110.pdf.

FCEA. 2019. "Geoengineering on the Agenda at the United Nations Environment Assembly." Forum for Climate Engineering Assessment. https://ceassessment.org/geoengineering-on-the-agenda-at-the-united-nations-environment-assembly/.

Fuhr, Lili. 2021. "Geoengineering at UNEA-4: Why the SDGs Require a Governance Debate Based on Precaution, Rights and Fairness." https://sdg.iisd.org/commentary/guest-articles/geoengineering-at-unea-4-why-the-sdgs-require-a-governance-debate-based-on-precaution-rights-and-fairness/.

Gardiner, Stephen M., and Augustin Fragnière. 2018. The Tollgate Principles for the Governance of Geoengineering: Moving beyond the Oxford Principles to an Ethically More Robust Approach." *Ethics, Policy and Environment* 21, no. 2: 143–174. https://doi.org/10.1080/21550085.2018.1509472.

Geden, Oliver, and Susan Drogge. 2019. "The Anticipatory Governance of Solar Radiation Management." Council on Foreign Relations. https://www.cfr.org/report/anticipatory-governance-solar-radiation-management

Ghosh, Arunabha. 2019. "Environmental Institutions, International Research Programmes, and Lessons for Geoengineering Research." In *Geoengineering Our Climate?*, edited by Jason J. Blackstock and Sean Low. London: Routledge.

Ghosh, Arunabha, and Blackstock, Jason. 2011. "Does Geoengineering Need a Global Response-and of What Kind?" Paper. New Delhi: Council on Energy, Environment and Water.

Ginzky, Harald, and Robyn Frost. 2014. "Marine Geo-Engineering: Legally Binding Regulation under the London Protocol." *Carbon & Climate Law Review* 8, no. 2: 82–96. https://www.jstor.org/stable/24323921?read-now=1&seq=3#page_scan_tab_contents.

Harvard Solar Geoengineering Research Program. 2019. "Perspectives on the UNEA Resolution." https://geoengineering.environment.harvard.edu/blog/perspectives-unea-resolution.

Harvard University. 2021. "Frank Keutsch—Stratospheric Controlled Perturbation Experiment (SCoPEx) |

Harvard's Solar Geoengineering Research Program." https://geoengineering.environment.harvard.edu/frank-keutsch-stratospheric-controlled-perturbation-experiment.

Hazra, Montu K., Sourav Ghoshal, Prabhash Mahata, and Biswajit Maiti. 2019. "Sulfuric Acid Decomposition Chemistry above Junge Layer in Earth's Atmosphere Concerning Ozone Depletion and Healing." *Communications Chemistry* 2, no. 1: 1–8. https://doi.org/10.1038/s42004-019-0178-4.

Heckendorn, P., D. Weisenstein, S. Fueglistaler, B. P. Luo, E. Rozanov, M. Schraner, L. W. Thomason, and T. Peter. 2009. "The Impact of Geoengineering Aerosols on Stratospheric Temperature and Ozone." *Environmental Research Letters* 4, no. 4: 045108. https://doi.org/10.1088/1748-9326/4/4/045108.

Hubert, Anna Maria. 2021. "A Code of Conduct for Responsible Geoengineering Research." *Global Policy* 12, no. S1: 82–96. doi: 10.1111/1758-5899.12845.

IAEA. 2016. "The Statute of the IAEA," 2–9. https://www.iaea.org/sites/default/files/statute.pdf.

IAEA. 2021. "History." https://www.iaea.org/about/overview/history.

IC Centre for Governance. 2019. *The Journal of Governance*. Vol. 18, Special issue. http://moef.gov.in/wp-content/uploads/2019/10/SpecialEdition_Journal-of-Governance.pdf.

IISD. 2012. "Summary Report: October 2012." *Earth Negotiations Bulletin* 9, no. 595. https://enb.iisd.org/events/cbd-cop-11/summary-report-8-19-october-2012.

IISD. 2019. "Summary of the 4th Session of the UNEA : 11–15 March 2019." *Earth Negotiations Bulletin* 16, no. 153. http://enb.iisd.org/unep/oecpr4-unea4/.

IISD. 2021. "4th Meeting of the OECPR and 4th Session of UNEA: 4–8 March 2019." *Earth Negotiations Bulletin*. https://enb.iisd.org/events/4th-meeting-oecpr-and-4th-session-unea.

IPCC. 2011. "IPCC Expert Meeting on Geoengineering." https://archive.ipcc.ch/pdf/supporting-material/EM_GeoE_Meeting_Report_final.pdf.

