Global Governance Futures

ROBERT BOSCH FOUNDATION
MULTILATERAL DIALOGUES

Human Intervention in the Earth's Climate: The Governance of Geoengineering in 2025+

MASAHIKO HARAGUCHI
RONGKUN LIU
JASDEEP RANDHAWA
SUSANNE SALZ
STEFAN SCHÄFER
MUDIT SHARMA
SUSAN CHAN SHIFFLETT
AKIKO SUZUKI
YING YUAN

MAY 2015

Supported by

Robert Bosch Stiftung

GGF Partners

GPPi
The Tokyo Foundation 東京財団
BROOKINGS
Hertie School of Governance
Keio University
ashoka UNIVERSITY
Woodrow Wilson School

Acronyms

AR5	Fifth Assessment Report of the Intergovernmental Panel on Climate Change
BECCS	Bioenergy with Carbon Capture and Storage
CDR	Carbon Dioxide Removal
COP	Conference of the Parties
GE	Geoengineering
GGRC	German Geoengineering Research Center
INDCs	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel on Climate Change
MoST	Ministry of Science and Technology of the People's Republic of China
SRM	Solar Radiation Management
SRSRM	Special Report on Solar Radiation Management
UNCG	United Nations Convention on Geoengineering
UNFCCC	United Nations Framework Convention on Climate Change

Table of Contents

About the Program

The Global Governance Futures program (GGF) brings together young professionals to look ahead 10 years and to recommend ways to address global challenges.

Building on the success of the first two rounds of the program (GGF 2020 and GGF 2022), GGF 2025 assembled 25 GGF fellows from Germany, China, Japan, India and the United States (five from each country). Over the course of 2014 and 2015, the fellows participated in four dialogue sessions: in Berlin (8-12 June 2014), Tokyo and Beijing (9-15 October 2014), New Delhi (18-22 January 2015) and Washington, DC (3-7 May 2015).

The GGF 2025 fellows – a diverse mix from the public, private and non-profit sectors, and selected from a highly competitive field of applicants – formed three working groups that focused on Internet governance, geoengineering governance and global arms control, respectively. Using instruments from the field of futures research, the working groups produced scenarios for their respective issue areas. These scenarios are potential histories, not predictions, of the future. Based on their findings, the fellows produced a range of publications – including this report – that present recommendations for steps to take on these issues towards a more desirable future.

The greatest asset of the program is the diversity of the fellows and the collective energy they develop when they discuss, debate and engage with each other during the four intense working sessions. This is why the fellows occupy the center stage of the program, setting GGF apart from many other young-leaders programs. The fellows play an active role in shaping the agenda of their working groups. The working process draws upon the GGF method and brings together the unique strengths, experiences and perspectives of each fellow in working towards a common goal. In addition, the fellows meet with leading policymakers and experts from each participating country. The GGF team works closely with the fellows to help them achieve their goals and, in the process, cultivates a community that will last well beyond the duration of the program, through a growing and active alumni network.

GGF is made possible by a broad array of dedicated supporters. The program was initiated by the Global Public Policy Institute (GPPi), along with the Robert Bosch Stiftung. The program consortium is composed of academic institutions, foundations and think tanks from across the five participating countries. The GGF partners are GPPi, the Hertie School of Governance, Tsinghua University, Fudan University, Ashoka University, the Centre for Policy Research, the Tokyo Foundation, Keio University, the Woodrow Wilson School of Public and International Affairs, and the Brookings Institution. The core responsibility for the design and implementation of the program lies with the GGF program team at GPPi. In addition, GGF relies on the advice and guidance of the GGF steering committee, made up of senior policymakers and academics. The program is generously supported by the Robert Bosch Stiftung.

The fellows of the global geoengineering governance working group would like to thank the organizers of GGF 2025, the Robert Bosch Stiftung and everyone else who contributed to making the program possible – especially Thorsten Benner, Michelle Chang, Mirko Hohmann, Johannes Gabriel and Joel Sandhu. We are also grateful to Alex Fragstein for the design work, Oliver Read and Esther Yi for editing and colleagues at GPPi for commenting on this report.

Executive Summary

Introduction

Portrayed by some as a potential way to bypass the political barriers that have stymied action on climate change, and by others as "playing God," geoengineering (GE) has provoked impassioned debate.

Geoengineering, or climate engineering, is the umbrella term for large-scale technological interventions into the climate system that seek to counter some of the effects of global warming. Due to limited progress in reducing global greenhouse-gas emissions thus far, geoengineering has been increasingly investigated as a potential addition to the portfolio of climate responses. At this point, however, the shape and role that geoengineering will take in the future remain highly uncertain. In this report, we look 10 years ahead, at the year 2025, and present two scenarios of geoengineering's possible evolution, with the goal of providing policy recommendations for its effective governance.

Geoengineering technologies are generally divided into approaches that aim to reflect sunlight away from the earth (solar radiation management, SRM), and approaches that aim to remove carbon dioxide from the atmosphere (carbon dioxide removal, CDR). This report focuses on SRM interventions, and particularly on those methods that aim to reflect sunlight by injecting reflective particles into the stratosphere.

Such interventions raise important governance issues that are different from those raised by CDR techniques. This is because SRM would have a quick, global effect, could be deployed by a single actor or a small group of actors at a relatively low cost, and would have different impacts on different regions of the world. SRM is also likely to be perceived as a more fundamental intervention than CDR into the workings of the planet, with the potential for significant societal conflict to result from different worldviews and value systems. Most CDR technologies, on the other hand, would act only over long timescales, are prohibitively expensive at the moment and would require collaboration between many actors in order to have a significant effect on the climate.

SRM has also generated various concerns. First, it has been argued that SRM would create a "moral hazard" by reducing the incentive for states to engage in mitigation and adaptation efforts, for SRM may prove to be faster, cheaper and less difficult to agree upon in international negotiations. Second, its potential impacts are highly uncertain. Factors that will be particularly difficult to predict and understand include regional and local impacts on agricultural production, water resources and biodiversity. Third, it has been questioned whether it is ethically permissible to interfere with Earth-system processes at such a fundamental level.

The global governance of SRM will have to take these concerns into account. Although SRM is still in its infancy and may take decades to research, develop and deploy, it is precisely this early stage of development that offers a critical window of opportunity for developing collaborative and inclusive approaches to effective global governance of the potential SRM lifecycle, or parts thereof.

Scenarios

We consider the above characteristics of SRM and the concerns it generates in two hypothetical scenarios set in the year 2025:

1. Mitigating for the Future?: The first scenario describes a world that achieves a binding agreement on reducing greenhouse-gas emissions and yet experiences unilateral SRM testing in the absence of global SRM governance.

2. Geoengineering the Future?: The second scenario describes a world in which negotiations at the United Nations Framework Convention on Climate Change (UNFCCC) fail to reach a binding global agreement on reducing emissions, leading involved parties to pay greater attention to SRM as a potential means of reducing expected climate-change impacts, and to its governance.

SCENARIO 1: MITIGATING FOR THE FUTURE?
In this scenario, countries are in the process of implementing binding emissions reductions that had been agreed upon at the Conference of the Parties of the UNFCCC in 2017. While the rate of global emissions is on a downward trend, the overall stock of greenhouse gases in the atmosphere continues to cause climate-related natural disasters. Agreement on reducing emissions has lessened concerns about the possibility of SRM creating a "moral hazard" by lowering the incentive for states to engage in mitigation and adaptation efforts; as a result, SRM research has been given a measure of legitimacy. With the onslaught of recent natural disasters, there is a renewed sense of urgency to pursue SRM research. At the same time, there is a lack of concerted effort to govern or collaborate on geoengineering. Therefore, some countries engage in unilateral research and testing of SRM approaches. These unilateral activities breed mistrust among countries when it comes to issues of SRM testing and deployment plans.

