Humanities and Social Sciences Review,
CD-ROM. ISSN: 2165-6258 :: 08(02):139–148 (2018)

GEOENGINEERING CLIMATE CHANGE SOLUTIONS: PUBLIC POLICY ISSUES FOR NATIONAL AND GLOBAL GOVERNANCE

Dianne Rahm

Texas State University, USA

With temperature increases likely to be above the 2 degrees Celsius maximum desired to avoid the worst effects of climate change, the idea of using controversial geoengineering approaches has become an open discussion. Using such approaches, however, raises many public policy issues in global and national governance including what agency or governing body should monitor and regulate such potentially risky activities. This paper will describe several approaches to geoengineering currently being proposed. The potential problems and unintended negative effects that might result from activities will be discussed. Suggestions regarding how such activities may be monitored and regulated as well as what organizations or agencies should be the monitors and regulators will be presented.

Keywords: Geoengineering, Solar radiation management, Carbon dioxide reduction, Governance.

Introduction

Frustrated over the ongoing failure of the world's governments to successfully negotiate a treaty that will guarantee necessary reductions in carbon dioxide and other greenhouse gases (GHGs), many of the world's scientists, engineers, and climate activists have begun to consider geoengineering options. Two of the world's most important science-based advisory groups, the UK's Royal Society and the U.S. National Academy of Sciences, have produced reports on the topic in 2009 and 2015, respectively. Drawing heavily on these comprehensive reports, this paper begins with a definition of geoengineering, or climate intervention, and descriptions of the many potential methods of implementation. While there is little support for deploying some of the more promising and controversial methods, there has been increasing demand among climate scientists and other advocates for a serious research program that includes both computer simulations and field experiments. The goal of this research program is not only to examine the technical feasibility of proposed methods along with their potential risks and benefits to the climate but also the political, social, ethical, and legal framework for controlling research programs that might lead to possible deployment. The paper discusses these, and the possible ways geoengineering might be governed. Since some of the most promising methods of geoengineering could potentially be cheap enough to be deployed by a rogue actor, the paper concludes with a brief discussion of the highly controversial counter-geoengineering proposals now under consideration.

What is Geoengineering?

Geoengineering involves "actions taken with the primary goal of engineering (controlling by application of science) the climate system" (Keith and Dowlatabadi, 1992, 289). Geoengineering is defined by the

UK's Royal Society as the "deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming" (The Royal Society, 2009, ix). Geoengineering methods are typically divided into two classes: carbon dioxide removal (CDR) and solar radiation management (SRM). CDR methods include land use management activities designed to enhance the ability of land to absorb carbon dioxide (by acting as a sink), the use of biomass for carbon-neutral energy production and carbon sequestration, heightened natural weathering processes that remove carbon dioxide from the atmosphere, engineered direct capture of carbon dioxide from the atmosphere through the use of equipment such as air scrubbers, and fertilizing the ocean with nutrients that increase ocean uptake of carbon dioxide. SRM methods include increasing the surface reflectivity of the Earth by brightening structures by painting them white, replacing dark plants with plants that are more reflective, or laying highly reflective materials in areas such as deserts. Other SRM methods include enhancing marine cloud reflectivity, imitating volcanic eruptions by injecting sulphate aerosols into the stratosphere, or launching shields or deflectors into space to reduce the amount of light reaching the atmosphere (Visioni et al. 2017).

Before describing these methods in further detail, it is important to note that use of the term geoengineering is disputed. When the U.S. National Academy of Sciences Committee on Geoengineering the Climate looked into the issue 6 years after the UK's Royal Society, it rejected use of the term geoengineering, calling it misleading. The Academy instead adopted use of the term climate intervention arguing that the use of the term engineering "implies a more precisely tailored and controllable process than might be the case for these climate interventions" (National Academy of Sciences, 2015a,1). While the National Academy of Sciences was comfortable with the use of the term CDR, it did not accept the use of the term SRM as management also implies more control than likely. The language it prefers is "albedo modification" which describes that group of techniques that seek to increase the reflectivity of the planet to reduce global temperatures. Captured under albedo modification are "intentional efforts to increase the amount of sunlight that is scattered or reflected back to space, thereby reducing the amount of sunlight absorbed by Earth, including injecting aerosols into the stratosphere, marine cloud brightening, and efforts to enhance surface reflectivity" (National Academy of Sciences, 2015b, 2).

