THE DEBATE
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The Time for Abatement Alone Is Passing Us By — Should Humanity Consider Geoengineering?

Scientists have begun to hedge their bets and not count on society decarbonizing in time to avoid disruption to the Earth's climate system. Even if the dreams of the Paris Agreement are fully realized, the planet may become uncomfortably warm in the near term, bringing severe conditions. Consider current events.

Houston has been hit with two 500-year rainstorms this decade alone. The American West has turned into a tinderbox, with water running out and wildfires devastating populated areas every summer. Miami along with a lot of the rest of southern Florida is slowly slipping into the sea. Russian cargo ships are sailing from Vladivostok to Europe by way of an ice-free Arctic Ocean.

Enter a once-taboo topic shunned by greens and governments alike — geoengineering, a suite of technological remedies to solve the climate crisis or at least buy humanity more time to rid our energy and agricultural systems of greenhouse gas emissions. AT&T's Braden Allenby wrote about such intervention in these pages 18 years ago. In "Global Warning," he declared that international efforts at emissions abatement were doomed to failure and that "society should actively manage the entire carbon cycle, using a broad array of technologies and policies to achieve climate stabilization." What seemed like science fiction then has become today's unfortunate reality.

The proposals are as diverse as they are serious. One of the most-touted solutions is to reflect incoming solar radiation, perhaps by injecting sulfur particles into the upper atmosphere. Or water droplets injected into clouds could make them more reflective. Another method would attempt to increase heat leaving the Earth by seeding the atmosphere with particles to thin high cirrus clouds that block energy outflow. Engineers have even suggested a huge mirror in solar orbit that would reflect a significant percentage of the sun's incoming heat.

Other possibilities revolve around removing greenhouse gases from the atmosphere, which can be accomplished through engineering techniques or even seeding the oceans with iron to cause algae blooms that sequester carbon on the seabed. More naturally, planting trees locks up carbon, and silicate rocks can be granulated to enhance their uptake of atmospheric carbon.

All well and good, but scientists are also aware that these techniques could play havoc with the planet's natural systems, disrupting flows of energy and elements that are vital to habitability. In addition, effects may perhaps worsen some conditions, and may be uneven, creating winners and losers. These unpredictable downside risks as well as climate-saving opportunities imply some sort of international body to manage geoengineering, but society has had some bad experiences in regulating technologies of much less consequence.

Is geoengineering necessary? What techniques will be the most successful while minimizing risks? And who will answer these questions and begin any needed interventions in the Earth's climate system?

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Transparency Needed for Public Trust Globally

By Arunabha Ghosh

The world remains on track for more than 3°C of average warming by 2100. That will trigger calls for drastic measures to combat a climate emergency, including carbon removal from the atmosphere or solar radiation management. Geoengineering urgently needs governance — and transparency lies at its heart.

Undeveloped or untested geoengineering technologies are likely to have impacts on rainfall, the hydrological cycle, tropical forests, the ozone layer, and the oceans. Uncertainties abound about the shock if solar geoengineering were deployed at scale and then stopped suddenly. The risk of unilateral action worries those unable to regulate independent scientists, or any country or alliances who choose to experiment or possibly deploy measures. Even if global average temperature were to be controlled, how could responsibility be assigned and liabilities imposed for adverse regional consequences?

There are also ethical concerns about intentions and legitimacy. By reducing incentives to mitigate emissions, geoengineering potentially creates a moral hazard. There is a related worry that investments in research could build momentum down a slippery slope toward deployment. Another concern is the difficulty in ascertaining intent behind geoengineering research or deployment. The ostensible reason could be a response to climate emergencies. But adversely impacted countries or regions would claim a legitimate right to verify if there were malafide intentions. The legitimacy of any experiment or deployment would rest on who has a say over how transborder impacts are assessed.

The long list of risks and uncertainties generates the demand for regulating geoengineering. Answering these concerns implies that research must continue. But effective outdoor research may require large-scale testing, bordering on deployment. Imposing a moratorium only on deployment while permitting research would be challenging to enforce. Thus, not just deployment but also research needs to fall within the ambit of governance.

Transparency must occupy a central role in geoengineering governance. But toward what end? Transparency is needed to minimize public risk. Impacts at a planetary scale need governance arrangements that are more risk-averse than for technologies that have limited physical impacts. In the absence of national or international regulation, a code of conduct for geoengineering research could serve as a stop-gap to control public risks, until more formal governance mechanisms are established. Information on research proposals, risk assessments, and disclosure of research results would be essential components of such a code.