SCENARIO 2: GEOENGINEERING THE FUTURE?
In this scenario, there is no global binding agreement on reducing greenhouse-gas emissions. The Intended Nationally Determined Contributions (INDCs) are vastly insufficient for keeping global warming below the 2°C threshold. With global greenhouse-gas emissions still rising, climate change continues to be perceived as one of the most serious and urgent threats to society and the economy. The increasing severity and frequency of climate-related natural disasters increase interest in SRM. Public funders and non-profit foundations support initial research on SRM, and commercial capital soon gets involved, with expectations of financial returns from a new technology that the world desperately needs. A major international research collaboration on SRM begins, which leads to a breakthrough in the technology and eventually to its deployment under a newly established global convention on geoengineering, which is ratified by a majority of UN member states. Although the deployment is intended only to reduce the near-term impacts of climate change while the economy transitions to carbon-neutral production, critics point out that it is unlikely that deployment will be time-limited, given the heavy investment of private capital and a new economic sector emerging from the supplying of technological components to SRM.

Policy Recommendations

We identified the following as crucial elements of the global governance of SRM:

- Inclusiveness;
- Transparency in decision-making;
- Promotion of research collaboration and consultation;
- Prevention of large-scale testing and deployment in the absence of a binding agreement on SRM.

Our recommendations call for greater collaboration between science and policy communities. Scientists should embrace values such as transparency and inclusiveness, and build on the strong history of international cooperation in research. This can contribute significantly to effective and accountable international governance.

The policy recommendations presented in this report are based on these principles of SRM governance, with implications drawn from the specific scenarios. Our recommendations also have implications for the global governance of geoengineering more broadly, and focus on three areas:

Publish an Intergovernmental Panel on Climate Change (IPCC) special report on SRM. In the case that SRM research intensifies significantly, the IPCC should publish a comprehensive assessment of the latest results of SRM research to identify research priorities and possible ways forward, and to ensure that state-of-the-art scientific results are comprehensively collected in a central, accessible document. Such reports may, depending on scientific progress, be published on a semi-regular basis.

Form a UN advisory board on SRM. If SRM research gains momentum and proceeds significantly, an advisory board should be established under the auspices of the UN that discusses the socioeconomic context of, and ethical questions raised by, SRM, within the larger context of geoengineering, climate change and sustainability. The board should encompass a broad spectrum of expertise and backgrounds in the public, private and civil society sectors.

Create a new negotiation track for geoengineering under the UNFCCC. Irrespective of the outcomes of the current UNFCCC negotiations, scientific and regulatory attention should be paid to SRM as a potential supplement to mitigation and adaptation efforts. According to our scenarios, one of the key opportunities for regulating SRM is to have a global body be held responsible for the governance of SRM and other geoengineering techniques. The UNFCCC is currently the most suitable forum within which to create a new multi-stakeholder negotiation track, in coordination with other bodies that have already adopted the topic (for example, the Convention on Biological Diversity, and the London Dumping Convention and its 1996 Protocol).

Introduction

Geoengineering[1] – large-scale technological intervention into the climate system to counteract some of the effects of global warming – has been receiving greater attention against the background of faltering progress in reducing global greenhouse-gas emissions. As it appears increasingly difficult to keep global climate change and its impacts under control, proponents view geoengineering as a promising addition to adaptation and mitigation efforts in the portfolio of potential climate responses. At this point, it remains highly uncertain whether geoengineering will ever be used, and whether such use would be in the form of an addition to, or a substitute for, mitigation and adaptation efforts.

The purpose of this report is to look ahead approximately 10 years from now – at 2025 and beyond – and present two scenarios for how developments concerning geoengineering and its governance may unfold, and to derive policy recommendations from these scenarios. The scenarios and recommendations presented in this report are the product of a structured group process that is specified in the annex.

Definition of Geoengineering

The United Kingdom's Royal Society defines geoengineering as "deliberate large-scale intervention in the earth's climate system, in order to moderate global warming." In other words, the term "geoengineering" is very broad and encompasses a wide range of approaches – from the purely hypothetical, such as the injection of sulfate aerosols into the stratosphere to reflect sunlight away from the earth, to technologies that are currently being implemented at the pilot stage, such as bioenergy generation with subsequent carbon capture and storage (BECCS).

Geoengineering approaches are conventionally divided into two broad categories (see Figure 1):

- *Solar radiation management (SRM):* approaches that aim to reflect a fraction of incoming sunlight away from the earth, eg, by introducing reflective aerosol into the atmosphere.
- *Carbon dioxide removal (CDR):* Approaches that aim to remove carbon dioxide from the atmosphere, eg, by enhancing carbon uptake in ecosystems.

[1] *The terms "geoengineering" and "climate engineering" are synonymous and used interchangeably. We have chosen "geoengineering" as the consistent term of use in this report.*

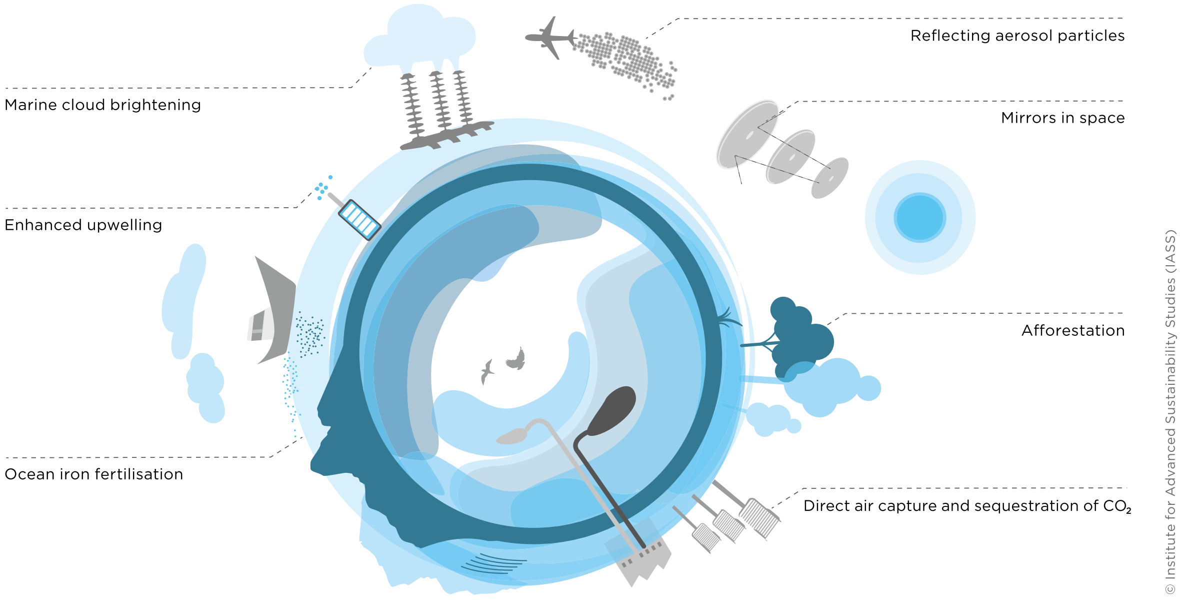

Figure 1: Different Geoengineering Approaches[2]

Scope of Report

This report focuses on SRM. SRM has been described as potentially "fast, cheap and imperfect."[3] Were SRM to prove effective, it would be the only known method of reducing some of the near-term impacts of climate change that cannot be addressed by mitigation and adaptation. Yet it is characterized by high uncertainty, and controversy over SRM is likely to result from the different worldviews and value systems that individuals bring to bear on the topic. This is already relevant in the early research stages and produces a specific need for governance.