Carbon Dioxide Removal Methods

Plants remove about 30 percent of the CO_2 produced by fossil fuel burning each year. In addition, the world's forests store more than twice the CO_2 in the atmosphere. The key idea behind land-based methods is to increase the contribution of land-based ecosystems to carbon dioxide removal through avoiding deforestation, reforestation or replanting forests, and adopting land-use practices that have been shown to be regionally effective in both CO_2 reduction and economically beneficial to industries such as agriculture. Any of these efforts are safe and reasonably affordable however their potential to impact global levels of CO_2 are relatively low and the time involved for such reductions would be slow. Biomass-related methods also include actions such as burying wood and agricultural waste on land and deep in the ocean to prevent decay and subsequent release of the CO_2 held in the wood and waste back into the atmosphere through decomposition. Bioenergy approaches have also been considered. In these scenarios biomass can be used as fuel so that the CO_2 held and released are roughly balanced. Consideration is also given to the use of biomass and biofuels with carbon capture and sequestration (CCS). While some of these solutions may come with land-use conflicts, such as using land for fuel production rather than for food, they are safe. However, they also suffer from the same limitations of low to medium likely effectiveness and they would be slow to reduce global warming (The Royal Society, 2009).

CO_2 is naturally removed from the atmosphere through a process called weathering. CO_2 from the atmosphere first becomes bicarbonate ions dissolved in the ocean which later turn to carbonate sediments on the sea floor as a result of natural carbonate and silicate weathering reactions that occur in soils and marine sediments. One proposal for CDR involves accelerating these natural processes so that CO_2 can be stored either as solid carbonate mineral or as dissolved bicarbonate in the ocean. Several ways of accomplishing this have been investigated including bring high concentrations of CO_2 into contact with appropriate rock formations thereby creating carbonate minerals in place, transporting appropriate minerals to industrial facilities for processing, or grinding minerals up and releasing them into the ocean. Accelerated weathering concepts are largely theoretical. There has been limited laboratory testing of these concepts and no pilot or demonstration projects exist. Moreover, deployment of such a CDR method sufficient to deal with climate change would involve a huge scale that poses a major barrier (National Academy of Sciences, 2015a).

CO_2 can be directly removed from ambient air. Commercial systems already exist which remove CO_2 from air for use in industrial processes. However, large scale systems sufficient to deal with the climate change problem do not yet exist and there is considerable question regarding their likely cost. Even if such systems could be economically developed and operated, CO_2 captured from ambient air would still have to be stored. CCS is reliant on the development of facilities and or locations where the CO_2 can be permanently housed. An alternative might be that the captured CO_2 could be re-used by converting it into a fuel by combining it with hydrogen. While CO_2 capture from ambient air might be a potential CDR method, its costs would be very high, and development of a substantial infrastructure would be necessary (The Royal Society, 2009).

A controversial CDR method is ocean iron fertilization (OIF). Algae and other microscopic plants (such as plankton) living at the ocean's surface naturally take up CO_2 and convert it to organic material. Some of this material sinks deep into the ocean where it serves as food for animals and other organisms which in turn respire and re-release CO_2 into the deep ocean. That CO_2 is effectively sequestered in the deep ocean. Scientists have suggested enhancing this natural process by increasing the nutrients available to the algae and microscopic plants so that they could increase the production of organic material, which in turn would result in more CO_2 being sequestered in the deep ocean. CDR methods have been proposed to deliberately add the micronutrient iron to fertilize ocean plankton. Scientists believe that adding iron to surface waters of the Southern Ocean which has adequate amounts of macronutrients (phosphorous and nitrogen) but low chlorophyll and phytoplankton growth, could result in increased CO_2 uptake. Other ocean regions also suffer from iron-limited conditions including the subpolar North Pacific and eastern Equatorial Pacific. These sites have been the location of field experiments. OIF is controversial because it can be implemented by unilateral actors. Indeed, several companies (Climos, Planktos, GreenSea Ventures, and the Ocean Nourishment Corporation) have proposed entering the carbon trading market by dumping iron into the ocean to spur plankton growth and CO_2 uptake. The long-term impacts of OIF are also not yet understood (National Academy of Sciences, 2015a). In 2008, the 191 national parties to the UN Convention on Biological Diversity agreed to a moratorium on major ocean fertilization projects until the risks are better understood (Tollefson, 2008).