Transparency is also needed to build public trust. This is critical to the sequential unfolding of research stages, from laboratory to field research to large experiments. Academic networks and peer-reviewed journals are insufficient to effectively communicate scientific findings to the public. Research registries might contribute to building trust but cannot replace political processes. National scientific assessments and public and parliamentary hearings would be necessary to effectively engage the public about geoengineering, within the broader context of climate responses.

In order to make transparency work for geoengineering, it has to be institutionalized, not ad hoc. A well-designed information system would perform three functions: disseminating information about national policies and research activities; promoting compliance with codes of conduct via peer pressure among research groups, member countries, explicit sanctions, or pressure from non-state actors; and evaluating the impact of geoengineering research and experiments.

Self-reporting is the most efficient way to disseminate but carries the risk that some information might come too late for regulation. Eventually, there should be mandatory state-to-state disclosure, via a globally negotiated agreement, to empower countries to make informed choices. Moreover, legitimate public engagement requires a bidirectional flow of information between project proponents and stakeholders. It can be long, hard, and sometimes inconclusive, but would be a necessary step in enforcing compliance with codes of conduct.

For overall assessments of geoengineering activities, progressively inclusive governance could be pursued. It would begin with national assessments and national-level consultations to yield governance and transparency templates for different stages of research and experimentation. Thereafter, national policies on geoengineering could be reported to international forums. A combination of government and nongovernmental entities could coordinate for independent peer reviews and international consultations. Accordingly, international assessments of the progress and risks of geoengineering research could be conducted in select multilateral forums.

If these steps increase public trust and minimize risks, an international geoengineering research program could be envisaged, taking account of research capacities, funding, intellectual property, and rules for accountability and liability. Without transparency, there will be more contestation. With transparency, conditions of distrust could be marginally abated.

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Assess Proposals in the Context of Climate Risks

By Edward A. Parson

The risks climate change poses to human societies and ecosystems are severe. Yet pursuit of cuts in global greenhouse gas emissions has stalled for so long that it is probably too late for emissions cuts alone to limit risks to acceptable levels. This stark reality provides essential context for all discussion of the potential contributions, costs, and risks of geoengineering.

Human activities have already heated the Earth by 1ºC, bringing impacts whose severity grows clearer each year. The 2015 Paris Agreement adopted targets to limit heating to 1.5 to 2ºC, but current policies and actions are far too weak to achieve these. Absent much stronger action, the Earth is headed for 2.5 to 5ºC heating this century, bringing likely disruption to lives, livelihoods, and ecosystems at a scale human societies have never experienced.

Stopping climate change requires cutting emissions to zero. Stopping it near the Paris targets requires cutting to zero within a few decades. This means going from today's 80 percent reliance on fossil energy to a fully decarbonized economy, plus profound changes to eliminate emissions from agriculture, forestry, and other land-use, and multiple industrial processes.

Some models say 2ºC is still technically feasible, but only with multiple favorable assumptions, including rapid emission cuts starting immediately, low global energy demand, and fortunate outcomes on major scientific uncertainties. This doesn't mean deep emissions cuts aren't essential, or that they can't reduce coming climate change risks: they are, and they can. But today's efforts are probably fighting to reduce heating of as much as 5ºC to maybe 2.5ºC, still more than the Paris goals.

If this situation is unacceptably dangerous but emissions cuts can't do much better, what can be done? This question is the reason to discuss geoengineering. It might be able to substantially reduce climate risks. It also presents new risks and challenges, including potentially serious problems of governance. Whether these problems are manageable or severe, they must be considered in the context of the risks of climate change.

The two main geoengineering approaches have different profiles of benefits and risks. One approach removes CO_2 from the atmosphere and puts it in some stable reservoir. Proposed methods range from large expansion of familiar forest or soil-conservation practices, to novel chemical methods of direct air capture. Specific methods differ in state of development, potential scale and limits, and environmental and socioeconomic impacts, but have two things in common. First, they act slowly: sucking CO_2 out of the atmosphere is draining a swimming pool through a straw. Second, if done at large enough scale they can make net emissions negative and thus reduce atmospheric CO_2, not just slow its increase, and so run climate change backwards.

The second approach, solar geoengineering, would reflect away a little incoming sunlight to change the Earth's energy balance. Promising methods include spraying reflective mist in the upper atmosphere, and making low-level ocean clouds denser and whiter. Unlike carbon removal, this approach does not target the cause of climate change, but instead makes an offsetting change. It is thus an imperfect, incomplete correction for greenhouse-driven climate change, but it has the unique advantage that it can be started, controlled, or stopped over time periods of a year or less. It would also bring its own impacts and risks. Early research suggests the most obvious impacts are surprisingly moderate and potentially correctable, but this is far from a clean bill of health.