[2] *Sean Low, Stefan Schäfer and Achim Maas, "Climate Engineering" (Potsdam: Institute for Advanced Sustainability Studies, 2013).*

[3] *Juan B. Moreno-Cruz, Katharine L. Ricke and Gernot Wagner, "The Economics of Climate Engineering" (Geoengineering Our Climate? Working Paper and Opinion Article Series, 2015).*

Scientific Background on Solar Radiation Management

Solar radiation management (SRM) aims to reflect a fraction (on the order of a few percent) of incoming sunlight away from the earth, in order to address some of the impacts associated with climate change. Examples for how this might be achieved include introducing reflective aerosol particles into the stratosphere, or increasing the brightness of marine clouds by seeding them with sea-salt particles. While analyses suggest that these approaches are plausible, neither has been proven to be effective.

Currently available evidence is limited, but early results from computer-modeling studies suggest that SRM could address many of the physical impacts of climate change that are associated with rising mean temperatures (such as glacial melt, rise in sea level and more droughts and floods). In addition, SRM – if shown to be feasible and effective – could be a way to address some of the impacts of near-term climate change. It would affect atmospheric processes almost immediately, whereas the climate effects of reducing emissions take far longer to manifest.

Thus, SRM could potentially help prevent the crossing of "tipping points" in situations where such events could otherwise not be avoided due to past emissions. It is possible that SRM could even reverse some tipping points after they have been crossed, or reduce the rate of change after the crossing of a tipping point.

However, regional responses to SRM would differ, and past climates cannot be perfectly reproduced, which has led to discussions about potential "winners" and "losers." Also, SRM is not designed to address other impacts of increased concentrations of greenhouse gases in the atmosphere, notably ocean acidification. Research on and development of SRM technologies are at a very early stage, and have mostly been confined to computer modeling and laboratory studies.

The technological characteristics of SRM will be determined by design choices and are not inherent to SRM itself. However, SRM is frequently presented as possessing the following technological traits:[4]

- *Effectiveness:* A comparatively small amount of material injected into the stratosphere could quickly affect global mean temperatures.
- *Speed:* SRM would affect atmospheric processes almost immediately. Thus, SRM is unique for its potential to address some of the near-term impacts of climate change. The effects of other measures to counteract climate change, such as CDR and mitigation, would only manifest on longer timescales.
- *Low costs:* SRM has the potential to reduce some of the effects of climate change at a relatively low cost – at least in comparison to the costs associated with the expected impacts of climate change. Nevertheless, SRM research is still in its early stages, and the full costs of deploying an SRM technology on a large scale are currently unknown.
- *High risks:* SRM is laden with unknowns, especially regarding its impact on, for example, agricultural production, water resources, biodiversity and stratospheric ozone.

[4] *Daniel Bodansky, "Governing Climate Engineering: Scenarios for Analysis" (Cambridge, MA: Harvard Project on Climate Agreements, November 2011).*

Some of the major concerns voiced about SRM are associated with these characteristics:

- *SRM could produce "winners" and "losers."* SRM impacts would not be distributed equally, and some countries and regions may benefit more than others, so that some regions might consider themselves "winners" and others "losers" based on SRM impacts.

- *SRM could be deployed unilaterally.* SRM could be deployed by a single state or a powerful coalition, even against the will of those who would be affected by such action.

- *SRM could create a "moral hazard."* SRM could lower the incentive for states to engage in mitigation and adaptation efforts.

- *SRM could be perceived as "playing God."* Some critics argue that SRM should never be implemented because it amounts to "playing God" by interfering with processes that are fundamental to life on Earth.

There is a need for SRM governance to take these concerns into account, and to allow for the accommodation of different worldviews and value systems in determining the future of SRM (including whether it should have one). Depending on their purpose and the concerns they are intended to address, individual governance measures can range from discussions between experts and societal stakeholders, to legally binding regulation at the national or international level.

We acknowledge that discussions on SRM are situated within a broader context of geoengineering approaches, climate change and sustainability (see Figure 2). Discussions on global geoengineering governance reflect the increasing challenges the world faces with the emergence of new technologies that have transboundary impacts, ranging from information technology to the use of unmanned aerial vehicles for military and civilian purposes. SRM thus needs to be understood in this broader context, taking into account various intersecting and partially overlapping topics and trends of global relevance.

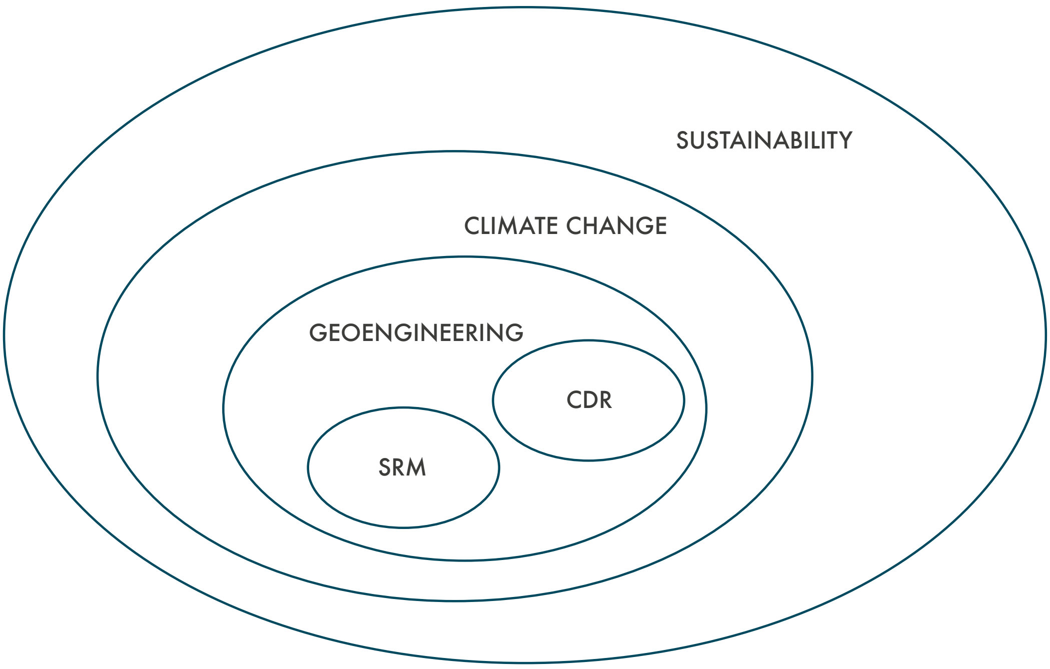

Figure 2: Geoengineering in Context

Geoengineering Governance: Why Look Ahead to 2025 and Beyond?

The temporal scales that need to be taken into consideration when discussing geoengineering approaches vary markedly between techniques. Some technologies, such as BECCS, are currently being implemented at the pilot stage, while the implementation of an SRM approach could happen decades into the future, should it ever occur. This report focuses on SRM, and it may seem premature to discuss governance of a technology that could be 15 to 50 years away from deployment. However, especially at such early stages of technological development, there is a critical window of opportunity for beginning to establish an appropriate global governance structure. This structure has to be designed with all possible developments in mind. Our aim is to anticipate alternative futures, allowing us to derive robust policy recommendations that are capable of addressing a set of potential events and developments that might emerge in the future (our methodology is explained in detail in the annex).

The current round of the Global Governance Futures program looks ahead to 2025. For the field of geoengineering, which is only now beginning to emerge and in which future developments are highly uncertain, this timeframe of 10 years seems rather short and too definite. Therefore, the scenarios produced in this report do not necessarily correspond to what might be expected as realistic over the next decade. Nonetheless, it is plausible to assume that the sequences of events described in this report could happen – albeit not in the exact timeframe considered, but later.

Scenario 1: Mitigating for the Future?