With the exception of OIF, CDR methods are generally considered safe but are currently unaffordable. Moreover, they would be very difficult to scale up to the level needed to deal with the billions of tons of excess CO_2 in the atmosphere. Even if they could be built to global scale, they would act slowly, requiring many decades before their impact would be felt. CDR methods do, however, address the root of the problem -- the vast increases in CO_2 levels in the atmosphere and in this way are supportive of mitigation efforts (Romm, 2016).

Solar Radiation Management/Albedo Modification Methods

Land-based surface albedo approaches try to make the Earth more reflective so that it will absorb less of the sun's heat. One very simple way to do this is to brighten human settlements by painting roofs and other structures a bright reflective white. This approach would be most effective in sunny regions in the summertime. This method is easy to implement, and it might also bring with it co-benefits of lowering air-conditioning bills. However, the method would be costly and, given the small area of the Earth's land mass that is urban, the ability to impact global warming is small. Increasing the reflectivity of plant canopies is another similar surface albedo strategy but it is unclear what the net benefit would be and economic impacts on crop selections might be great. Finally, surface albedo approaches also include placement of desert reflectors on the world's 2 percent of land that is desert. This method might increase the Earth's reflectivity, but it would come with ecological consequences to desert life by covering up vast stretches of land area and may pose risks for shifts in atmospheric circulation. Desert reflectors would also be relatively expensive (The Royal Society, 2009).

Ocean-based albedo approaches include marine cloud brightening (MCB). The basic theory is that if the 20 to 40 percent of the dark ocean covered with low-lying stratocumulus clouds could be more reflective, a great deal of solar radiation would never reach the Earth. Scientists theorized that introducing additional aerosols into clouds would increase the number of cloud condensation nuclei available for cloud formation thus increasing reflectivity. There is some evidence that MCB might be possible drawn from a known phenomenon called "ship tracks." NASA has satellite images of ship tracks off the coast of California. These are visible bright areas of clouds produced by aerosol particles coming from commercial ship exhaust emissions. However, very little is known of the relationship between aerosols and clouds. MCB is clearly possible but the feasibility of MCB at deployment scales is yet unknown. Much more needs to be learned about how best to increase cloud brightness, the potential consequences to atmospheric circulation, and how costly this approach might be (National Academy of Sciences, 2015b).

Of the SRM methods, the most widely discussed is stratospheric aerosol albedo modification (SAAM) by injection of sulfur to mimic volcanic eruptions which are known to cool the atmosphere. The eruption of Mt. Pinatubo in 1991 injected between 14 to 26 megatons of sulfur dioxide into the atmosphere. While the eruption resulted in the cooling of the planet it also had negative consequences including changes in rainfall patterns and damage to the ozone layer. Scientists have suggested that SAAM could be economically achieved by having aircraft deliver the sulfur to the lower stratosphere, however, effects on precipitation patterns and ozone depletion remain unclear. Some studies suggest that injection of enough material to the stratosphere to bring down current levels of CO_2 could delay ozone recovery by several decades. (National Academy of Sciences, 2015b). Scientists have considered a wide range of particles that could be injected into the stratosphere with the goal of scattering sunlight back into space, but sulfur aerosols have properties that make them particularly interesting. Hydrogen sulfide or sulfur dioxide could be injected into the stratosphere as gases and then oxidize into sulfur particles with the size of several tenths of a micron. Injection of solid particles is far more challenging because they are likely to clump. Moreover, proof that sulfur aerosols cool the planet is known from volcanic eruptions. SAAM, however, would differ from a volcanic eruption in that it would require constant injection of sulfur for decades to counter the effects of GHGs. Of particular concern, models predict that injection of sulfur as a stratospheric aerosol would affect the Asian and African summer monsoons, reducing precipitation and potentially affecting food production for many millions. Models suggest that many regional effects could result from sulfur geoengineering that may further reinforce the effects of climate change itself (The Royal Society, 2009). Most importantly, SAAM does nothing to address the underlying causes of global warming – the amount of greenhouse gases in the atmosphere. Nor does it address the issue of ocean acidification, caused by the oceans absorbing vast amounts of CO_2 (Pain, 2010).