Neither approach can replace efforts to cut emissions and adapt to coming climate changes. These both remain essential. But both approaches can complement these to further reduce climate risks. Both need research to characterize how and how well they could work, what risks they would carry, and how these could be mitigated. Both also need serious consideration of how to develop needed capacity for governance, able to make competent, prudent, and legitimate decisions on whether and how they are used, to manage associated impacts and conflicts, and to integrate them into an effective overall climate strategy.

Neither approach is getting the serious investigation and critical scrutiny it needs, but in nearly opposite ways. Assumptions of enormous future carbon removals have quietly become a mainstay of climate planning, heavily relied on in nearly all 1.5 and 2ºC scenarios, with little examination of feasibility, limits, or impacts. Solar geoengineering has been marginalized in climate assessments and policy debates, based on presumptions of severe harm or impairment of climate policy that have also received inadequate research or critical scrutiny.

This has to change. To bet the future on carbon removal working at the required billion-ton scale with acceptable impacts is a reckless gamble. To exclude solar geoengineering from consideration based on untested intuitions that it would be a cure worse than the disease is equally reckless. For all their challenges, these approaches may make things less bad than they otherwise will be, for human society, for vulnerable people and communities, and for ecosystems.

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It's Smart Risk Management and a Political Investment

By Cynthia Scharf

When I speak to audiences about geoengineering, I often start by saying I wish my job never existed. There would be no need to inform and encourage governments to create international guardrails around emerging climate technologies because decades ago my generation had taken care of job number one: radical, immediate decarbonization and strengthened adaptation.

Alas, that's not the world we live in. Even at current levels of warming, climate change impacts are devastating, as we saw last summer, especially for those who did least to contribute to the problem but suffer first and worst from its effects. The longer the anemic global response to the climate crisis, the greater the pressure to deploy large-scale carbon removal, and potentially even solar geoengineering, to reduce dangerous climate impacts.

These technologies could potentially provide significant, if unequal, benefits if governed in an inclusive, just, and transparent manner. But they also pose critical environmental and geopolitical risks — known and unknown. Geoengineering will affect every country, hence all countries — and all sectors of society — need a say in how it is governed.

In speaking with governments and civil society organizations, it is abundantly clear we do not know enough about the risks, costs, and potential benefits of these technologies. Nor are we doing near enough to address how we might govern them in an equitable, accountable manner.

Several international agreements have potential relevance for geoengineering, but at present there is no systematic set of international frameworks. This needs to change —now.

We need a society-wide discussion about how to govern these technologies, before events overtake our ability to respond in an informed way. Indeed, this could be one of the most important conversations any government and civil society leader has in coming years.

To do so is not to abdicate responsibility for reducing emissions. Rather, it's smart risk management and a wise political investment in a safer world.

Effective governance should be grounded in the precautionary principle and be inclusive, transparent, and equitable. It also should be developed in parallel with research, so the latter informs the former. Large-scale carbon removal and solar geoengineering will require multilateral governance, as both entail transboundary risks and challenges and could affect all countries, if unequally, creating global winners and losers.

Current UN bodies, primarily the climate convention, are appropriate for governing carbon removal at the multilateral level. National and subnational governance also will play a key role. Solar geoengineering, however, poses thornier challenges. No existing institution covers the full range of issues that might arise. A polycentric approach will be needed, since the world evidences no appetite for creating new multinational institutions in the current political atmosphere. Existing institutions could include the UN Environment Assembly, the Convention on Biological Diversity, the General Assembly, and regional bodies.

The Intergovernmental Panel on Climate Change's recent report makes clear that the world will need tremendous amounts of carbon removal in coming decades to avoid runaway climate change. Are existing climate convention mechanisms, including Paris, sufficient to address the full range of issues that may arise? These include land use, storage, liability, and compensation as well as responsibility, monitoring and reporting, and impacts on the Sustainable Development Goals. Equity and political responsibility are also key. Governments will need to cooperate on technology, funding, and the policy and market mechanisms that can make those technologies that have a social license to operate viable.

Even with a massive ramp up, it may not be possible to remove enough carbon in time to keep global temperatures from breaching danger points. Some countries might then consider solar geoengineering. At best, it might buy the world some time.

But who would be making the decisions to use this powerful technology? Whose hand will set the global thermostat? Under whose authority and with what political legitimacy? How, when, and under what circumstances? Political, as well as profound ethical and moral issues, are in play.