YEAR	EVENT
2015	Paris UNFCCC Conference of the Parties (COP) fails.
2017	Maldives COP succeeds, and an international binding agreement takes effect.
2017-2020	Major emitters invest in mitigation and finance adaptation measures in developing countries.
2018	US and China invest in geoengineering research without much international cooperation or a global governance framework in place.
2018-2020	US Midwest experiences severe droughts, leading to rise in food prices.
2021	US emergency-response bill includes $2 billion of funding for geoengineering research and testing.
2022-2025	NGOs, the media and the public are aware of SRM and voice differing opinions.
2025	US and China announce plans to conduct large-scale SRM without a global governance framework in place.

Figure 3: Timeline of Scenario "Mitigating for the Future?"

TENSIONS FLARE OVER PLANNED CHINESE AEROSOL-INJECTION TEST

New York International Times, 7 July 2025

At a United Nations General Assembly meeting yesterday, tensions flared once again between major powers over the issue of solar-geoengineering research. Several attendees, who asked to remain anonymous, said that Indian officials walked out of the room during a heated discussion on the Chinese Ministry of Science and Technology's (MoST) announcement last week of its plans to conduct a large-scale test of solar radiation management (SRM) – a technology that aims to reduce the impacts of global climate change by reflecting incoming sunlight away from the earth.

Ever since the United States and China conducted their first small-scale SRM tests a few years ago, the international community has been wary. The technique involves injecting reflective sulfate aerosols into the stratosphere, about 25 kilometers above the surface of the earth. While the science behind SRM has significantly advanced in recent years, the effects of large-scale tests remain difficult to predict.

China and United States Move Ahead on Geoengineering

After it became clear to decision-makers in the late 2010s that climate change could not be stopped with mitigation efforts alone (regardless of scale and costs), China and the US began to actively pursue their own research programs on SRM. Due to the lack of international coordination on the issue, however, these programs have thus far avoided moving from small-scale tests to larger-scale field trials.

Recent events have altered this situation, which had long appeared to be stable. The western region of China experienced a severe drought last year, resulting in millions of climate refugees pouring into eastern provinces. China declared a "climate emergency" and mobilized billions of dollars to finance further adaptation measures for easing climate-change impacts on its drying-out western regions. It did not come as a surprise when MoST announced that it wanted to reduce its expensive mitigation program in order to finance adaptation measures.

In light of these developments, MoST announced its plans for an SRM climate-impact experiment that would be carried out over 10 years in order to measure the global climate response to the injection of large amounts of sulfur into the stratosphere. In response to China's announcement, the US has suggested that it may also consider conducting a large-scale experiment, and that collaboration would be crucial to prevent the experiments from interfering with each other. But the absence, at the international level, of an institutionalized governance framework that could convey multilateral legitimacy upon such an enterprise means that conflict over this planned experiment is almost certain.

Such large-scale field tests would have impacts that are not restricted to the territory of the implementing state. Both China and the US point out that the large-scale tests could reduce the frequency and severity of natural disasters, like the floods in Bangladesh (in 2024, massive flooding across Bangladesh killed 10,000 people and left hundreds of thousands homeless, drawing greater attention to SRM as a potential means of reducing the frequency and severity of such floods). But the international community faces a potentially dangerous situation, for the new technology also comes with many uncertainties and high risks.

Successful 2017 Maldives COP Builds on Failure of 2015 Paris COP

The current situation can be better understood in the context of developments in SRM research and governance over the past decade.

"The 2015 Paris COP [Conference of the Parties] failed to achieve binding emissions-reduction targets because developing countries such as China felt that they were being asked to take on too much of a burden," said Zhou Shijing, a professor at Renmin University of China. "However, it became clear that major emitters were, in principle, willing to constructively engage in further negotiations. This paved the way for the 2017 Maldives COP, which concluded with ambitious pledges towards globally agreed-upon targets."

Analysts have pointed out that the successful negotiations at the 2017 COP and the consequent high hopes for preventing the exacerbation of climate change may have led to the neglect of geoengineering in international discussions and to the continuation of research without international coordination. Subsequently, countries have kept their pledges and set the world on the right path for reaching peak emissions in 2030.

As Attention Strays From Geoengineering Governance, Small-Scale Tests Begin

With international attention focused on domestic implementation of the agreed-upon emissions-reduction targets and on the supply of adaptation assistance from richer countries to poorer ones, SRM was largely absent from the international political agenda in the late 2010s. Research continued nonetheless, but it was carried out without meaningful opportunities for collaboration at the international level and thus remained mostly at the level of individual researchers and publicly funded research groups.

Impacts of climate change became more severe, especially in developing countries in Africa and Asia. Some researchers and policymakers argued that SRM could provide an important tool for addressing some of the near-term climate impacts that cannot be addressed by mitigation, but they failed to spur global cooperation in research or governance. Institutionalized cooperation and governance – beyond existing measures of peer review, voluntary adherence to suggested norms (such as those contained in the Oxford Principles[5]), environmental-impact assessments (where required under national law) and the decision-making procedures of funding bodies – still remained absent.

Commentators have pointed out that the 2017 binding agreement on reducing emissions may have contributed to making research funders more comfortable with funding solar-geoengineering research, even in the absence of international agreement on the issue. In a series of small-scale tests in 2017 and 2019, the US positioned itself as a forerunner of solar-geoengineering science. Efforts in the European Union remained limited to modeling studies and laboratory research. China, however, announced a significantly ramped-up solar-geoengineering research budget under its national research framework, announced in 2020.

Chinese familiarity with, and general acceptance of, weather-modification research provided fertile ground for SRM testing. While no large-scale testing of the technology has occurred until now, last week's announcement of Chinese plans for a large-scale climate-response test does not come entirely unexpected against this background.

SRM Controversy Emerges, Research Continues

Notwithstanding the successful implementation of emissions-reduction measures worldwide, severe droughts repeatedly hammered the American Midwest between 2018 and 2020. Farmers across the Midwest, particularly in Iowa, saw their corn and soybean harvests drop to century-year lows, crippling the US food supply and exports. Since China relies on the US for half of its soybeans (commonly used for livestock feed and cooking oil), the commodity's price on the global market more than doubled. Global food prices skyrocketed, and American consumers saw their average weekly grocery bill increase from $100 to $140. At the same time, incomes were stagnant throughout the previous three years, and the American public was desperate for food prices to return to pre-drought prices.

[5] *The Oxford Principles are five guiding principles for the governance of geoengineering that were proposed by the Oxford Geoengineering Programme in 2009.*

Given this situation, scientists' demands that SRM be considered a serious option in the quest to ward off the worst impacts of climate change fell on fertile ground. Climate-modeling research had long established that the intensity of extreme events like the Midwest drought could, on average, be reduced by lowering global average temperatures. With rising temperatures, the atmosphere's capacity to hold water had increased, so that precipitation events were less frequent but more intense, leading to prolonged periods of drought in some regions and severe flooding in others. A reduction of global average temperatures was expected to reverse this trend. In the context of the Midwest drought, policymakers thus saw an option to directly address concerns about recurring drought events by investing in SRM research. In 2021, the US Congress passed an emergency bill that injected additional capital of $2 billion into solar-geoengineering research.

After the introduction of the emergency bill, the US media began to regularly report on advances in SRM research, and NGOs paid closer attention to the results achieved by scientists. As a result, the public was aware of ongoing geoengineering research, and public perception depended, to a strong extent, on these mediators.

When a group of prominent scientists claimed that the consequences of a global deployment of SRM geoengineering could never be predicted precisely and that catastrophic "black swan" events could not be ruled out, the public opinion of geoengineering soured. NGOs like Geoengineering Watch pointed out that even discussions on SRM could potentially distract from mitigation efforts, and that implementing formal governance arrangements could facilitate research that is eyed suspiciously by the public. Other NGOs felt that there was a responsibility to research every possible option that might alleviate the increasing impacts of climate change, which are particularly threatening to the world's poorest and most vulnerable populations. With NGOs representing split opinions, and with controversy limited to an interested but small public, SRM research continued, and governance efforts remained absent.