SRM could also be accomplished by blocking sunlight from reaching Earth's atmosphere by deployment of space-based methods. Included in the literature are options such as a large opaque disk, a large transparent prism, a large sail, a large scattering screen, mirrors, and a ring of space dust placed either in low Earth orbit or at the L1 point (between the Earth and the Sun where the gravitational attraction between the two bodies is equal). Several of these technologies would require the ability to manufacture in space, so they are not possible at the current time. Space-based SRM methods would also be vastly expensive, rendering them largely impractical (National Academy of Sciences, 2015a).

While technically not a SRM method, another upper atmosphere option is cirrus cloud modification. Cirrus clouds form in the cold upper portion of the troposphere and are composed mostly of ice crystals. They contribute to the greenhouse effect by reflecting radiating heat back down to the surface of Earth. They also act to increase planetary albedo by reflecting some incoming solar radiation back to space but overall, they contribute to greenhouse warming. Studies have shown that thinning cirrus clouds could reduce their greenhouse warming capability, allowing more heat to pass back to space. Thinning might be accomplished by introducing aerosols that would affect the ability of ice crystals to form. However, some studies suggest that modifying cirrus clouds might produce reduced global rainfall. Scientific understanding of cirrus clouds is limited and so considerable research into thinning agents and their potential impacts is needed (National Academy of Science, 2015a).

SRM is generally considered highly risky because of the potential for negative outcomes that might affect billions. Of all the SRM methods, however, SAAM is generally considered the best potential alternative because it would be cheap and fast. It is estimated that deploying SAAM could offset temperature increases more cheaply than emission cuts. Cost estimates for an effective SAAM program run just into several billions per year. The low cost is very attractive, but it also raises the issue that a rogue actor could proceed alone (Keith, Parson, and Morgan, 2010). While the National Academy of Sciences opposes deployment of SAAM, they do favor research in order to better understand it. They warn, however, that before any deployment, the world should explore and understand the political, social, economic, legal, and ethical dimensions of such a deployment (National Academy of Sciences, 2015a).

The Growing Case for Geoengineering

Speculation about geoengineering dates back to the beginning of the 20th century when Svante Arrhenius, a Nobel Prize-winning Swedish scientist, suggested that burning fossil fuels might help prevent a coming ice age (Keith and Dowlatabadi, 1992). After the Second Word War, both the U.S. and the Soviet Union began exploring weather modification schemes that might provide a military advantage. Cloud seeding was the primary focus. While no battlefield advantage was found, cloud seeding was regularly used in attempts to produce rain for crops before being abandoned in the 1970s. Beginning in 1962, American researchers associated with Project Stormfury, tried to make tropic storms less intense, but with little success. The U.S. military flirted with the idea of using nuclear explosions to alter the climate, resulting in the UN adoption of the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques. In 1965, when President Lyndon Johnson received the first presidential briefing on climate change, the only action recommended was geoengineering (David et al., 2009).

By the late 1970s, concern over global warming led scientists to study possible ways to reverse the effects of CO_2 on the environment. By the 1990s, Keith and Dowlatabadi (1992) called for systematic evaluation of geoengineering options. They argued that geoengineering might be needed if climate change proved worse than expected, that it seemed unlikely that GHGs could be kept low enough to avoid the worst effects of climate change, and that political failure to achieve cooperative mitigation made consideration of geoengineering a reasonable fallback strategy.

Before 2006, few scientists or environmentalists wanted to discuss the possibility of geoengineering. The main argument was that of moral hazard, that is, if people seriously think geoengineering solutions, especially SRM, might provide a fast and cheap way out of the climate crisis, they might turn to them rather than put their efforts into CO_2 reduction. But in 2006, Paul Crutzen, winner of the Nobel Prize for Chemistry, published an editorial essay in the journal *Climate Change* arguing for the creation of a research program for albedo enhancement by stratospheric sulfur injections. Crutzen concluded “the very best would be if emissions of the greenhouse gases could be reduced so much that the stratospheric sulfur release experiment would not need to take place. Currently, that looks like a pious wish” (Crutzen, 2006).