The world needs rules of the road to stop anyone ——a government or even a non-state actor — from testing and deploying solar geoengineering unless the risks and potential benefits are sufficiently understood, and international governance frameworks are agreed and in place. Absent this, the world would be faced with environmental and geopolitical risks that could affect current and all future generations.

The era of risk-free options is past. Three years after Paris, there is a grave risk in assuming that our present tools — emission cuts and removals of small amounts of carbon dioxide — may be enough. It is critical that society as a whole wake up and weigh in on how geoengineering should be governed. The voices of the poor and marginalized, as well as faith communities, are essential to this discussion.

Governments need to learn more about geoengineering and put it on their shortlist of priorities. It is up to them to create the international guardrails that can help the world stay safer in a climate-chaotic future. The stakes could not be higher.

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Solar Control As Part of Mitigation Portfolio

By Simone Tilmes

Delayed actions to reduce greenhouse gas emissions will have irreversible effects on the planet's ecosystem and on society. Some of these changes have already become apparent, including dying coral reefs, melting glaciers, and sea-level rise. Even with the most ambitious emission abatement efforts, permanent changes to the climate system are very likely unavoidable.

Enter geoengineering technologies, which could provide an opportunity to prevent temperatures from reaching critical limits. But besides developing a framework that governs geoengineering research and potential applications, we need a robust understanding of the benefits as well as the limitations and risks of different geoengineering proposals.

Two that are getting the most attention of late are carbon dioxide removal from the atmosphere and solar radiation management. While the development of CDR technologies has gained support in recent years, relatively little work has been done to explore SRM options which, moreover, lack significant R&D funding. In particular, there seems to be a misconception that SRM research would distract from emissions-abatement efforts. Further, unlike CDR, it may pose too many risks — a conclusion which ironically is a consequence of the limited understanding and development of these technologies.

If society instead decides to explore SRM options, decisionmakers can make better judgments as to whether they should become an important element of the global mitigation portfolio. Indeed, SRM may provide an opportunity in the future to reduce some of the suffering in case abatement efforts and CDR will not be sufficient.

The full effect of global SRM applications can only be tested using comprehensive Earth-system models. Such testing demonstrates that global solar reduction through enhancing of stratospheric aerosols is the most effective geoengineering approach to reach global temperature targets. However, since this application changes the Earth's energy balance, it will not result in the restoration of past climate conditions and could in fact produce unfortunate regional climate shifts and other side effects.

So far, scientists have mostly explored the effects of global SRM using idealized modeling experiments. These often do not result in realistic outcomes in terms of impacts and side effects but have been an important first step in increasing the scientific understanding of physical changes to the atmosphere. More recent modeling has demonstrated that some side effects from earlier experiments can be reduced by applying newly derived strategies.

Continued research in this direction is promising and could provide a more robust understanding of benefits and impacts. For this, Earth-system scientists and engineers need to work with ecologists, social scientists, and economists to optimize strategies that would help society determine whether these technologies should be considered. International engagement rather than work performed by single actors would likely produce the best results.

The amount and timing of potentially implementing SRM are still unknown and presumably dependent on assumptions about future emissions of greenhouse gases. Ideally, limited SRM could be temporarily phased in and phased out to reduce a projected peak in global warming in order to prevent irreversible climate changes from happening until emissions abatement and CDR efforts have taken effect. However, since SRM would then be masking the warming from greenhouse gases still in the atmosphere, it may create a false sense of security and thereby promote the continued use of fossil fuels. A continued rise of greenhouse gases in the atmosphere would result in a prolonging of the application, with more risks and side effects.

In particular, potential interruptions of very large SRM applications would force temperatures to bounce back up at dangerously fast rates. Additional risks of SRM applications could arise from feedback in the climate system that triggers unexpected reactions, requiring much larger or smaller applications than expected.

The conclusion is clear. Society needs to work hard at continually improving climate models as well as gathering observational data to increase confidence in projections and to reduce the risks of the unknowns of inaction countered against the unknowns — and knowns — of geoengineering strategies. Potentially safe and effective amounts of SRM under different future climate scenarios have yet to be developed.

Global solar geoengineering approaches may become an important addition to other efforts to help reduce future climate impacts. Scientists will need to design SRM strategies that will produce the desired mitigation with minimal side effects — and with international approval. However, only binding international targets to ensure the rapid and complete phase-out of greenhouse gas emissions is needed to prevent long-term dependency on geoengineering and artificial interference with the climate system.

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