The Absence of Geoengineering Governance Leads to Mistrust

Scientists have long pointed out that even with successful mitigation measures in place, climate change will continue throughout the next decades. Concentrations of carbon dioxide in the atmosphere are still high, and temperatures have risen by 1.3°C, from the pre-industrial global average.

"Over the last 10 years, globally the data shows that we have undoubtedly experienced an increase in climate-related natural disasters such as floods, droughts, heat waves and storms," said John Stevenson, a professor at Harvard University's Belfer Center for Science and International Affairs. "Over the next decade, this trend will only continue."

SRM is increasingly becoming an option, but there is no binding, specific and formal international legislation in place to govern it. While countries have been increasingly eager to explore SRM as a potential tool for addressing some of the near-term impacts of climate change, the lack of international agreement has brewed mistrust among some of the major international powers.

Thus, mistrust regarding unilateral SRM testing and deployment plans dominates the geoengineering space, intensified by MoST's announcement last week of its plans to conduct a large-scale SRM test. Will China go ahead with its plans even in the absence of global governance, thus risking the escalation of international tensions? Or will countries use this occasion to embark upon the creation of global norms to govern geoengineering research and deployment? We must wait for the answers to emerge.

Opportunities and Threats

OPPORTUNITIES	THREATS
While research is still at an early stage, there is a window of opportunity to build cooperation on SRM. This will create important precedents for later, larger-scale activities.	Most countries do not have a voice in geoengineering or geoengineering governance, as no forum for ensuring inclusiveness in geoengineering governance is established before international tension arises over the large-scale testing of SRM.
	The actors in this scenario consider geoengineering a separate policy field, disconnected from other climate-response strategies. This could lead to a shift in focus from mitigation to SRM.
	The main threat of this scenario is the general lack of attention to SRM governance.

The core dynamic of this scenario stems from the tension between the continued scientific interest in SRM research and the absence of international governance structures to guide research and to eventually coordinate larger-scale activities. In this scenario, the absence of SRM governance is explained to a significant extent by political inattention to the subject, due to successes at the UNFCCC climate negotiations. With emissions seemingly under control, and perhaps out of fear that drawing political attention to the subject might prove unpopular, political decision-makers neglect the near-term risks that might result from already heightened concentrations of greenhouse gases in the atmosphere.

Continued scientific interest, however, is met with the greater willingness of funding agencies to support SRM research. In a dynamic similar to that which leads to political inattention to the subject, funders feel more comfortable funding SRM research after climate action at the international level is perceived to have been successful. The achievement of global agreement on reducing emissions releases SRM from the stigma of being an excuse for inaction on emissions reductions. This scenario thus highlights that action on reducing emissions may be a prerequisite for increased funding for SRM research (whether this is achieved via the UNFCCC negotiations or some other process).

The scenario also highlights the dangers of neglecting to address the concerns associated with SRM. Especially when research moves from smaller- to larger-scale tests, international agreement becomes indispensable for avoiding conflict. That said, while the scenario just outlined focuses on the international political dimensions of SRM research with transboundary impacts, it is also important to emphasize that smaller-scale activities may suffer from a lack of acceptance if early governance cannot accommodate diverse worldviews and value systems that existed before and during the research process.

Scenario 2: Geoengineering the Future?

YEAR	EVENT
Continuous	Natural disasters strike around the world with serious consequences, leading to domestic and international conflicts.
2015	UNFCCC negotiations fail. All of the countries' pledges add up to far fewer than needed in order to keep global warming below the 2°C threshold. Other fora come up. Greenhouse-gas emissions keep rising.
2016	US billionaire Steve Herzer backs and funds geoengineering research.
2020	EU, US, Japan, India, Brazil, China and others increase funding for geoengineering research and actively cooperate on its governance.
2022	Founding of the UN Convention on Geoengineering (UNCG).
2024	NGOs and the global public start to perceive geoengineering as a necessary component of the climate-change response portfolio.
2025	Ratification of UNCG. First SRM deployment.

Figure 4: Timeline of Scenario "Geoengineering the Future?"

NEWS

WORLD'S FIRST SOLAR-GEOENGINEERING DEPLOYMENT TAKES OFF, UN CONVENTION ON GEOENGINEERING RATIFIED

Technology Review, 14 November 2025

All over the world, people tuned into their TVs to witness the first successful deployment of a solar radiation management (SRM) technology. Yesterday, the International Research Consortium, led by the German Geoengineering Research Center (GGRC) in Berlin, successfully deployed an SRM technology for the first time in history. Hundreds of airplanes flew from a strip near the equator, injecting sulfur aerosols into the stratosphere, 25 kilometers above the surface of the earth.

As scientists and engineers celebrated the culmination of years of hard work, industrial tycoon Steve Herzer, whose company provided key technology for the deployment, said, "This new technology is not only cost-effective but, more importantly, the seed for developing a large and highly profitable economic sector to supply components of SRM technology in the near future."

The injection of sulfate aerosols is expected to lead to an increased reflection of solar radiation away from the earth. Thorsten Bach, the lead GGRC scientist, said, "We have high hopes that over the coming decades, we'll see reduced global average temperatures with positive impacts on water-food-energy systems globally."

Natural disasters like Typhoon Ana – which killed 10,000 people and decimated communities across the Philippines last month – have increased in severity, with droughts and floods threatening communities worldwide as sea levels keep rising. Floods continue to ravage Eastern Europe, prompting large-scale migration to the European Union and Russia. Russia, already facing increasing economic isolation, is especially hard-pressed to take in more immigrants. Droughts and floods are also increasingly common in India, Africa, China and South America, where resulting hardships have contributed to several instances of severe social unrest and political instability. Tropical Cyclones Amy and Nishiba, which hit Tokyo and New York, killed over 2,000 people and caused economic damage of $500 billion, even in these highly developed countries, stoking fears across the globe.

"The risks of deploying SRM are far lower than the risks of allowing climate-related natural disasters to continue unabated, from Typhoon Ana to Cyclones Amy and Nishiba," said Shihoko Doma, a geology professor at Columbia University.

The recently ratified United Nations Convention on Geoengineering (UNCG) provides a forum for states to negotiate the extent of SRM that is to be undertaken.

SRM Deployment as Byproduct of Failed 2015 Paris Climate Conference

Yesterday's SRM deployment has been a long time coming. Many would say that the starting point was the UN Framework Convention on Climate Change (UNFCCC) conference in Paris in 2015, which, in the lead-up, had been billed as potentially delivering the ambitious and global political agreement needed for climate-change mitigation. Expectations had been high for a global agreement based on reduction pledges by all countries – called Intended Nationally Determined Contributions (INDCs) – that would add up to enough to keep global warming below 2°C in the 21st century.

Negotiations, however, once again ended in a stalemate between developed and developing countries. In the end, the pledges made by countries fell short of what had been hoped for. In the years following the failed Paris negotiations, and as emissions continued to soar, it became clear that not even these low pledges would be kept. As a result, major actors withdrew from the UNFCCC process, and hopes for securing a reduction in global emissions under the UNFCCC vanished.

Industry Pours Funds Into Geoengineering Research

Against this backdrop, scientists in several countries cooperated on SRM research and had access to significant and increasing funding from both public and private sources. Initial private funders were motivated by a desire to find innovative solutions to the largest global threat of the 21st century. The most important funder and early supporter of geoengineering research was Steve Herzer, a US entrepreneur who spent millions of dollars on early research and field tests, as well as on a media campaign in support of SRM research. As research on SRM technology progressed and deployment began to seem less far-fetched, venture capitalists also started to invest, expecting significant financial returns from a new technology that the world would desperately need.