In 2007, Bill Gates began funding research into geoengineering. He provided more than $4.5 million of his own money over 3 years to study SAAM, techniques that could filter CO_2 directly from the atmosphere, and MCB. Gates has not, however, funded any field research. Decisions regarding the projects to be funded have been made by Ken Caldeira of the Carnegie Institution for Science at Stanford and David Keith of the University of Calgary in Canada. The money has thus far funded research into designing a spray system for MCB, research on the stratosphere, and has helped to support scientific meetings on geoengineering in Cambridge, Massachusetts and Edinburgh, Scotland. Gates is also an investor in a company called Intellectual Ventures, a firm that has applied for patents on techniques to geoengineer the stratosphere. Gates also applied for a patent to reduce the force of hurricanes by mixing surface and deep ocean water (Kintish, 2010).

Efforts to advance a research program in geoengineering continue. Oxford's Martin School has a geoengineering program as does Harvard University. Other participants, like UCLA's School of Law, are actively involved. Harvard researchers plan to move forward with field experiments of SAAM. In 2017, several major conferences were held to discuss geoengineering. In July 2017, a Gordon Research Conference titled Radiation Management Climate Engineering: Technology, Modeling, Efficacy and Risks was held in Maine. In March 2017, a Forum on U.S. Solar Geoengineering Research was held in Washington, D.C. At that forum, discussion took place regarding the future operational use of SRM along with the benefits and risks. Three proposed methods of solar geoengineering are at the center of the current debate: SAAM, MCB, and Cirrus cloud thinning. Each has the characteristic of fast action -- some probably able to cool the planet in months. But because they do not address the root of the problem (CO_2 and other GHGs), once deployed if untoward consequences arose, the heat being offset would return rapidly which could bring severe risks. Most solar geoengineering methods once deployed would have global reach, posing many challenges for governance. Solar geoengineering is less expensive than making the changes necessary for carbon removal or mitigation, putting it well within the reach of many nations or even private rogue actors. This fact underscores the importance of a global governance regime. The forum explored 3 ways in which solar geoengineering might be beneficially used: as a "Plan B" in response to some future severe climate change impacts, in conjunction with aggressive mitigation to win "buying time," and deployment at less than a global scale to target regional problems such as Arctic sea ice loss or tropical cyclone formation (Parson, et al., 2018).

Social and Ethical Implications and the Need for Governance

The fundamental question geoengineering raises is whether intentionally manipulating the climate is ethical. This question must be answered within the framework of understanding the devastating consequences of a three or four-degree temperature rise if no other action is taken. If such temperature increases were to occur, human settlements and ecosystems could be devastated. It is also important to put in the context of many centuries of anthropogenic manipulation of many of Earth's natural systems, whether intentional or unintentional. Climate change is, after all, the unintentional result of human manipulation of Earth's natural systems. However, the global scale of geoengineering has never before been intentionally undertaken and it is that very intentionality that marks it as unique. Intentionality is a concept recognized in law and is used to distinguish crimes on the basis of intentionality. People will respond to large-scale intentional efforts to engineer the climate differently. Some will see it as hubris and advise against it. Others may accept it, seeing attempts to force them to change their consumption patterns (away from fossil fuels) as an illegal violation of their rights (Corner and Pidgeon, 2010).

As geoengineering can be traced back to early weather modification efforts undertaken by the U.S. and the Soviet Union, the question arises if geoengineering violates the UN Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques. Early weather modification attempts also raise the issue of legal liability for harm caused. Project Stormfury was alleged to change the direction of a hurricane that struck landfall on the coasts of Georgia and South Carolina causing significant damage (Willoughby et al., 1985). Having political mechanisms in place to deal with potential legal liability and conflict resolution will be critical.