IPCC. 2013. "AR5 Climate Change 2013: The Physical Science Basis—IPCC." https://www.ipcc.ch/report/ar5/wg1/.

IPCC. 2021. "AR6 Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change." https://www.ipcc.ch/report/ar6/wg1/.

Jones, Andy, Jim Haywood, and Olivier Boucher. 2009. "Climate Impacts of Geoengineering Marine Stratocumulus Clouds." *Journal of Geophysical Research: Atmospheres* 114 (D10). https://doi.org/10.1029/2008JD011450.

Jungcurt, Stefan, Tallash Kantai, Elisa Morgera, Eugenia Recio, Nicole Schabus, and Elsa Tsioumani. 2010. "CBD COP 10 Highlights Wednesday, 20 October 2010." https://enb.iisd.org/biodiv/cop10/29oct.html.

Keith, David, Stefan Hain, Peter J Irvine, Achim Maas, Nigel Moore, Phil Renforth, Alan Robock, Stefan Schäfer, Harald Stelzer, and Thilo Wiertz. 2015. "An Exploration of a Code of Conduct for Responsible Scientific Research Involving Geoengineering. Introduction, Draft Articles and Commentaries." https://publications.iass-potsdam.de/rest/items/item_1092905_4/component/file_1092906/content.

Kruger, Tim. 2018. "A Commentary on the Oxford Principles." In *Geoengineernig Our Climate?*, edited by Jason J. Blackstock and Sean Low, 190–198. London: Routledge.

Llanos, David. 2015. "Stratospheric Aerosol Injection—Solar Radiation Management." Standford University PH240. http://large.stanford.edu/courses/2015/ph240/llanos2/.

Lin, Albert C. 2016. "The Missing Pieces of Geoengineering Research Governance." *Minnesota Law Review* 100, no. 6: 2509–2576. https://www.minnesotalawreview.org/wp-content/uploads/2016/08/Lin_Online.pdf.

Long, Jane, and Edward (Ted) A. Parson. 2019. "Functions of Geoengineering Research Governance (October 27, 2019)." UCLA School of Law, Public Law Research Paper No. 19-42. http://dx.doi:10.2139/ssrn.3476376.

Geoengineering Monitor. 2021a. "Geoengineering Technology Briefing." https://map.geoengineeringmonitor.org/.

Geoengineering Monitor. 2021b. "Geoengineering Technology Briefing." https://www.geoengineeringmonitor.org/wp-content/uploads/2021/04/surface-albedo-modification. pdf.

National Academies of Sciences Engineering and Medicine. 2021. "Reflecting Sunlight: Recommendations for solar geoengineering research and research governance." National Academies Press. https://www.nap.edu/catalog/25762/reflecting-sunlight-recommendations-for-solar-geoengineering-research-and-research-governance.

Nature. 2021. "Giving research into solar geoengineering a chance." Nature. https://www.nature.com/articles/d41586-021-01243-0

Oxford University. 2021. "The Oxford Principles." http://www.geoengineering.ox.ac.uk/www.geoengineering.ox.ac.uk/oxford-principles/principles/.

Ozone Secretariat. 2021. "Decision I/3: Establishment of Assessment Panels." https://ozone.unep.org/treaties/montreal-protocol/meetings/first-meeting-parties/decisions/decision-i3-establishment-assessment-panels.

Ozone Secretariat. 2021. “Environmental Effects Assessment Panel (EEAP).” https://ozone.unep.org/science/assessment/eeap.

Redgwell, Catherine, Alan Robock, Ken Caldeira, Paul Crutzen, Peter Liss, Granger Morgan, Laban Ogallo, et al. 2011. “Does Geoengineering Need a Global Response-and of What Kind? International Aspects of SRM Research Governance.” https://web.whoi.edu/ocb-fert/wp-content/uploads/sites/100/2017/08/SRMGI-International-background-paper.pdf.

Reynolds, Jesse L. 2019. “Solar Geoengineering to Reduce Climate Change: A Review of Governance Proposals.” *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* 475: 20190255. https://doi.org/10.1098/rspa.2019.0255.

Ripley, Keith, Tallash Kantai, Priscila Pereira de Andrade, and Nadia Sohier Zaman. 2018. “Earth Negotiations Bulletin A Reporting Service for Environment and Development Negotiations MOP 30 #5.” *Earth Negotiations Bulletin*. https://enb.iisd.org/events/30th-meeting-parties-montreal-protocol-substances-deplete-ozone-layer.

Scientific Assessment Panel. 2018. “Scientific Assessment of Ozone Depletion : 2018.” https://ozone.unep.org/sites/default/files/2019-05/SAP-2018-Assessment-report.pdf.