The major international research collaboration, which was based on earlier work but gained momentum in 2020, has been actively supported by the US, the EU, Japan, India, Brazil and China. The GGRC, which coordinated yesterday's successful deployment, quickly developed into a leading institution on geoengineering. In less time than expected, GGRC researchers reached a major breakthrough and developed an SRM technology that was widely considered to be feasible and cost-effective. This development reached its next stage with yesterday's first large-scale deployment.

The deployment involved specialized airplanes injecting sulfur into the stratosphere, 25 kilometers above the surface of the earth. The particles scatter sunlight and lead to a lower incidence of solar radiation on the earth's surface. The effect is expected to last around two years and could then be repeated as needed. Models have shown that cloud formation in the troposphere will not be affected by the released sulfur, and that stratospheric ozone levels will not be significantly affected.

Accordingly, major companies have shown significant interest in various components of the new technology in order to gain a competitive advantage in this emergent economic sector. Public-private partnerships are set to be a driving force of future developments in SRM technology.

Growing Political Support for Geoengineering

What in hindsight appears like a natural progression of events may have seemed far-fetched in 2015, especially with regard to the political support that SRM enjoys today.

In the late 2010s, NGOs began to participate in the conversation. This put states under pressure to coordinate a political response to the ongoing and growing research efforts. After lengthy and complex informal discussions, states agreed to initiate formal global discussions on geoengineering within a new framework. Fresh from the failure of negotiations under the UNFCCC, governments needed to show that they were able to cooperate in solving urgent global crises, especially since severe climatic natural disasters continued to occur frequently. Fearing severe criticism from NGOs and the global and domestic public, many governments quickly agreed to convene a High Level Political Forum on Geoengineering.

Creation of a Specialized UN Body: The UNCG

In 2022, the High Level Political Forum on Geoengineering convened at the UN headquarters in New York and produced a proposal for a UN Convention on Geoengineering (UNCG). The UNCG established rules for conducting field tests in SRM, and created a technical body to coordinate research activities, a scientific advisory body to regularly assess the latest SRM research, a permanent secretariat and a dispute-resolution mechanism. The UNCG enjoyed broad support from the outset. It quickly became apparent that countries would rather be members of an institution that develops SRM – so as to be able to guide such development and to ensure that eventual deployment aligns with their own interests as much as possible – than be left out and risk not having a say in a matter that is bound to affect everyone. Last month, the prerequisite 80th UN member state ratified the UNCG, which consequently came into force on 16 October 2025.

Experts and political commentators attributed the quick political agreement to the fast progress of research efforts, culminating in yesterday's breakthrough by the international research and technology collaboration led by GGRC. The emerging industrial sector supplying the airplanes, chemicals and other complex component technologies for SRM is expected to grow quickly.

OP-ED

MAJOR TECHNOLOGICAL BREAKTHROUGH IN GEOENGINEERING AT THE EXPENSE OF SUSTAINABILITY

Technology Review, 14 November 2025

Yesterday's so-called "successful deployment" is neither a deployment nor a success.

First of all, the "deployment" was intended to test the technique's climate effects. Re-branding this test as a deployment neglects the fact that it remains unclear whether injecting aerosol particles into the stratosphere will produce the desired outcomes – and only the desired outcomes. Over the last few years, laboratory experiments and small-scale tests may have brought new insights. However, they have never been able to simulate the effects of solar radiation management (SRM) deployment. Yesterday's "deployment" was designed to be a test in which all of humanity is used as a guinea pig.

Secondly, as long as we don't know all of the side effects, we cannot talk about success. We must wait and see how the massive injection of particles will play out. We can be quite certain that it will decrease the global temperature, and we can also be certain that it will lead to better climatic conditions for the parties that ratified the United Nations Convention on Geoengineering (UNCG), for it is they who now decide where to set the world's thermostat. However, it is still highly uncertain how yesterday's test will alter the climatic parameters in all global regions, and locally.

It is mere propaganda to call a risky test a successful deployment. Nobody knows this better than the entrepreneur who is pulling the strings behind the scenes, Steve Herzer. His pro-SRM media campaign is testament to this.

Yesterday's SRM deployment makes a revitalization of the UN Framework Convention on Climate Change (UNFCCC) process even less likely than before, though the world needs nothing more than joint action on reducing emissions. Is it still clear that the UNCG's goal is to stave off global warming long enough to allow the world the time to make the economic and social changes needed to cut greenhouse-gas emissions by the necessary amounts? Even the lead article of today's Technology Review did not mention this small but important fact. Or is SRM here to stay forever? A transformative reduction in carbon emissions through mitigation measures by the countries that agreed to use SRM as a transitional measure is yet to be seen. In addition, the large industrial sector being developed for geoengineering will surely prefer to keep up sulfur-aerosol injections for longer than currently foreseen, simply to guarantee its own continued existence and profitability. This is Economics 101.

Yesterday, we witnessed the victory of a cheap technological "quick fix" over long-term, sustainable and complex problem solving. We saw the final defeat of the UNFCCC by the UNCG, as transformations towards a sustainable post-carbon future were replaced with a risky technological quick fix.

Opportunities and Threats

OPPORTUNITIES	THREATS
Countries see the need to create a global governance mechanism for geoengineering, given its transboundary nature (eg, UNCG). An inclusive governance mechanism is created under the UN umbrella, following negotiations in a rather informal forum.	Although SRM is originally justified as a time-limited response intended to ward off some of the near-term impacts of climate change while the economy is decarbonized, SRM governance finds itself increasingly decoupled from mitigation and adaptation. This creates disincentives for relevant parties to work further on the root causes of climate change.
The governance mechanism for geoengineering put in place draws, at least on paper, a clear link to mitigation and adaptation.	Vested interests could create powerful lobbies in favor of geoengineering, as funders and companies supplying the technological components may be interested in maintaining deployment in order to safeguard their own futures.
Government agencies and private actors cooperate on the development of a geoengineering governance framework.	

The core dynamic in this scenario stems from the tension between the intention to deploy SRM only for a limited time and the difficulty of actually achieving cessation of an ongoing SRM deployment, given the vested interests of a new industrial sector that emerges from the deployment. This latter aspect is not a dominant part of the discourse around SRM deployment in our scenario, due in part to a successful media campaign by one of the leading entrepreneurs in the field. Furthermore, the scenario points out the importance of framing and highlights how the terms “test” and “deployment” might come to be contested in the case of SRM. Finally, the scenario suggests that while establishing early governance is an important part of preventing future conflict over SRM, governance may also have a facilitating effect by making future deployment of the technology more likely (or even possible in the first place). In the scenario, this manifests in the absence of sustained and impactful engagement with the topic on the part of civil society.

Policy Recommendations

This report is based on the following elements of good global SRM governance:

- Enhance inclusiveness;
- Create transparent decision-making structures;
- Promote research collaboration and consultation;
- Prevent deployment in the absence of legally binding international agreement.

The policy recommendations presented in this report are developed with these elements of SRM governance and the potential consequences of our two scenarios in mind. These recommendations also have implications for the global governance of geoengineering more broadly. They are intended for a situation in which geoengineering research significantly gains momentum.

PUBLISH AN INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE SPECIAL REPORT ON SRM

- In the case that SRM research intensifies significantly, periodic comprehensive assessments of the state of SRM research are critical for ensuring that research results are available to a broad audience. This will help build trust by providing a transparent, common reference point for discussions about the science, technology, impacts and broader societal context of SRM.
- To this end, the IPCC should establish a permanent working group with rotating membership that builds off of the discussions of geoengineering in the Fifth Assessment Report (AR5) to compile a Special Report on SRM (SRSRM). As research is currently only in the very early stages and the overall research effort remains limited, establishing such a working group should be conditional upon the speed at which research proceeds in coming years.
- The IPCC should create a mechanism now to decide when the time is right to begin compiling and issuing the SRSRM, taking progress in SRM research into account. The report should then be updated on a semi-regular basis, accompanied by active outreach activities to promote discussions on the subject. As need arises, these special reports could be extended to other geoengineering approaches that merit attention.