While geoengineering may produce beneficial results, it is also clear that the potential exists for geoengineering to produce global conflicts. If, for instance, implementation of climate modification resulted in one nation believing that another nation was pursuing its own interests above those of other nations, conflict may result. It is also possible that a wealthy individual or corporation could develop geoengineering technologies that might be viewed by one or more nations as threatening. Even if a multilateral agreement could be reached, conflict could still arise if one nation undertook geoengineering efforts that resulted in harm to another country, such as SRM affecting the monsoons for Asia or Africa. Sorting out whether climate changes in one nation were the result of another nation's geoengineering or the result of natural causes could be extremely difficult (Corner and Pidgeon, 2010).

The problem of one region of the world affecting another is no longer just theoretical. A 2017 research study by scientists at the University of Exeter suggest that injection of aerosols in the northern hemisphere could result in reduced tropical cyclone activity in the North Atlantic, which is desirable, but would also lead to drought in sub-Saharan Africa. The study results confirm that regional geoengineering is likely to result in benefits to one region while detriments to other regions (Jones et al., 2017). It is also important to note a related ethical and social dilemma. Those with the resources and ability to deploy geoengineering solutions tend to be the wealthy nations, individuals, or companies while those experiencing the negative consequences are those that lack resources to mount an adequate response.

One of the key ethical dilemmas is the "moral hazard" that arises from potential geoengineering solutions to global warming. A moral hazard arises when one feels insured and therefore takes greater risks. In the case of SRM, moral hazard is a vexing issue for it is clear that several SRM methods would be far cheaper than mitigation. The belief that humanity can "techno fix" itself out of the problem belies the truth of the matter – that the only solution to climate change is not just temperature reduction but getting GHGs down to pre-industrial level. This can only be done through mitigation efforts and changes in patterns of consumption and production that will result in the de-carbonization of the world's economic system. Moreover, deploying SRM technologies that only reduce temperatures will do nothing to address ocean acidification (Keith, 2017).

Certain questions centering on human nature arise from the consideration of geoengineering. Are humans capable of handling the unintended consequences that will likely result from geoengineering? History has shown that sufficiently complicated technical or environmental systems often fail because of unanticipated interactions between their component parts. Can we trust society to see early warning signs of failure? Even if we could, can we rely on scientists and engineers to put in place a series of perpetual treatments to respond to failures (Corner and Pidgeon, 2010)?

If it is determined that geoengineering is technically doable and politically acceptable, how will public consent be obtained? How will citizens be involved in decision making? In 2010, the Asilomar International Conference on Climate Intervention Technologies was held in California. The final report included five recommendations, one of which was that the public participation in planning, oversight, assessments, and in the development of decision-making mechanisms and processes must be assured. Perhaps one way to do this at the research stage is to require those that wish to undertake research to obtain prior informed consent from any who might be affected by the research. For instance, experiments in capturing carbon dioxide and storing it in a particular location should require permission of the locality, or its elected officials. Whereas experiments or deployment of methods that will affect the entire planet, like SAAM, should need international approval (National Academy of Science, 2015a).

Oxford University's Geoengineering Program began the move toward governance by laying out the Oxford Principles – a set of 5 guidelines to govern geoengineering going forward. These include "geoengineering to be regulated as a public good, public participation in geoengineering decision-making, disclosure of geoengineering research and open publication of results, independent assessment of impacts, and governance before deployment" (Oxford University, n.d.).

Oxford's guidelines may be sound but there are many barriers to their implementation. For instance, parties that stand to gain or lose fortunes will seek to promote or oppose geoengineering decisions and will seek to manipulate the process of decision-making to assure the outcome they desire. Researchers or companies with a financial interest in research or possible deployment may seek to promote their own financial gain rather than society's best interest. For example, a company seeking to sell carbon credits conducted a rogue test of iron fertilization off the coast of Canada without obtaining any permission to do so (the Haida experiment). At the present time, there is no legal structure in place to assure that society's interests will be dominant to financial gain. Countries and companies that profit from fossil fuels may see geoengineering as a means to continue business-as-usual. Vested interests must be controlled through transparency, as the Oxford Principles suggest (Long and Scott, 2013).

It is clear that several treaties already in place relating to climate change, marine pollution, air pollution, biological diversity, and the use of outer space have provisions that may inform geoengineering activities (Bracmort, Lattanzio, and Barbour, 2010). Nevertheless, an emerging literature on the governance of geoengineering tends to agree that no current treaty or institution controls geoengineering and no current treaty or organization has the authority to effectively govern it. The literature also concludes that it is unwise to begin a process of international negotiation for a new treaty and/or organization to govern climate engineering until more is known about specific methods from additional research. Current knowledge lacks detailed data regarding regional and seasonal effects and risks. Because of this, the future governance needs remain uncertain (Parson, 2012).