Stockholm Resilience Centre. 2015. “The Nine Planetary Boundaries.” Stockholm University, Stockholm Resilience Centre. https://www.stockholmresilience.org/research/planetary-boundaries/the-nine-planetary-boundaries.html.

The Economist. 2021. “Geoengineering Is Conspicuously Absent from the IPCC’s Report.” https://www.economist.com/science-and-technology/2021/08/14/geoengineering-is-conspicuously-absent-from-the-ipccs-report.

Tingley, Dustin, and Gernot Wagner. 2017. “Solar Geoengineering and the Chemtrails Conspiracy on Social Media.” *Palgrave Communications* 3, no. 1: 1–7. https://doi.org/10.1057/s41599-017-0014-3.

Tollefson, Jeff. 2018. “First Sun-Dimming Experiment Will Test a Way to Cool Earth.” *Nature* 563, no. 7733: 613–615. doi:10.1038/d41586-018-07533-4.

Tollefson, Jeff. 2019. “Geoengineering Debate Shifts to UN Environment Assembly.” *Nature* 567, no. 7747: 156. doi:10.1038/D41586-019-00717-6.

United Nations. 1972. “Report of the UN Conference on the Human Environment.” *United Nations* 4: 127. doi:10.1016/0006-3207(72)90013-4.

United Nations. 1992. “Rio Declaration on Environment and Development.” United Nations Publication. https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.151_26_Vol.I_Declaration.pdf.

UNEA. 2019. “Resolution for Consideration at the 4th United Nations Environment Assembly.” https://geoengineering.environment.harvard.edu/files/sgrp/files/draft_unea_resolution.pdf.

UNEA. 2021. “Fifth Session of the United Nations Environment Assembly.” https://www.unep.org/environmentassembly/.

UNEP. 2018a. “Environmental Effects and Interactions of Stratospheric Ozone Depletion, UV Radiation, and Climate Change.” https://ozone.unep.org/sites/default/files/2019-04/EEAP_assessment-report-2018%282%29.pdf.

UNEP. 2018b. “The Need to Study the Relationship Between Stratospheric Ozone and Proposed Solar Radiation Management Strategies.” https://ozone.unep.org/system/files/documents/MOP30-CRP7.e.docx.

UNEP. 2019. “Report of the Forty-First Meeting of the Open-Ended Working Group of the Parties to the Montreal Protocol on Substances That Deplete the Ozone Layer.” https://ozone.unep.org/system/files/documents/OEWG-41-5E.pdf.

UNEP. 2020. *Handbook for the Montreal Protocol on Substances That Deplete the Ozone Layer (2020)*. https://ozone.unep.org/sites/default/files/2019-07/MP_Handbook_2019.pdf.

UNEP. 2021. “Non-Compliance Procedure.” https://ozone.unep.org/treaties/montreal-protocol/non-compliance-procedure.

United Nations General Assembly. 2005. “Prevention of Transboundary Harm from Hazardous Activities 2001.” *UN*. Vol. 10.

Wieding, Jutta, Jessica Stubenrauch, and Felix Ekardt. 2020. “Human Rights and Precautionary Principle: Limits to Geoengineering, SRM, and IPCC Scenarios.” *Sustainability* 12, no, 21: 8858.. doi:10.3390/SU12218858.

World Meteorological Organization. 2010. “Scientific Assessment of Ozone Depletion: 2010 Executive Summary.” *Scientific Assessment of Ozone Depletion: 2010*. https://csl.noaa.gov/assessments/ozone/2018/executivesummary/#section-4.

Xing, Jia, Jiandong Wang, Rohit Mathur, Shuxiao Wang, Golam Sarwar, Jonathan Pleim, Christian Hogrefe, et al. 2017. “Impacts of Aerosol Direct Effects on Tropospheric Ozone through Changes in Atmospheric Dynamics and Photolysis Rates.” *Atmospheric Chemistry and Physics* 17, no. 16: 9869–9883. https://doi.org/10.5194/acp-17-9869-2017.

Yang, Cheng-En, Forrest M Hoffman, Daniel M Ricciuto, Al -, Katharine L Ricke, Juan B Moreno-Cruz, Ken Caldeira et al. 2020. “The Cost of Stratospheric Aerosol Injection through 2100.” *Environmental Research Letters* 15, no. 11: 114004. doi:10.1088/1748-9326/ABA7E7.

The purpose of further research is to improve our understanding of the scientific uncertainties surrounding SRM, without furthering them.

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