FORM A UN ADVISORY BOARD ON SRM

- An advisory board should be established under the auspices of the UN that discusses the international socioeconomic context of, as well as ethical questions related to, SRM, within the broader context of geoengineering, climate change and sustainability. This board should be composed of stakeholders representing a broad spectrum of expertise and backgrounds in the public, private and civil society sectors, including the academic community (in the natural sciences, social sciences and humanities), NGOs and other organizations, like religious groups.

› The IPCC SRSRM may help determine when this advisory board is needed, as the wisdom of creating a high-level UN board on a set of currently hypothetical techniques that are largely not even past the proof-of-concept stage and are receiving little to no funding is questionable. But given the severity of the threats associated with climate change, the promising (but uncertain) results from early computer-modeling studies of SRM, and the many difficulties and large uncertainties associated with SRM, it may be advisable to establish an open, critical and inclusive discussion on SRM at an early stage.

› Alternatively, this advisory board could be established at a later stage, once the IPCC SRSRM pronounces significant advances in relevant research and technology.

CREATE A NEW NEGOTIATION TRACK FOR GEOENGINEERING UNDER THE UNFCCC

› SRM has been and should be considered supplementary to mitigation and adaptation efforts to combat climate change. It should not be considered a substitute for mitigation. It is therefore important to create a central global forum to discuss SRM and to do so in connection with climate-change policy more broadly.

› Should SRM research continue and funding significantly increase, a new multi-stakeholder negotiation track for geoengineering should be created under the UNFCCC.

› In particular, there are five important factors that need to be considered in the creation and initial framework-setting of this new geoengineering track:

1. Parties in this negotiation should design a linkage mechanism ensuring that geoengineering is considered a supplementary means, and not an alternative, to climate-change mitigation and adaptation. One way to effectively implement such a linkage is to make any significant funding for SRM conditional upon strong mitigation efforts.

2. Parties should have a clear definition of the scope of geoengineering covered in this track in order to have focused discussions and pathways for ensuring targeted steps and actions.

3. Parties should formulate a set of global norms or rules for small-scale geoengineering research experiments that can provide legitimacy for such activities and ensure their environmental safety.

4. Non-party stakeholders such as the private sector and civil society – currently represented at the UNFCCC negotiations as part of the nine Major Groups – should ensure that their diverse voices are heard over the course of forming the negotiation track on geoengineering, as well as in the negotiations to be held under this track. In addition, the UNFCCC communications and outreach department should actively issue regular media releases on the progress of the geoengineering negotiation track to engage with the global public.

5. Concerned parties should closely monitor progress in geoengineering research, techniques and other related activities. There should be regular reports on country- and region-specific geoengineering developments. Countries and organizations of advanced technologies should also use and increase existing scientific capacities to monitor geoengineering activities that the geoengineering development and update reports may not be able to cover.

Fellows of the Global Geoengineering Governance Working Group

MASAHIKO HARAGUCHI is a PhD candidate in the Department of Earth and Environmental Engineering at Columbia University. His research interests include climate risk assessment and mitigation, water resource management, critical infrastructure management and supply chain resilience. He also studies urban planning as a National Science Foundation trainee and conducts research at the Earth Institute of Columbia University. As a lead researcher, Masa has written twice, in 2013 and 2015, for the Global Assessment Report, a biennial report of the UN International Strategy for Disaster Reduction. Previously, Masa worked for the World Bank to design a training program on how cities should address climate mitigation and adaptation by utilizing climate finance. Before the World Bank, he worked on a research project at the NASA Goddard Institute for Space Studies that investigated the impact of climate change on cities. At the Goddard Institute, he assisted in launching the first book of the "Climate Change and Cities" series. He also led a UN Human Settlements Programme research project on greenhouse-gas emissions from the New York metropolitan area as a case study for the Global Report on Human Settlements 2011, and he worked at the Asian Development Bank in 2008. He earned a master's in climate policy from Columbia University as a World Bank Graduate Scholar, and a postgraduate degree in development economics from the Institute of Developing Economies under the Ministry of Economy, Trade and Industry in Japan.

RONGKUN LIU currently works as a technical advisor for the Koshi Basin Programme at the International Centre for Integrated Mountain Development (ICIMOD), based in Kathmandu, Nepal. At ICIMOD, he is focusing on a rapid freshwater ecosystem assessment in the Tibet Autonomous Region's Koshi River basin. Previously, Rongkun was a program manager at the Pendeba Society of the Tibet Autonomous Region, where he was in charge of projects that promoted environmental conservation and community development in the Mount Everest region. He also worked with the Mekong Institute in Thailand, Yunnan Provincial Environmental Protection Department in China and the

World Resources Institute in the US on various environmental projects funded by bilateral government agreements and multinational development organizations. Rongkun holds a bachelor's in international relations from Peking University and a master's in global environmental policy from American University in Washington, DC.

JASDEEP RANDHAWA is a consultant at the UN Human Settlements Programme in Nairobi, Kenya. As a lawyer and public policy analyst, Jasdeep has expertise in international development, having advised governments and international organizations on water resource management and sanitation and on public-sector reforms. She has worked for the Environment Directorate at the Organisation for Economic Cooperation and Development, for the Government of India (Ministry of Home Affairs and Ministry of Law and Justice, and the Planning Commission) and for the Water Security Initiative at Harvard. She has also been a law clerk for the Supreme Court of India, and a judicial marshal in the High Court of Hong Kong. She has engaged in corporate law, litigation and arbitration practices. In 2013, she represented India as a Young Delegate at the G20 Youth Forum in St. Petersburg, Russia. Jasdeep holds a master's in law from Yale Law School, a bachelor's in civil law from the University of Oxford and a master's in public policy from Harvard Kennedy School, where she was a recipient of the International Peace Scholarship for Women.

SUSANNE SALZ is a project manager at the Collaborating Centre on Sustainable Consumption and Production (CSCP), with a focus on translating sustainability policy into concrete action on the ground in the public and private sectors. Prior to joining CSCP, Susanne managed the involvement of local governments in the UN Rio+20 summit in her role as head of the secretary general's office at ICLEI - Local Governments for Sustainability. Susanne has also worked at UN Volunteers and the Organisation for Economic Cooperation and Development. She holds a master's in international relations from the London School of Economics and a bachelor's from the University of Sussex, including an exchange year at the Instituts d'études politiques (Sciences Po) in Paris. Susanne speaks fluent German, English and French, as well as some Spanish. She loves sports and enjoys rowing in particular.

STEFAN SCHÄFER is the academic officer of the Sustainable Interactions with the Atmosphere research cluster at the Institute for Advanced Sustainability Studies (IASS) in Potsdam, Germany. He is also the co-leader of the research group on climate engineering at the IASS, together with IASS Scientific Director Mark Lawrence. A political scientist by training, Stefan currently focuses on national and international governance of emerging technologies in general and of climate engineering technologies in particular. Stefan holds a master's in political science, philosophy and history from the University of Tübingen and is currently pursuing his doctorate at the Free University in Berlin.

MUDIT SHARMA is a consultant at the Nairobi office of the management consulting firm Dalberg Global Development Advisors. At Dalberg, he has worked on a number of strategy projects spanning multiple African countries, mainly in the following sectors: access to finance, energy, agriculture, youth development and inclusive business. Prior to Dalberg, he was a senior project manager for new innovations at KickStart International, a social enterprise based in Kenya. Reporting to the COO of KickStart, he was responsible for special projects in product management, marketing and supply chain. Before KickStart, Mudit worked with the Wildlife Conservation Society in Uganda, where he developed business plans for national parks in the country and advised the parastatal managing the national parks on revenue-growth strategy. Mudit also has extensive experience managing software projects in various industries in the US and India. He holds a bachelor's in mechanical engineering from Saurashtra University in India and a master's in business from INSEAD in France.