In 2018, the Carnegie Climate Geoengineering Governance Initiative (C2G2), a project of the Carnegie Council for Ethics in International Affairs, presented a briefing to the UN's Environment Programme's Committee of Permanent Representatives outlining the need for a new international agreement on geoengineering. C2G2 calls for a global agreement that will prevent the deployment of solar geoengineering unless the risks and benefits are sufficiently understood and that an international governance structure is agreed to. They hope to achieve a resolution by 2021 (C2G2, 2018).

Counter-Geoengineering

Because of the lack of a governance framework and the fact that solar geoengineering could be deployed quickly and cheaply even by a unilateral rouge actor, scientists have begun a discussion of counter-geoengineering technologies. Counter-geoengineering would enable an opponent of SRM deployment the means to stop it. Counter-geoengineering could be accomplished in several ways: countervailing with a warming agent that could reverse the impact of the original SRM or neutralizing the original SRM agent by removing it or rendering it inert. The most likely warming agents would be GHGs including sulfur hexafluoride, CFCs, and HCFCs. Neutralizing might be accomplished by using a high-altitude aircraft to distribute an agent to the stratosphere that would counteract a sulfate aerosol. Techniques to reverse MCB or cirrus thinning seem less plausible. However, if the direct deployment costs are low and the direct benefits a single actor could get from unilateral SRM deployment are large, then in principle every capable state, or groups of states, or perhaps even parties would seek to deploy SRM to the level most likely to benefit them. But the whole globe would be affected by this action and some of the effects would be negative. Counter-geoengineering would allow actors to cancel the efforts of another actor thus giving them political power. Counter-geoengineering is thought of much like nuclear deterrence. If it is known that the capability exists to reverse a deployment of SRM, actors would be less likely to deploy without international agreement to such deployment (Parker, Horton, and Keith, 2018).

Conclusion

Geoengineering or climate intervention is the deliberate human attempt to modify the climate to reverse the effects of climate change. Under the broad classification of CDR, many techniques have been suggested – from planting trees to engineering devises that strip CO_2 from the air. With the exception of ocean iron fertilization, most CDR methods are viewed as safe. However, most CDR methods would work very slowly and to work they would have to be deployed globally at vast expense. Some CDR methods, such as engineered scrubbers, would also require a large infrastructure to permanently sequester the CO_2.

SRM methods that seek to reduce the amount of heat in the atmosphere are the methods that scientists consider the most promising – in particular stratospheric sulfur aerosols or SAAM, MCB, and cirrus thinning. It is thought that these techniques could be deployed cheaply and would have a rapid effect on bringing down global temperatures. However, the early modeling that has been done and laboratory studies seems to suggest that effects of deployment would come with risky side-effects including potential changes in the hydrological cycle that would reduce precipitation and further depletion of the ozone layer. Perhaps most importantly, SRM methods would not address the root cause of climate change, so once deployed they would have to remain in operation to assure the world would not experience rapid temperature increases.

Because of the lack of progress the world has made in mitigation of climate change, a growing number of scientists are calling for increased research, including field experiments, to advance our knowledge of whether and which of these proposed methods might prove useful. Until very recently, such a call has been vigorously opposed for two reasons. First, the view was widely held that research would lead to deployment. Second, focusing on techniques such as SRM would undermine mitigation efforts. However, in the last several years there have been a series of conferences seeking to promote research particularly on SAAM, MCB, and cirrus thinning.

A host of social, ethical, legal, and governance issues has arisen with discussion of geoengineering. The world is ill-prepared to deal with the issues associated with the regulation of research – let alone deployment. Issues span the gamut from how to obtain consent from those that might be affected, establishing legal liability, understanding the limits of technological fixes, and controlling rogue actors. No international governance structures, institutions, or treaties exist with authority to control geoengineering. The threat of rogue actors has caused some to suggest the development of counter-geoengineering methods as a deterrence.

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