SUSAN CHAN SHIFFLETT is a program associate at the Woodrow Wilson Center's China Environment Forum (CEF), specializing in the water-energy-food nexus. Susan works with governments, companies and NGOs to address China's most pressing energy and environment challenges. Prior to joining CEF, Susan worked at the Asia Foundation on anti-human trafficking programs. She also served as a research assistant at China's Center for Disease Control and Prevention, working on projects funded by the National Institute of Health researching high-risk HIV/AIDS populations near the border of China and Vietnam. She holds a master's in international relations from Johns Hopkins School of Advanced International Studies and a bachelor's in biology from Yale University.

AKIKO SUZUKI is a deputy director in the Financial Affairs Division at the Japanese Ministry of Foreign Affairs. Akiko joined the Ministry in 2004 and focuses predominantly on environmental issues and development assistance. She was a member of the Japanese delegation to UN climate change negotiations, specializing in tropical deforestation. She has also worked for G8 and G20 processes, covering discussions in the Development Working Groups. Akiko graduated from the University of Hitotsubashi, where she majored in law. She holds a diploma in diplomatic studies from the University of Oxford and an LLM in international law from the University of Edinburgh.

YING YUAN works as senior campaign manager with the Greenpeace Beijing office, leading its renewable energy works. Before joining Greenpeace, Ying was a Knight Science Fellow at MIT from 2012 to 2013, researching extensively on climate policy and science. Ying was also a senior journalist, with seven years of experience covering environmental and energy issues in China, and recognized as a top practitioner in these fields. She has written for publications including Southern Weekly and The New York Times. Ying holds a master's in foreign language and literature as well as a bachelor's in economics from the University of International Business and Economics in Beijing. She is currently a PhD candidate at Peking University, with a focus on climate change and international governance.

Annex: Scenario-Planning Methodology

The methodology underlying this report is structured scenario planning. Commonplace at private- and public-sector organizations, the methodology is designed to facilitate strategic long-term planning in the face of an uncertain future. A "scenario" is a possible and internally consistent trajectory of the future. To develop scenarios, the GGF 2025 geoengineering group performed four steps. First, we collected and investigated what we hypothesized would influence the future of global geoengineering governance. Second, we performed a factor-system analysis to distill the most crucial factors. Third, drawing upon this analysis, we constructed two scenarios. And fourth, we derived key strategic implications and policy options.

Factor Collection and Selection

We collected the most salient technological, social, economic, environmental and geopolitical developments that influence global geoengineering governance. These included trends related to the UNFCCC negotiations, cooperation on geoengineering research, country positions and geopolitical dynamics. From the list of 43 factors, we identified 14 that stood out for their potential impact and their level of uncertainty (see Table 1). We subsequently defined two or three possible future trajectories for each crucial variable to complete our factor analysis.

FACTOR	POSSIBLE OUTCOMES		
Public awareness of GE	Low	High	
NGO engagement	Many are well informed and engaged	Only a few are commenting	
UNFCCC negotiations	Binding reduction agreement in 2015-2025 COP	No binding agreement; UNFCCC loses relevance, while other fora rise	No binding agreement; UNFCCC remains central
Research cooperation on GE	Strong international collaboration	Ad hoc research collaborations, mostly bilateral	Competition and mistrust between countries prevent research collaboration
Industry interest in investing in GE	Significant interest	Little interest	
Degree of institutionalization and formalization of a governance framework	Low	Medium	High
Number or severity of climatic natural disasters	Increase	Moderate increase	No increase or decrease
Impact of GE on water-food-energy systems	Considerable negative impact	Considerable positive impact	Little impact
GE test results	GE is increasingly perceived as feasible	GE is increasingly perceived as unfeasible	
US view regarding GE research, funding and governance	US takes leading role in promoting GE	US provides little funding and takes similar status quo stance on GE governance	US prohibits research and commercialization; US also plays the “spoiler” in negotiations on GE governance
EU view regarding GE research, funding and governance	EU takes a leading role in promoting GE	EU provides funding, undertakes small-scale projects and is more proactive in getting allies; EU takes similar status quo stance on GE governance	EU prohibits research and commercialization; EU takes similar stance on GE governance
Global emissions	Rapidly increasing (“business as usual”), or even worse	Stabilized (2025=2014)	
Geopolitical dynamics	No conflicts (economic cooperation is intact)	Conflicts (in a broad sense, including economic sanctions) involving at least two major powers	
BRICS view regarding GE research, funding and governance	Agreed on taking a leading role	Agreed on blocking GE research and deployment	Split and diverse opinions

Table 1: Crucial Factors and Trajectories

Factor-System Analysis and Scenario Construction

To observe cross-impact and interaction effects, we rated cross impacts between all crucial-factor trajectories and created a matrix of rules for how these factors and their respective outcomes are interrelated. We utilized a computer program (ScenarioWizard, developed at the Stuttgart Research Center for Interdisciplinary Risk and Innovation Studies) to run a cross-impact balance analysis that separates the plausible and consistent sets of factor outcomes from the inconsistent ones. Then we selected two relatively diverse, abstract scenario frameworks, illustrating a rather wide room of possible developments (see Table 2). We named our scenarios "Mitigating for the Future?" and "Geoengineering the Future?" In the two scenarios, some factors take similar trajectories, while other factors develop in differing or opposing ways. For example, we envision NGOs and the media being engaged in both scenarios. On the other hand, factors like the success of UNFCCC negotiations follow very different trajectories in the two scenarios. Thus, the two scenarios represent two different directions on a continuum of possible futures.

	MITIGATING FOR THE FUTURE?	GEOENGINEERING THE FUTURE?
UNFCCC negotiations	Binding reduction agreement	No binding agreement; UNFCCC loses relevance
Research cooperation on GE	Competition and mistrust between countries prevent research collaboration	Strong international collaboration
Degree of institutionalization and formalization of a governance framework	Low	High
BRICS view regarding GE research, funding and governance	Split and diverse opinions	Agreed on taking a leading role

Table 2: Scenario Comparison

Having defined two plausible and selective future states of geoengineering governance, we employed a driver-driven analysis to learn more about the forces that primarily influence developments versus those that are influenced or "driven" by other factors. We then determined the status quo in 2025 in so-called "Pictures of the Futures" and then created corresponding histories for our pictures of the future by engaging in a collective writing process to describe the developments between 2015 and 2025. Recognizing that the future rarely proceeds in a linear fashion, we incorporated turning points into each scenario.

To write the scenarios, we relied on intra-group discussions, methodological guidance and exchanges with experts in the field. In our internal group interaction, we were able to draw on a variety of backgrounds, ranging from academia, NGOs, business and public affairs. The expertise of our invited experts during the sessions in Germany, Japan, China and India made us aware of points of contention that we had overlooked or interaction effects that we had neglected, and thus these experts provided not only tacit knowledge but also ample feedback on our factors and scenarios. Finally, we engaged in multiple rounds of editing.

Potential Consequences and Policy Recommendations

After they had been outlined and illustrated, the two scenarios, “Mitigating for the Future?” and “Geoengineering the Future?”, underwent extensive robustness checks during expert reviews. We first accounted for “positive” consequences (opportunities) and “negative” consequences (threats) arising from the two scenarios of geoengineering governance. Next, we derived strategic options for mitigating threats while utilizing opportunities in each scenario. We determined the best fit of these strategic options in both scenarios in order to determine the options that would be beneficial to implement no matter which of the two scenarios or other plausible futures becomes reality. Based on this multi-stage process, we arrived at a set of robust policy recommendations that would be appropriate across the scenarios.

www.ggfutures.net